Geology of the central Scotian Shelf and Slope - Call for Bids NS22-1

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Overview

The following report provides geological context for the Call for Bids NS22-1 parcels, helps explain recent drilling results, and provides a basis to evaluate several aspects of the exploration potential and exploration risk on the central Scotian Shelf and Slope. A more detailed account of the geology and exploration potential in the Sable Subbasin can be found in a number of previously published reports. In particular, the recently published SCOPE Atlas (Deptuck and Kendell 2020) provides a detailed seismic stratigraphic framework based on available 3D volumes west of Parcel 3 and new well calibration on the slope (see Figure 3 for study area). Likewise, additional geological information for the Sable Subbasin and the slope seaward of it, is available in Kidston et al. (2007), Deptuck (2008), Deptuck and Kendell (2012), Kendell and Deptuck (2012), Kendell (2012); Smith et al. (2016, 2018), Kendell et al. (2013; 2016), and OERA (2016). Most of these reports can be found here: Geoscience Publications | Canada-Nova Scotia Offshore Petroleum Board (CNSOPB).

Parcel summary

Call for Bids NS22-1 consists of eight nominated parcels (Figure 1). Parcels 1 to 5 are located in deepwater on the central Scotian Slope above or outboard the seaward parts of the Sable Subbasin (Parcels 2-5), or where the western Sable Subbasin transitions into the eastern Shelburne Subbasin (Parcle 1; see Figure 2). Water depths range from 100 to 4300 m. Parcels 6 to 8 are located on the central Scotian Shelf above the landward parts of the Sable Subbasin, in water depths less than 200 m. These parcels are located adjacent to the recently decommissioned gas and condensate fields of the Sable Offshore Energy Project (SOEP).

Eight exploration wells have been drilled in parcels 1 to 5, three of which (Newburn H-23 - Parcel 2; Aspy D-11/D-11A - Parcel 3; and Annapolis G-24 - Parcel 4) encountered noteworthy gas-charged deepwater sandstone reservoirs (Kidston et al. 2007; Deptuck 2008; Deptuck and Kendell 2020). All five deepwater parcels cover a region of highly complex structural deformation linked to the expulsion of salt that took place as Lower Cretaceous sediment from the "Sable Delta" built across the shelf. The seaward parts of Parcels 1 to 5 are covered by variably spaced 2D seismic profiles collected prior to 2001, while the landward parts of these parcels are also covered by a number of higher-quality 3D seismic volumes (Figure 3b). The central parts of Parcels 1 to 3 were most recently explored by BP who acquired a wide azimuth 3D seismic survey (Tangier 3D) and drilled our jurisdiction's most recent exploration well (Aspy D-11/D-11A). Wide azimuth 3D seismic surveys provide optimal imaging of the subsurface,

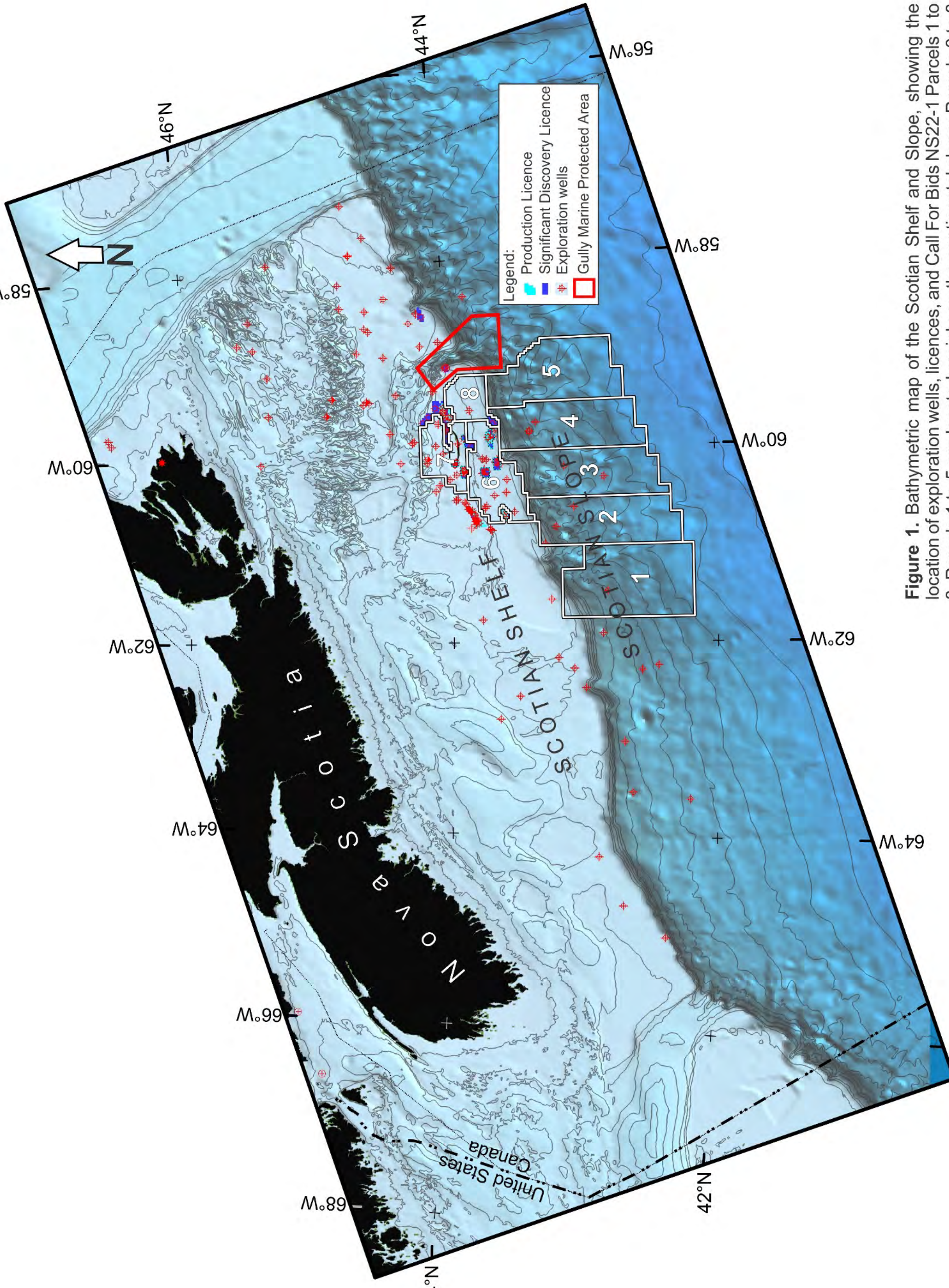


Figure 1. Bathymetric map of the Scotian Shelf and Slope, showing the location of exploration wells, licences, and Call For Bids NS22-1 Parcels 1 to 8. Parcels 1 to 5 are located mainly on the continental slope; Parcels 6 to 8 are located mainly on the continental shelf.

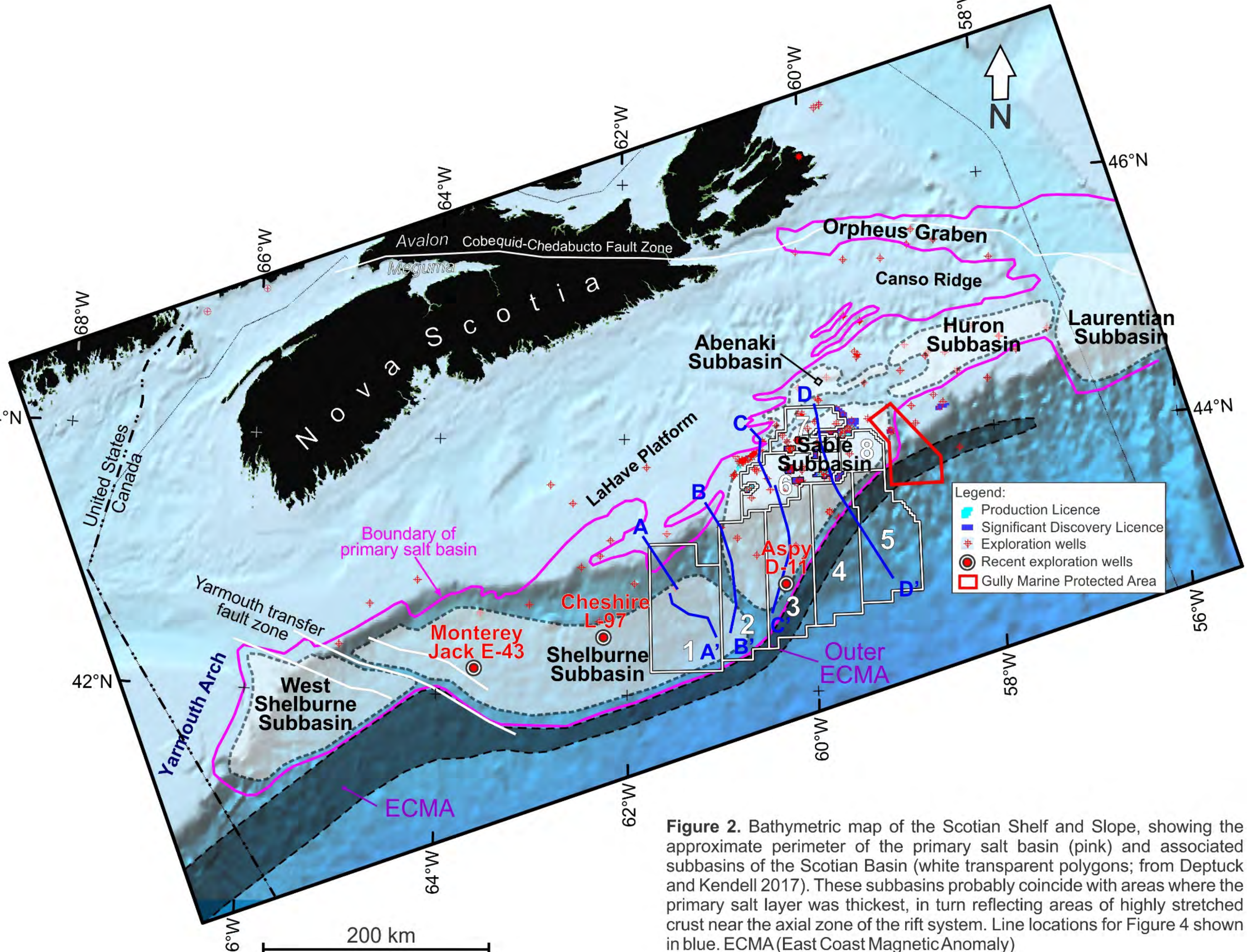


Figure 2. Bathymetric map of the Scotian Shelf and Slope, showing the approximate perimeter of the primary salt basin (pink) and associated subbasins of the Scotian Basin (white transparent polygons; from Deptuck and Kendell 2017). These subbasins probably coincide with areas where the primary salt layer was thickest, in turn reflecting areas of highly stretched crust near the axial zone of the rift system. Line locations for Figure 4 shown in blue. ECMA (East Coast Magnetic Anomaly)

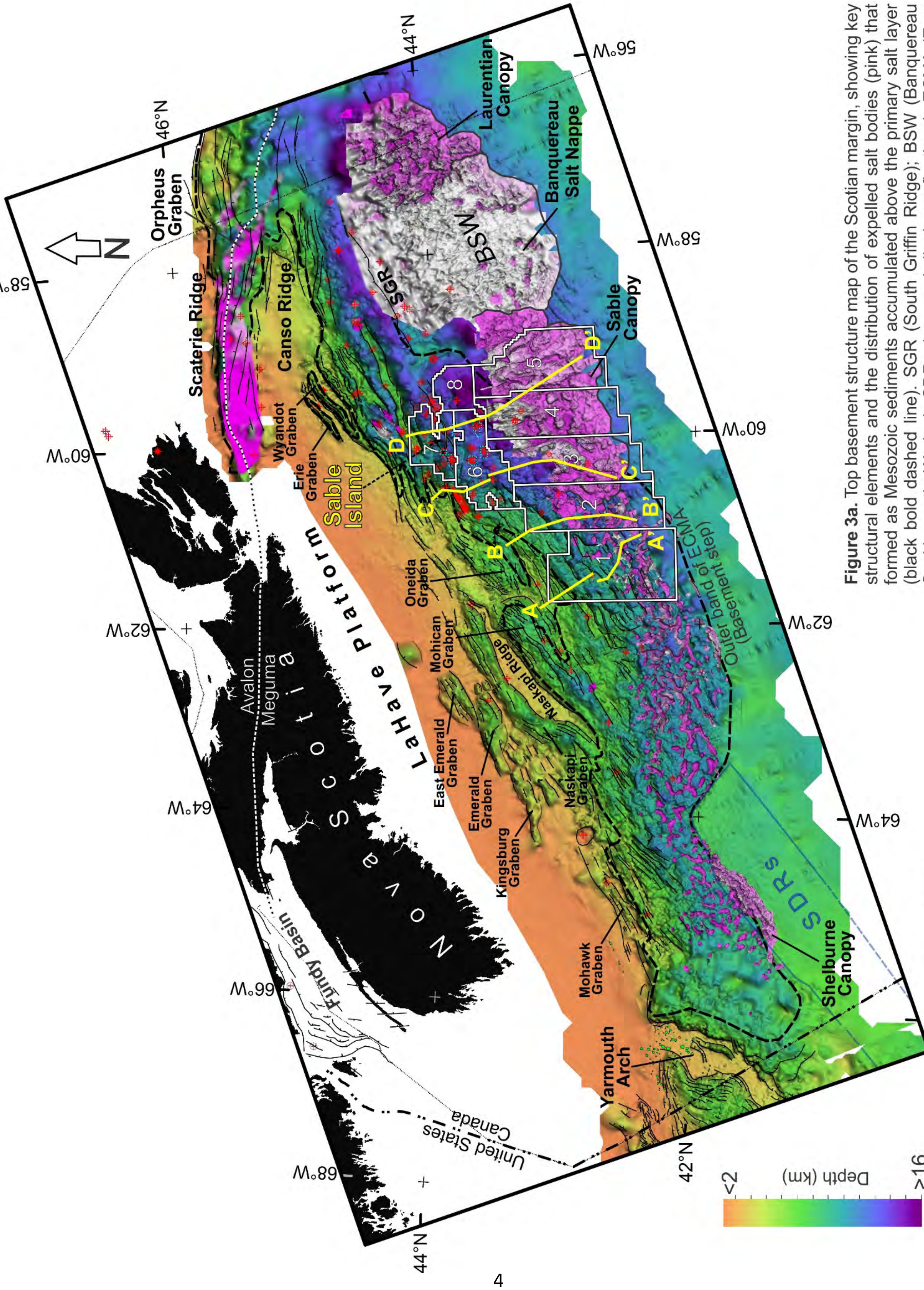


Figure 3a. Top basement structure map of the Scotian margin, showing key structural elements and the distribution of expelled salt bodies (pink) that formed as Mesozoic sediments accumulated above the primary salt layer (black bold dashed line). SGR (South Griffin Ridge); BSW (Banquereau Synkinematic Wedge); SDRs (seaward dipping reflections); ECMA (East Coast Magnetic Anomaly).

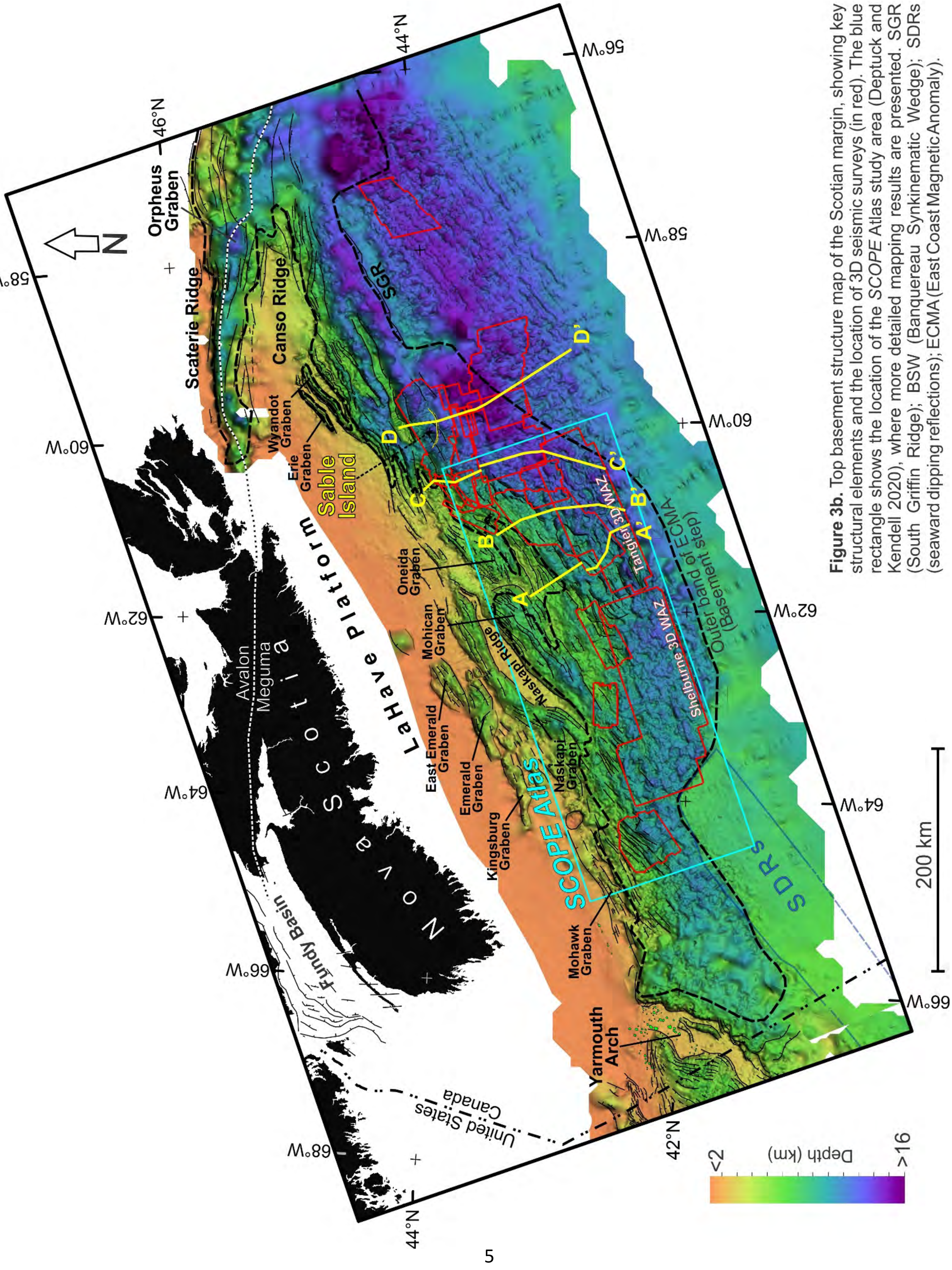


Figure 3b. Top basement structure map of the Scotian margin, showing key structural elements and the location of 3D seismic surveys (in red). The blue rectangle shows the location of the *SCOPE* Atlas study area (Deptuck and Kendell 2020), where more detailed mapping results are presented. SGR (South Griffin Ridge); BSW (Banquereau Synkinematic Wedge); SDRs (seaward dipping reflections); ECMA (East Coast Magnetic Anomaly).

particularly where complex salt structures hinder mapping in more traditional 2D and 3D seismic data-sets. All five deepwater parcels contain a number of mapped and undrilled leads, mainly associated with faulting and folding of strata above or adjacent to salt bodies. Primary exploration targets are believed to be gas-prone with reservoirs consisting of Cretaceous deepwater turbidite sandstones deposited seaward of the Sable Delta.

Parcels 6, 7 and 8 surround the five recently abandoned and decommissioned SOEP gas fields. These parcels include three undeveloped hydrocarbon discoveries (Marmora, Eagle and Penobscot) and a number of undrilled leads have also been identified on 2D and 3D seismic data-sets. The Marmora and Penobscot discoveries contain in-place resources of 148 Billion cubic feet of natural gas and 65 Million barrels of oil, respectively. The main reservoirs for these undeveloped discoveries and undrilled leads are Lower Cretaceous fluvial-deltaic sandstones associated with the Sable Delta. Like many of the developed fields in this area, reservoir quality is generally very good, with most traps linked to listric faults and rollover folds above layers of mobile salt. Parcel 7 also contains the Eagle gas discovery which is estimated to contain approximately 1.25 Trillion cubic feet of gas-in-place in Upper Cretaceous chalk reservoirs (Wyandot Formation).

Geological Setting – East versus West

The Scotian Basin, located along the Atlantic margin southeast of Nova Scotia, is a salt basin (Figures 2, 3a). Widespread precipitation of Late Triassic and earliest Jurassic evaporites took place during the latter stages of rifting between Nova Scotia and Morocco, resulting in the accumulation of the Argo Formation (Wade and MacLean 1990). Extensive seismic data coverage across the Scotian Basin provides a clearer picture of basement structure and the extent of the original salt basin (Deptuck and Kendell 2017, 2020). The primary salt layer lies principally beneath the present-day slope in the southwest and the present-day shelf in the northeast (Figure 2). Post-rift mobilization of salt played an important role in the structural and stratigraphic development of the Scotian margin. Recent mapping efforts have substantially improved our understanding of the timing and distribution of different post-rift salt tectonic styles. Wide variations in the shape, size, distribution, and timing of expelled salt bodies record a diverse range of salt-sediment interactions, as Mesozoic strata variously loaded the primary salt layer and modulated the timing and rate of salt expulsion (Shimeld 2004; Albertz et al. 2010; Deptuck and Kendell 2017). Some of this variability is captured in Figure 3 and the composite seismic sections shown in Figures 4 and 5.

In general, the Scotian margin can be separated geographically into two disparate salt-tectonic regimes. Beneath the western Scotian Slope, isolated vertical salt diapirs (stocks and walls) were expelled between vertically subsiding minibasins in the Shelburne Subbasin. In contrast, beneath the central to eastern Scotian Slope, more complex salt tongues, amalgamated salt canopies, and nappes were expelled from seaward-leaning salt feeders extending from the Sable, Huron, and Laurentian subbasins (Figure 2). In the *west*, most of the expelled salt lies immediately above the primary salt basin; in the *east*, expelled salt largely escaped and now lies up to 150 km seaward of the primary salt basin (Figure 3a). These distinctly different salt-tectonic styles can be explained by the substantial asymmetry in sediment delivery to the western versus eastern Scotian margin (both in terms of

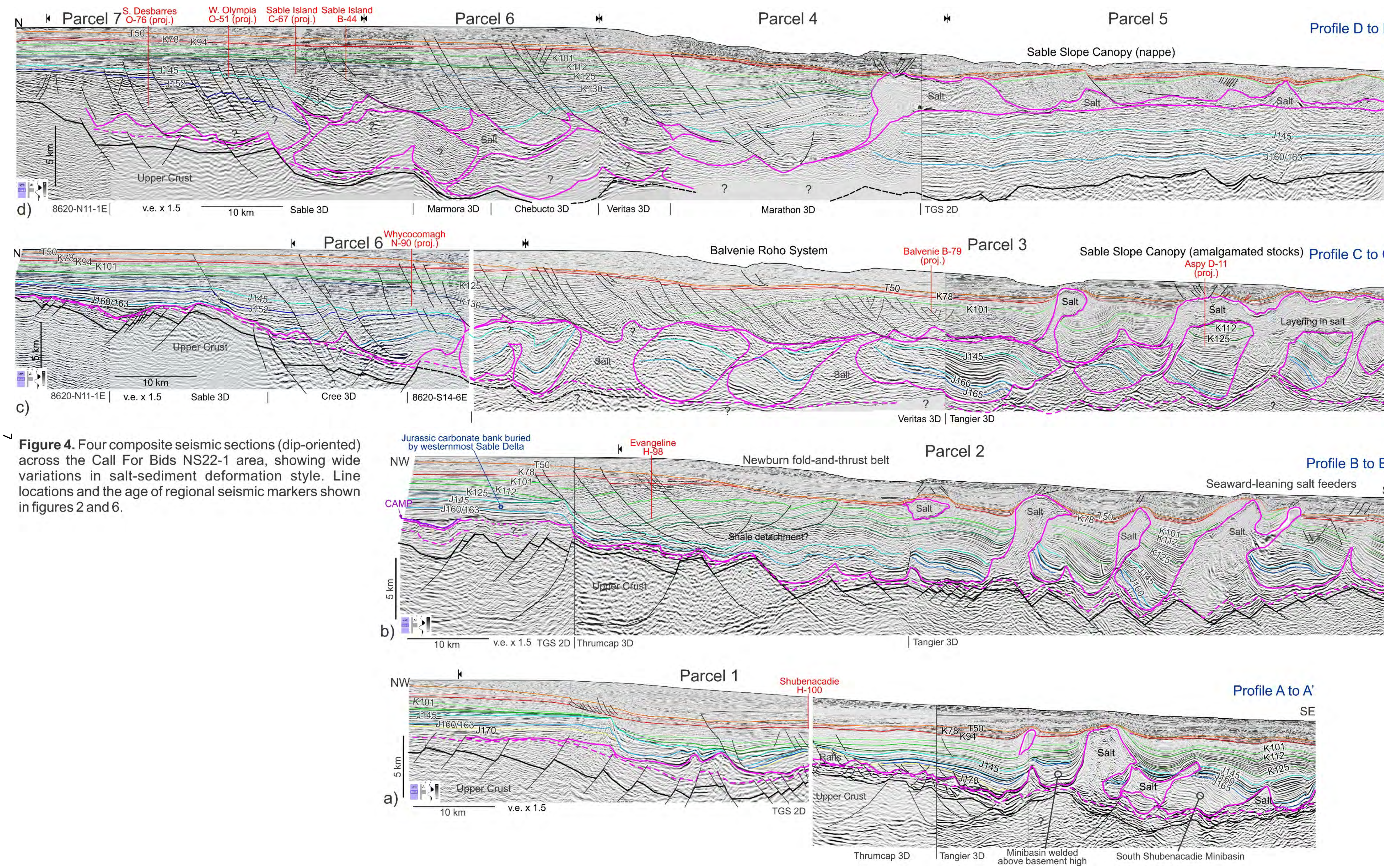


Figure 4. Four composite seismic sections (dip-oriented) across the Call For Bids NS22-1 area, showing wide variations in salt-sediment deformation style. Line locations and the age of regional seismic markers shown in figures 2 and 6.

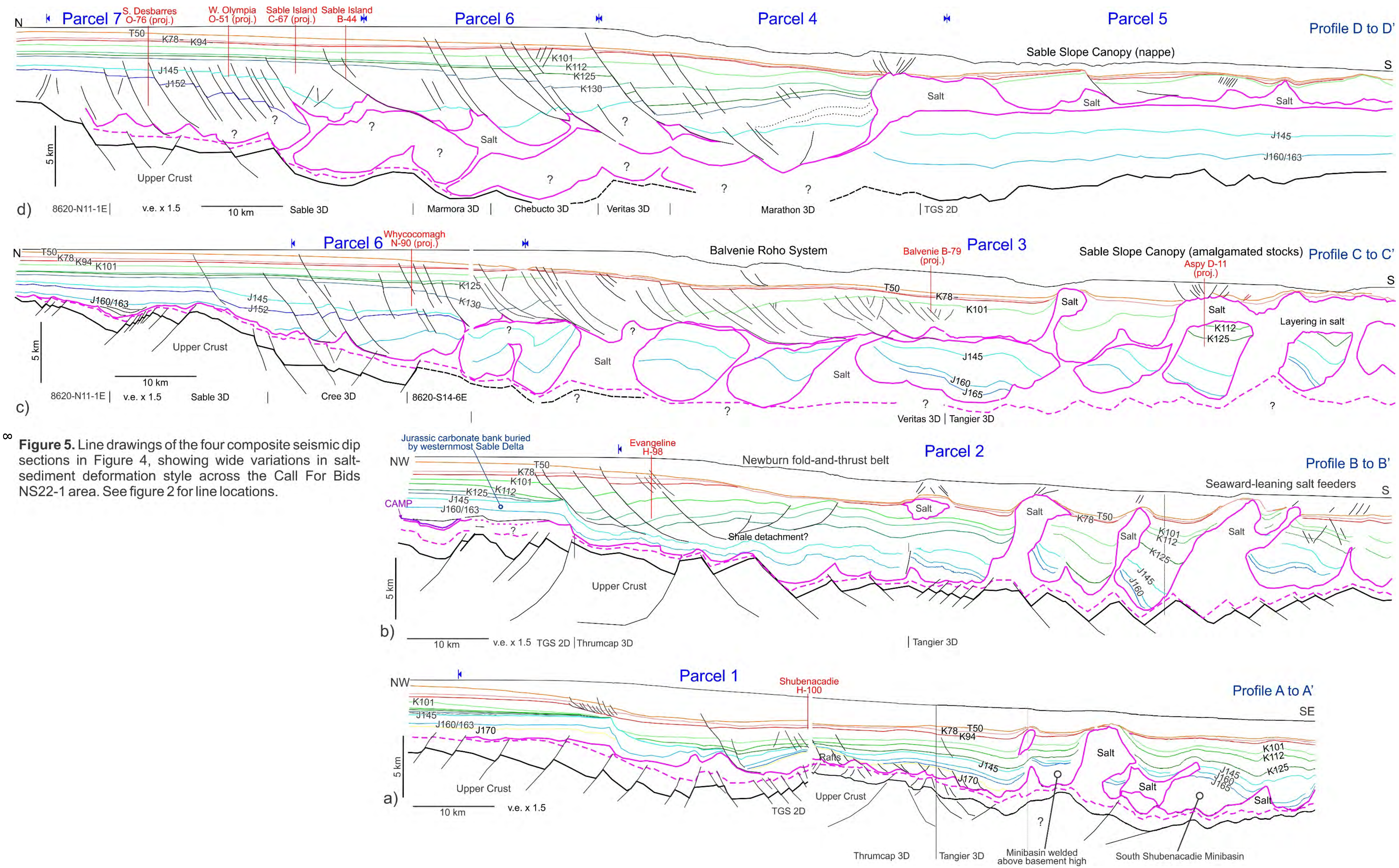


Figure 5. Line drawings of the four composite seismic dip sections in Figure 4, showing wide variations in salt-sediment deformation style across the Call For Bids NS22-1 area. See figure 2 for line locations.

volume and lithology). This asymmetry persisted for at least 65 million years from the Middle Jurassic through to the end of the Early Cretaceous.

Middle through Late Jurassic

Gravity gliding, sediment down-building, and shortening dominated the salt tectonic style in the west, where overall Middle to Late Jurassic sedimentation rates were low. Carbonate sedimentation prevailed, and by the end of the Jurassic a broad aggradational carbonate platform had developed across much of the western Scotian margin (Abenaki Formation; Wade and MacLean 1990). Here, a sharply-defined scalloped bank edge separates platform carbonates from slope carbonates and marls (see Figure 6). The shelf edge at this time was largely stationary, and most of the western Scotian Slope was sediment-starved, as confirmed by recent drilling results at Cheshire L-97 and Monterey Jack E-43 (discussed later; see Figure 2 for well locations). Cheshire L-97, for example, penetrated just 605 m of Callovian to Tithonian strata (mainly calcareous shales, marlstones, and limestone). Long-term sedimentation rates were just 4 cm/ky. This is in sharp contrast to the east, where more than 5 km of sediment accumulated in the same time period (see the thickness map in Figure 7), with sedimentation rates exceeding 25 cm/ky (without accounting for compaction).

Here, gravity spreading in response to the voluminous sediment supply and seaward progradation of the shelf edge produced a very different suite of salt tectonic products. For example, the 130 km wide, 150 km long, and up to 4.5 km thick ‘Banquereau Synkinematic Wedge’ (BSW; Shimeld 2004; Ings and Shimeld 2006) formed seaward of the Huron Subbasin at this time. It corresponds to a large and complex multi-phased Middle to Late Jurassic salt-based detachment that formed entirely above a salt nappe located seaward of the primary salt basin. Jurassic down-building landward of the BSW, into the narrow Huron Subbasin, was mainly responsible for expelling salt onto the slope that facilitated the seaward translation of the BSW (Albertz et al. 2010; Deptuck et al. 2014). Similar down-building took place between seaward-leaning Jurassic salt feeders within the much wider Sable Subbasin (area of the Call for Bids NS22-1 parcels; Figure 2). Although its deeper fill in places is poorly imaged (e.g. see section D-D’ in Figures 4, 5), a variety of extensional and compressional salt-related deformation styles are evident on the shelf and slope portions of the Sable Subbasin. Jurassic strata in the landward parts of the Sable Subbasin are commonly offset by seaward-dipping listric faults that sole into the primary salt layer (e.g. Section C-C, in Figures 4, 5). Early complex salt overhangs and amalgamation of salt feeders into early shelf canopies are also evident (referred to as the ‘Sable Shelf Canopy’ by Kendell 2012; e.g. Figure 4d), and early turtles developed locally where Jurassic down-building welded out the primary salt layer. Seaward of the Sable primary salt basin, Middle to Upper Jurassic strata generally thin basinwards and towards the southwest (see J163 to J145 in interval is Figures 4, 5).

Early Cretaceous

The asymmetry in sediment accumulation persisted into the Cretaceous (see Figure 8). In the *west*, the shelf continued to remain largely sediment-starved, where condensed clastics and carbonates of the ‘Roseway Unit’ accumulated. Sediment thickness range from 850 m on the shelf landward of Monterey Jack E-43 to 1200 m landward of Cheshire L-97. On the western slope, minibasins that began to form in the Jurassic continued to develop into the

Cretaceous, but were largely filled with finer grained sediments and marls bypassed across the steep slope. No Cretaceous reservoirs were encountered in either the Monterey Jack or Cheshire explorations wells here, in an Early Cretaceous succession of 1400 m and 1030 m, respectively. In the *east*, the onset of the Avalon Uplift in the latest Jurassic – thought to be linked to rejuvenated rifting between the Grand Banks and Iberia (Jansa and Wade 1975; MacLean and Wade 1992) – coincided with a change in bulk sediment composition, but otherwise, the high sedimentation rates continued into the Cretaceous. Siliciclastic-dominated fluvial-deltaic sediments of the Missisauga and eventually Logan Canyon formations (Wade and MacLean 1990) prograded across the Sable Subbasin, burying the eastern reaches of the Jurassic carbonate bank. Erosion of this broad basement arch truncated Jurassic and older strata, producing a clear angular unconformity on the eastern Scotian Shelf and southern Grand Banks (MacLean and Wade 1992; Deptuck et al 2014) (Figure 6). Lower Cretaceous strata thin above this unconformity, and likewise show an abrupt western shift in the thickest sediments, presumably in response to the increased relief of the Avalon Uplift that diverted rivers towards the Sable Subbasin. The Berriasian to Cenomanian succession is generally more than 4 km thick, locally exceeding 6 km thick where Cretaceous slope strata accumulated above Jurassic salt feeders (forming large, subcircular bowl-shaped welds; e.g. Section C to C’ in Figure 4). A comparison between the thickness maps in Figures 7 and 8 shows the westward shift of the Sable Delta depocenter nicely.

Whereas the primary salt budget was largely expended by the end of the Jurassic in the Huron Subbasin (i.e. the Huron Subbasin largely welded-out as the BSW formed), the primary salt layer in the Sable Subbasin had not yet been depleted. As such, progradation of the Sable Delta across the Sable Subbasin initiated a new generation of Cretaceous salt-related deformation that ultimately emplaced the younger ‘Sable Slope Canopy’ (Kendell 2012) on the central Scotian Slope (where NS22-1 Parcels 2 to 5 are located; see Figure 6). The Sable Slope Canopy can be split into two domains: a western domain located largely above the seaward parts of the primary salt basin, and an eastern domain located largely seaward of the primary salt basin (e.g. contrast sections C-C’ and D-D, in Figure 4). The canopy in the western domain is a complex amalgamation of reactivated salt sheets supplied from seaward-leaning primary salt feeders below and from salt expelled laterally along the margins of Cretaceous roho systems (e.g. Balvenie Roho System, Figure 4c). Salt sheets in the western part of the canopy were expelled 30 to 40 km beyond the edge of the primary salt basin. Most of the primary salt layer in the eastern parts of the Sable Subbasin lies under the modern continental shelf (Figure 2); salt sheets in the eastern part of the canopy were expelled up to 80 km beyond the edge of the primary salt basin, above well-imaged Jurassic and Cretaceous strata (Shimeld 2004; Kendell 2012) (e.g. Figure 4d). Both the western and eastern canopy domains were heavily reactivated during the Cretaceous and to a lesser extent in the Cenozoic, with widespread loading by minibasins and extensional turtles (Shimeld 2004; Kendel 2012; Deptuck and Kendell 2017).

Recent exploration results

Renewed exploration interest in 2011 and 2012 lead to the issuance of a number of exploration licences by the Canada-Nova Scotia Offshore Petroleum Board, covering large swaths of the central and western Scotian Slope. In the seven years that followed, two large wide azimuth 3D reflection

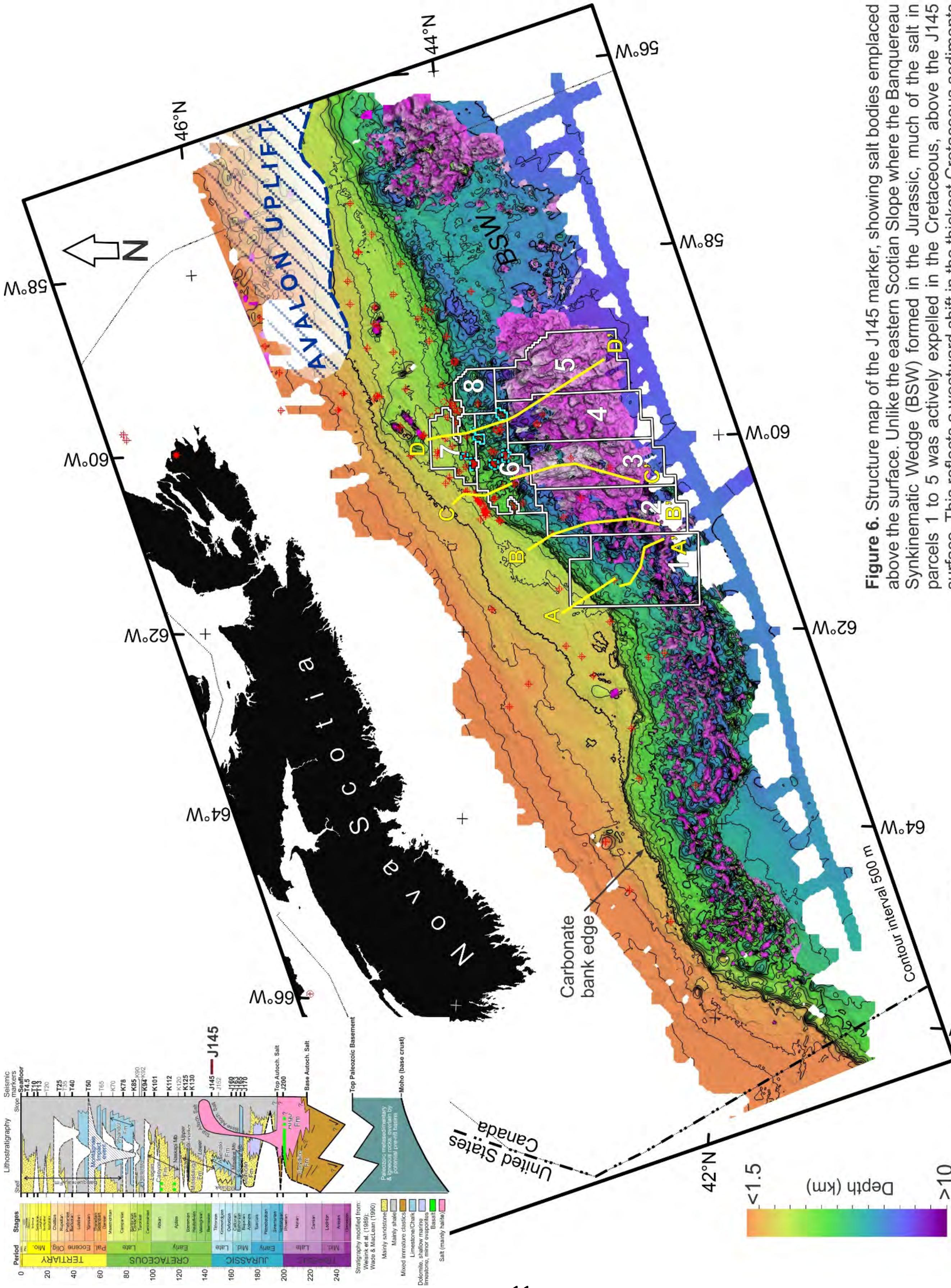


Figure 6. Structure map of the J145 marker, showing salt bodies emplaced above the surface. Unlike the eastern Scotian Slope where the Banquereau Synkinematic Wedge (BSW) formed in the Jurassic, much of the salt in parcels 1 to 5 was actively expelled in the Cretaceous, above the J145 surface. This reflects a westward shift in the thickest Cretaceous sediments linked to the Sable Delta, at least partly in response to the Late Jurassic development of the Avalon Uplift and associated angular unconformity.

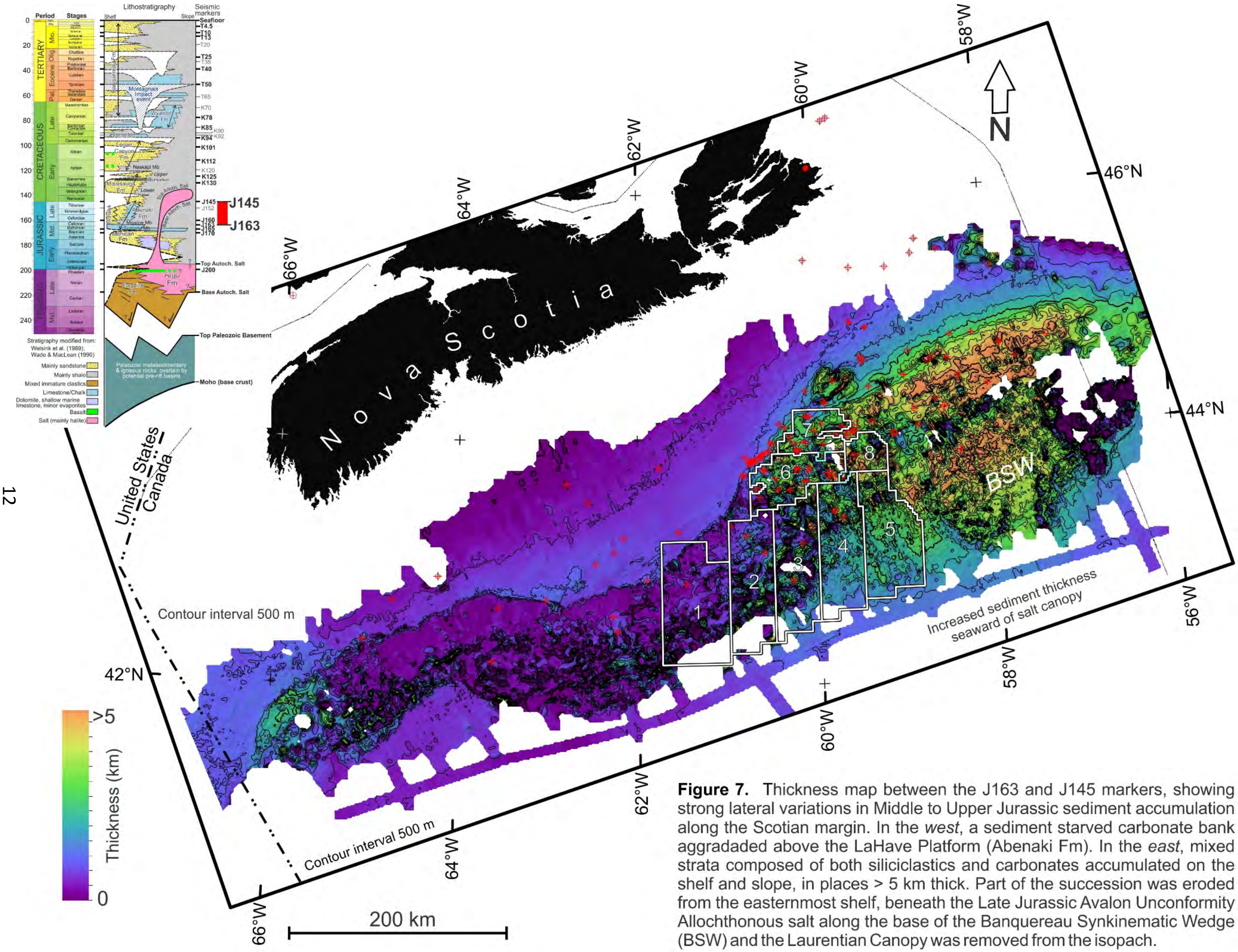


Figure 7. Thickness map between the J163 and J145 markers, showing strong lateral variations in Middle to Upper Jurassic sediment accumulation along the Scotian margin. In the *west*, a sediment starved carbonate bank aggradaded above the LaHave Platform (Abenaki Fm). In the *east*, mixed strata composed of both siliciclastics and carbonates accumulated on the shelf and slope, in places > 5 km thick. Part of the succession was eroded from the easternmost shelf, beneath the Late Jurassic Avalon Unconformity Allochthonous salt along the base of the Banquereau Synkinematic Wedge (BSW) and the Laurentian Canopy was removed from the isopach.

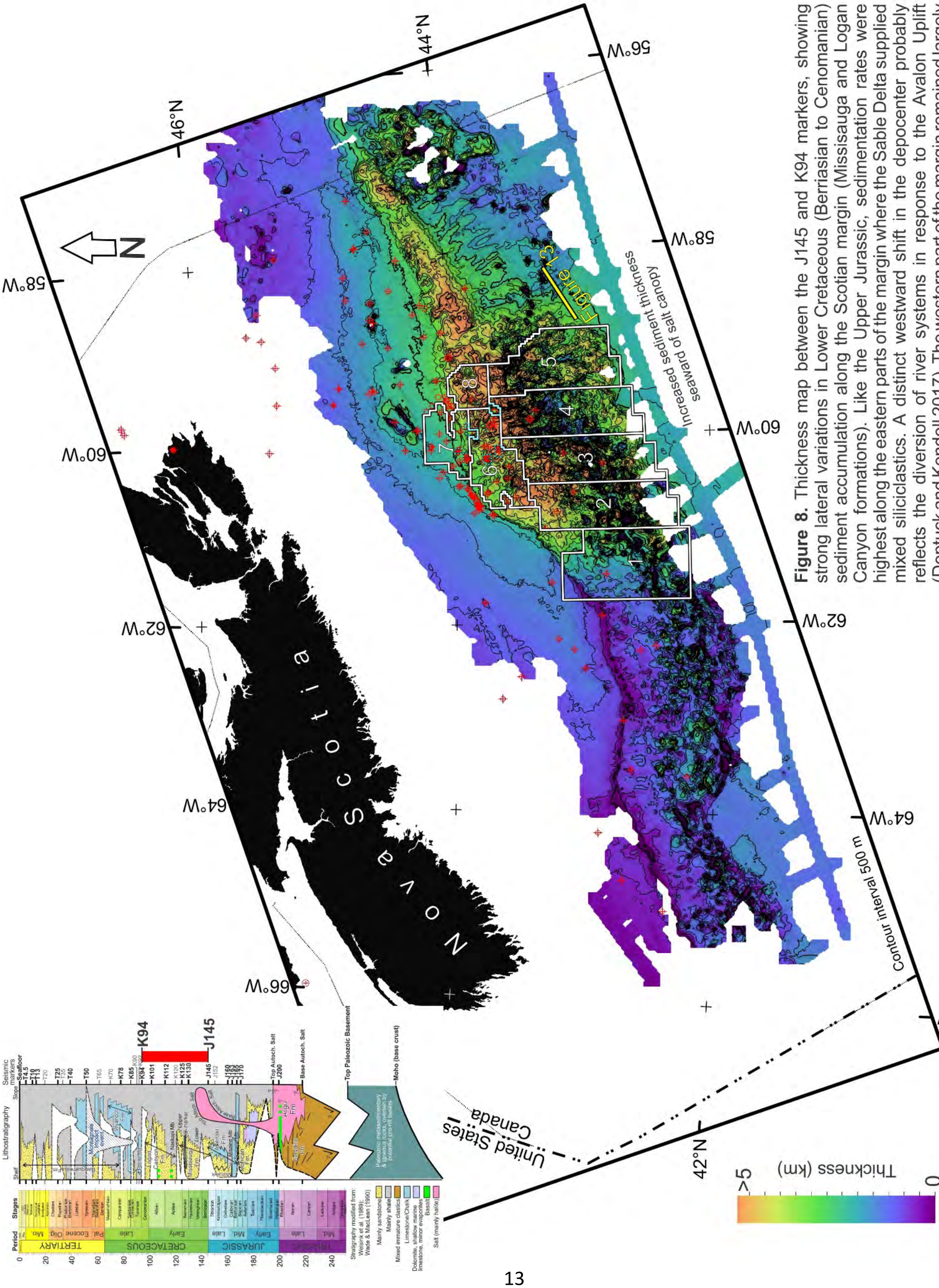


Figure 8. Thickness map between the J145 and K94 markers, showing strong lateral variations in Lower Cretaceous (Berriasian to Cenomanian) sediment accumulation along the Scotian margin (Missisauga and Logan Canyon formations). Like the Upper Jurassic, sedimentation rates were highest along the eastern parts of the margin where the Sable Delta supplied mixed siliciclastics. A distinct westward shift in the depocenter probably reflects the diversion of river systems in response to the Avalon Uplift (Deptuck and Kendell 2017). The western part of the margin remained largely sediment starved at this time. Salt thickness of the Sable Slope Canopy was removed from the isopach.

seismic volumes were acquired on the slope (Shelburne 3D and Tangier 3D) and three wildcat exploration wells were drilled (Cheshire L-97/L-97A, Monterey Jack E-43/E-43A, and Aspy D-11/D-11A) (Figure 2). These wells enable, for the first time, high-confidence correlation of post-Bajocian strata across wide areas of the continental slope, and also improve the correlation confidence to equivalent, generally better age-constrained strata on the continental shelf (see Deptuck and Kendell 2020).

Cheshire L-97/L-97A

In late 2015, Shell Canada Ltd. spudded the Cheshire well. It targeted a structural high between two north-south oriented salt diapirs (Figure 9). The trap appears to be a three-way closure against salt, with a salt overhang providing seal for deeper Jurassic reservoirs (if present). Pre- drill, the structure was interpreted to consist of an inverted minibasin of Cretaceous-aged, containing turbidite sands believed to be the age-equivalent of the Missisauga Formation (Figure 9). Jurassic-aged strata laterally equivalent to the Mohawk and Mic Mac formations formed a secondary pre-drill reservoir objective. Upon drilling, the prognosed top of the Jurassic section was encountered 160 m shallower than expected, 'thinning' the targeted Missisauga-equivalent reservoir interval. The brighter amplitude reflections in this interval were instead composed of Upper Jurassic claystone, shale and marl. The well continued drilling down to Bajocian strata, with no significant reservoir intervals or hydrocarbon-bearing zones encountered. The absence of reservoir here is consistent with regional Jurassic and Cretaceous sediment thickness maps and the well location on the slope seaward of sediment starved Middle Jurassic to Cretaceous shelf strata (see Figures 7 and 8).

Monterey Jack E-43/E-43A

Shell continued their exploration program in 2016, and drilled Monterey Jack E-43/E-43A 120 km west of the Cheshire well. The well targeted a simple four-way closure with large upside if filled across a saddle to the north-northeast (Figure 10). The Cretaceous and Jurassic intervals were intersected at the prognosed depths however, no hydrocarbon-bearing zones were encountered, and the targeted Missisauga-equivalent reservoir interval was predominantly claystone, shale and marl. The bottom of the well reached Callovian strata (RPS, 2017). Like Cheshire L-97, the absence of reservoir here is consistent with regional Jurassic and Cretaceous sediment thickness maps and the well location on the slope seaward of a sediment starved continental shelf (see Figures 7 and 8).

Aspy D-11/D-11A

In April of 2018 BP Canada Energy Group spudded the Aspy well. The targeted structure is a narrow, east-west trending, sub-canopy trap, requiring three-way closure against a combination of overlying salt and a fault/salt-weld to the east (Figure 11). This structure is within a geologically complicated area surrounded by younger mini-basins, salt-welds and salt feeder systems, immediately downslope from numerous fluvial-deltaic reservoirs associated with the Sable Delta (Figures 2, 4c).

The subsalt reservoir intervals were interpreted to be Lower Cretaceous turbidite lobes and channel complexes age-equivalent to the widespread sandstone reservoirs on the shelf in the Missisauga and Logan Canyon formations. The well encountered a 130 m thick interval containing multiple Aptian aged siltstones 45 m below the base of the salt canopy; throughout this interval the well had significantly elevated mud-gas readings and the

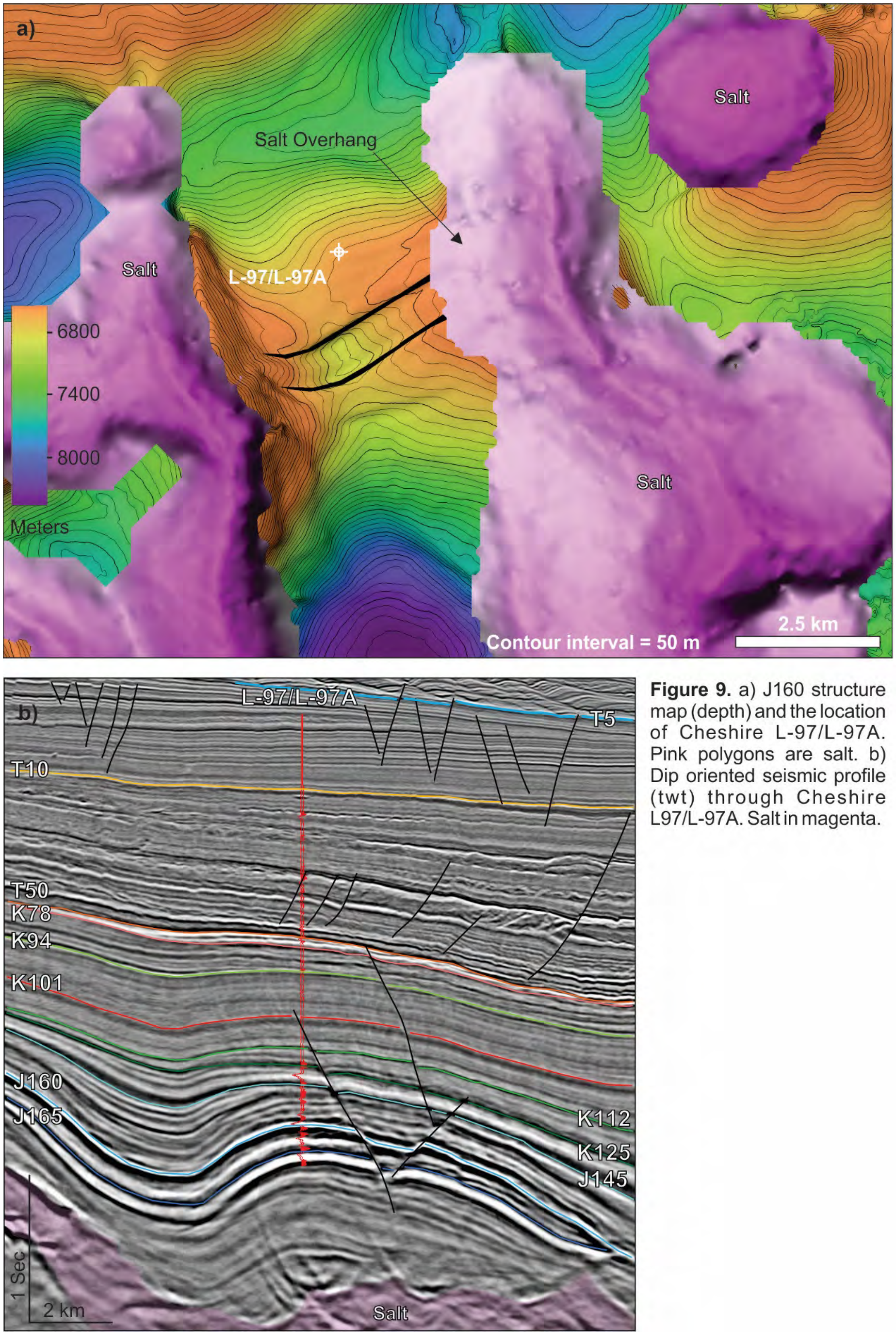
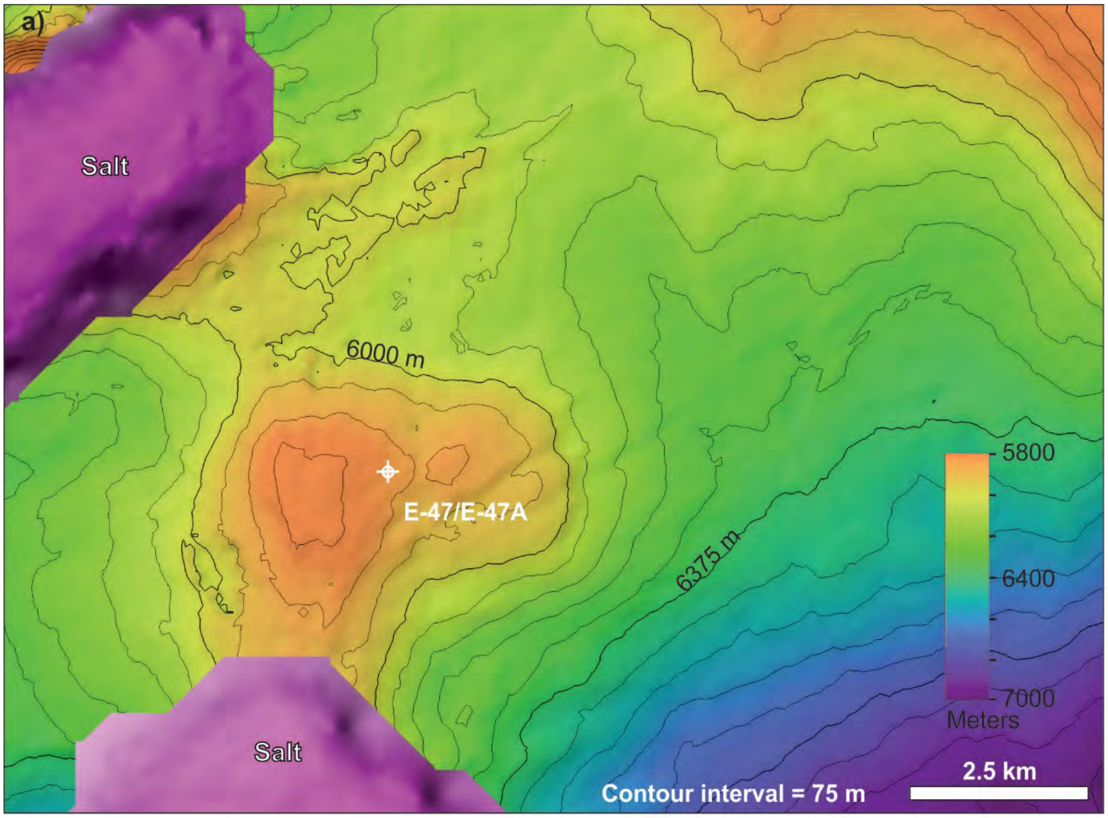


Figure 9. a) J160 structure map (depth) and the location of Cheshire L-97/L-97A. Pink polygons are salt. b) Dip oriented seismic profile (twt) through Cheshire L97/L-97A. Salt in magenta.



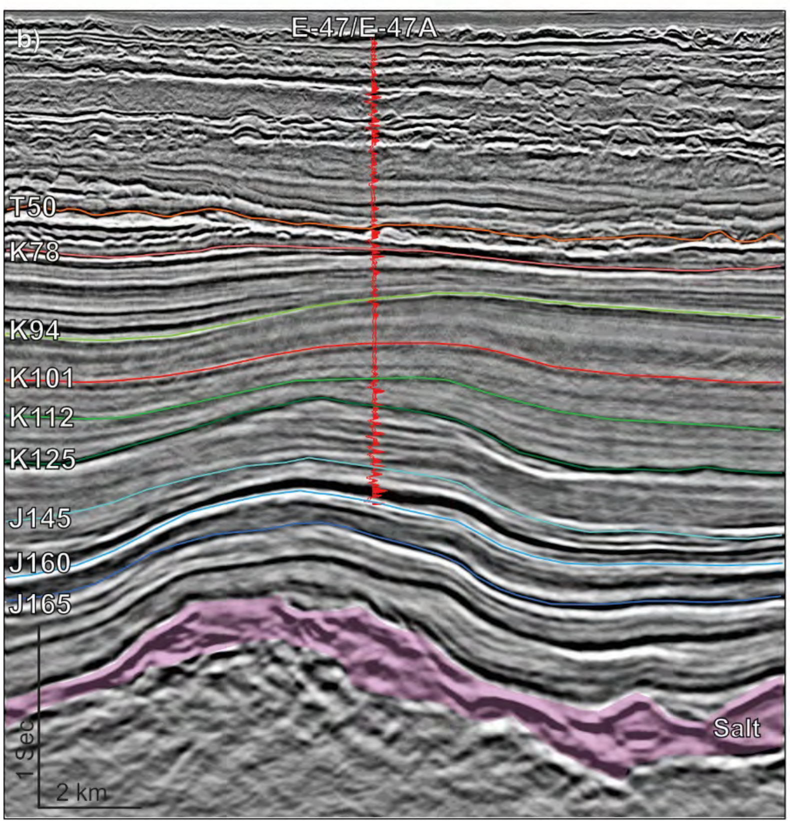
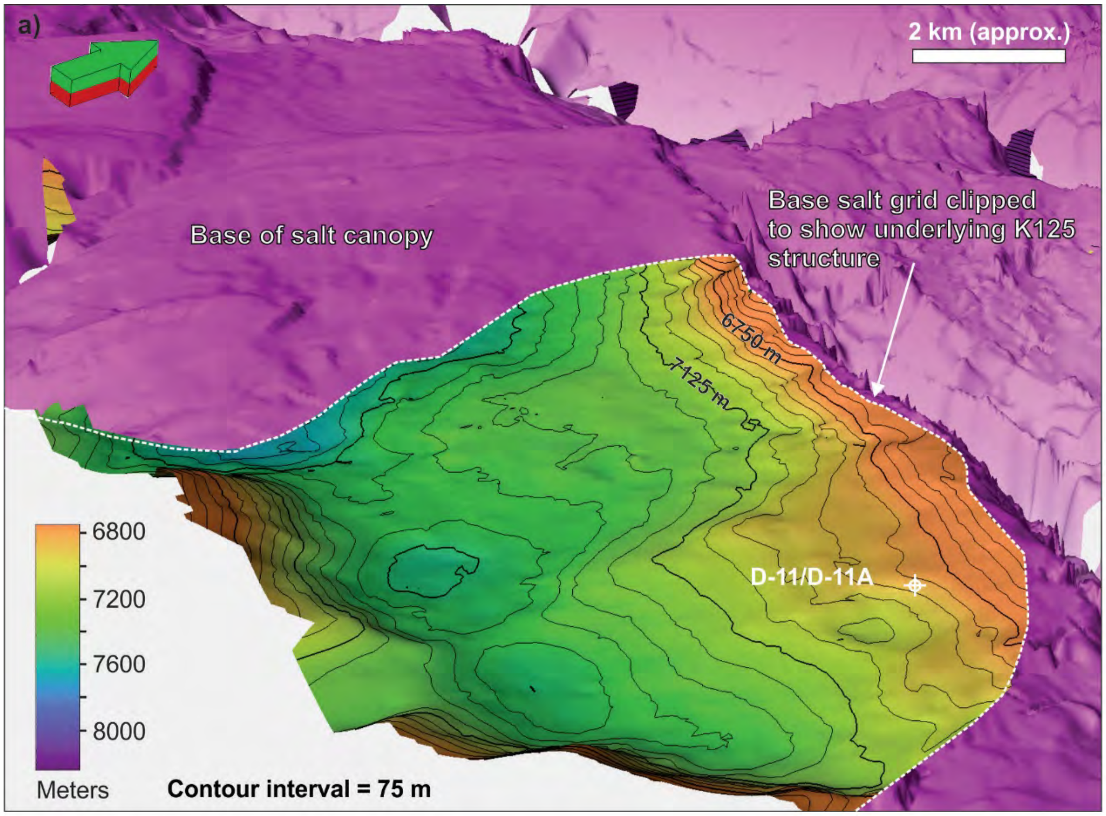


Figure 10. a) K125 structure map and the location of Monterey Jack E-43/E-43A. Pink polygons are salt. b) Strike oriented seismic profile (twt) through Monterey Jack E-43/E-43A. Salt in magenta.



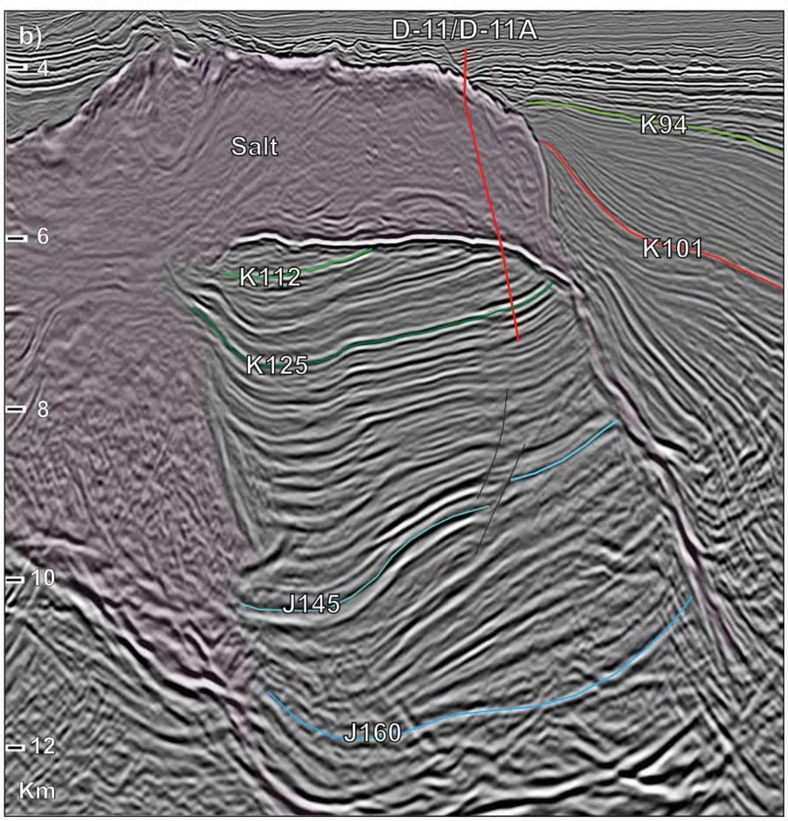


Figure 11. a) K125 structure map and the location of Aspy D-11/D-11A. b) Dip oriented (along deviated well) seismic profile through Aspy D-11/D-11A. Salt in magenta.

cuttings fluoresced. While reservoir quality sandstone were not encountered in this interval, there were clear indications of gas charge. Deeper in the well, two Barremian-Hauterivian aged sandstones were encountered. The shallower interval, from 7115-7134 m, is a 19 m sequence of three upward-coarsening reservoir-quality sands interbedded with shales and silts. The second sandstone is a 2 m thick sandstone interval at the base of the well. The two lower intervals have no indications of hydrocarbon charge and may have lacked an effective seal across a salt weld. Note that in the Aspy D-11/11A Well history Report, BP describes the well as a dry hole with gas shows (BP, 2019).

Exploration Potential

The eight parcels in Call for Bids NS22-1 are located along the central Scotian margin, within the high sedimentation rate and complex salt tectonic regime described earlier. As such, drilling results from Cheshire L-97/L-97A and Monterey Jack E-43/E-43A are not representative of exploration potential in the Sable Subbasin, whereas wells like Newburn H-23 (Parcel 2), Aspy D-11/D-11A – (Parcel 3), and Annapolis G-24 (Parcel 4) encountered noteworthy gas-charged deepwater sandstone reservoirs (Kidston et al. 2007; Deptuck 2008; Deptuck and Kendell 2020).

Traps

Most known and interpreted hydrocarbon traps along the Scotian margin formed in response to salt-related deformation above the Argo Formation. A wide array of potential hydrocarbon traps formed in the Call for Bids NS22-1 area as the uppermost Jurassic and Lower Cretaceous Sable Delta prograded across the region and displaced salt in the seaward direction. On the shelf (Parcels 6 to 8), most traps are linked to listric faults and rollover folds above layers of mobile salt. Improved imaging in vintage 3D seismic volumes on the shelf could also reveal sub-salt traps beneath early amalgamated salt sheets (e.g. areas of Parcel 6 and 7 in section D-D', Figure 4d). Parcel 7 also contains the Eagle gas discovery which is estimated to contain approximately 1.25 Trillion cubic feet of gas-in-place in Upper Cretaceous chalk reservoirs (Wyandot Formation). The structure is a faulted four-way closure above a salt diapir (Smith et al. 2016).

On the slope (Parcels 1 to 5), Cretaceous sedimentation above salt feeders, and Cretaceous and early Cenozoic sedimentation above salt canopies/nappes, produced an array of salt-related structures ranging from minibasins, to turtles flanked by younger rim-synclines, to half-turtles, and roho systems. Potential traps below salt canopies (or the equivalent salt weld) include folds cored by inflated autochthonous salt (e.g. Parcel 1; e.g. Figures 12 a, b) (Deptuck et al. 2009), turtles above the primary salt layer (e.g. section B-B' in Figure 4b; Parcel 2), three-way closures against salt feeders (e.g. the 'Crows Nest' and 'Piscatiqui' turbidite aprons in Parcels 1 and 2, shown in figure 26 and 31 of Deptuck 2008), and sub-salt cut-off traps sealed by the overlying salt (e.g. Parcels 4 and 5, sections D-D' and C-C' in Figure 4c, d). Potential traps above salt canopies/nappes include three-way or four-way closures against salt flanks or diapir crests, inverted turtle structures where supra-salt minibasins welded-out (e.g. 'Thorburn' structure in Figure 12c;), and rotated strata within roho systems (e.g. Parcel 5 in Figure 4d).

Reservoir potential

Latest Jurassic and Lower Cretaceous fluvial-deltaic and shoreface siliciclastics on the shelf are known to form high-quality reservoirs in the Sable Subbasin,

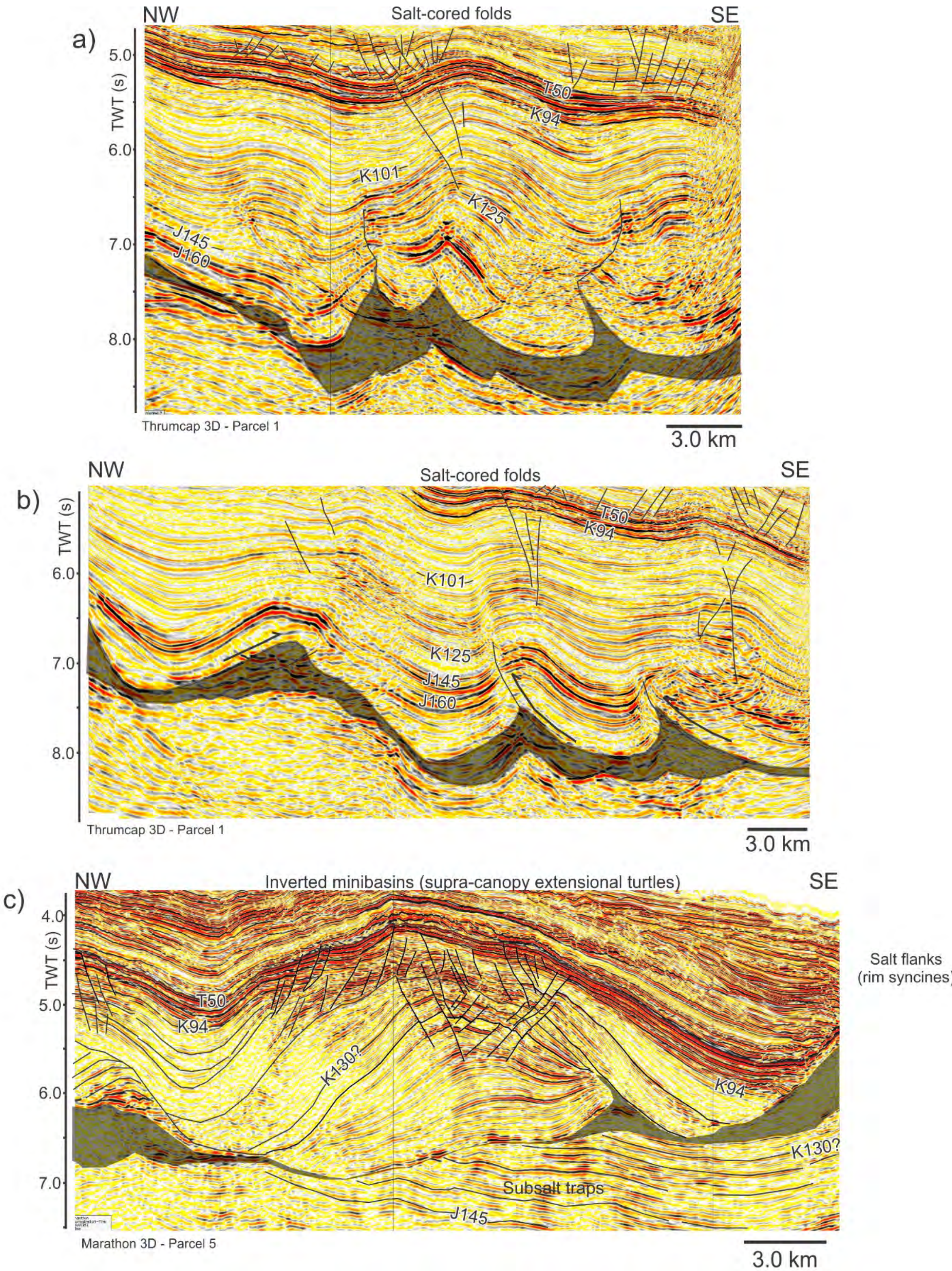


Figure 12. Potential hydrocarbon traps on the Scotian Slope. a), b) Example seismic profiles across salt-cored folds (detachment folds) in Parcel 1. c) Example seismic profile across an extensional turtle above the Sable Slope Canopy, and potential sub-salt cut-off traps beneath the canopy in Parcel 5. Potential reservoirs include Lower Cretaceous turbidites deposited seaward of the Sable Delta, as well as Upper Cretaceous to Lower Paleogene porous chalks deposited above the K94 marker. Grey transparency corresponds to interpreted salt (autochthonous in the top two profiles, and allochthonous in the bottom profile).

where they form the main gas and condensate reservoirs for the recently decommissioned Sable Offshore Energy Project. They also form the main reservoirs in a number of significant discoveries (Smith et al. 2014). As such, reservoir quality is considered to have a relatively low exploration risk in the areas covered by Parcels 6, 7, and 8.

Seaward of these proven gas and condensate reservoirs, turbidite channel and lobe sands are considered the primary Cretaceous reservoir targets. A number of deepwater wells like Newburn H-23, Annapolis G-24, Crimson F-81, and Aspy D-11/D-11A encountered turbidite sands with average net pay porosity ranging from 14 to 19% (Kidston et al. 2007; Kendell et al. 2016; Kendell and Deptuck 2020). Where 2D seismic coverage is available seaward of the Sable Slope Canopy (restricted to the area southeast of Parcel 5), detailed loop-scale interpretations show a number of areas with bright amplitude reflections consistent with 2 to 4 km wide sand-prone submarine channel-belts flanked by muddy overbank deposits. A number of these channel-belts are identified in yellow in Figure 13, and were correlated up to 70 km down the slope. More continuous bright amplitude soft reflections (downward decrease in impedance) ranging from 10 to 15 km wide and up the 33 km long were also identified near the base of several channel-levee systems (identified in green in Figure 13). Their distribution and character are consistent with sheet sands corresponding to submarine lobes deposited prior to the aggradation of channel-levees, in response to channel-levee avulsions, or at the mouths of submarine channels. As such, there is strong evidence that sand-prone turbidite corridors developed seaward of the sand-rich sable delta, passing through the Sable Slope Canopy system

Upper Cretaceous to Eocene strata in the Sable Subbasin are generally fine-grained, and more prone to form a regional seal interval on the slope than a reservoir interval. However, the interval also contains widespread chalks accumulations that have some potential to form reservoirs. Upper Cretaceous and early Paleogene chalks drape a number of shallower closures. On the shelf, the Eagle gas discovery consists of 52 m of net gas pay in porous Upper Cretaceous chalks in the Sable Subbasin. Likewise, 50 m of net gas pay was found in Wyandot chalks folded above a salt diapir in the Primrose Significant Discovery just east of Parcel 8 (Smith et al. 2014). Although neither of these were commercial developments, they demonstrate that chalks can form hydrocarbon reservoirs in Nova Scotia's offshore.

The generally low matrix permeability of chalk reservoirs remains a key risk element of Upper Cretaceous to Paleogene chalks, however, these reservoirs may be able to achieve commercially viable production rates if stimulated by fracking. Resedimented chalks appear to form more favourable, higher permeability reservoirs, though many complex factors affect reservoir quality (Megson and Tygesen 2005). Although there is widespread evidence for sediment failures involving chalks on the shelf where 3D seismic is available (in the Sable Subbasin; Smith et al. 2010), detailed study of chalk depositional environments has not been carried out.

Potential Seals

For Lower Cretaceous Missisauga fluvial-deltaic reservoirs, the Aptian Naskapi Member shale has proven to be an excellent regional seal. Shallower seals are also known on the shelf, like the Paleogene

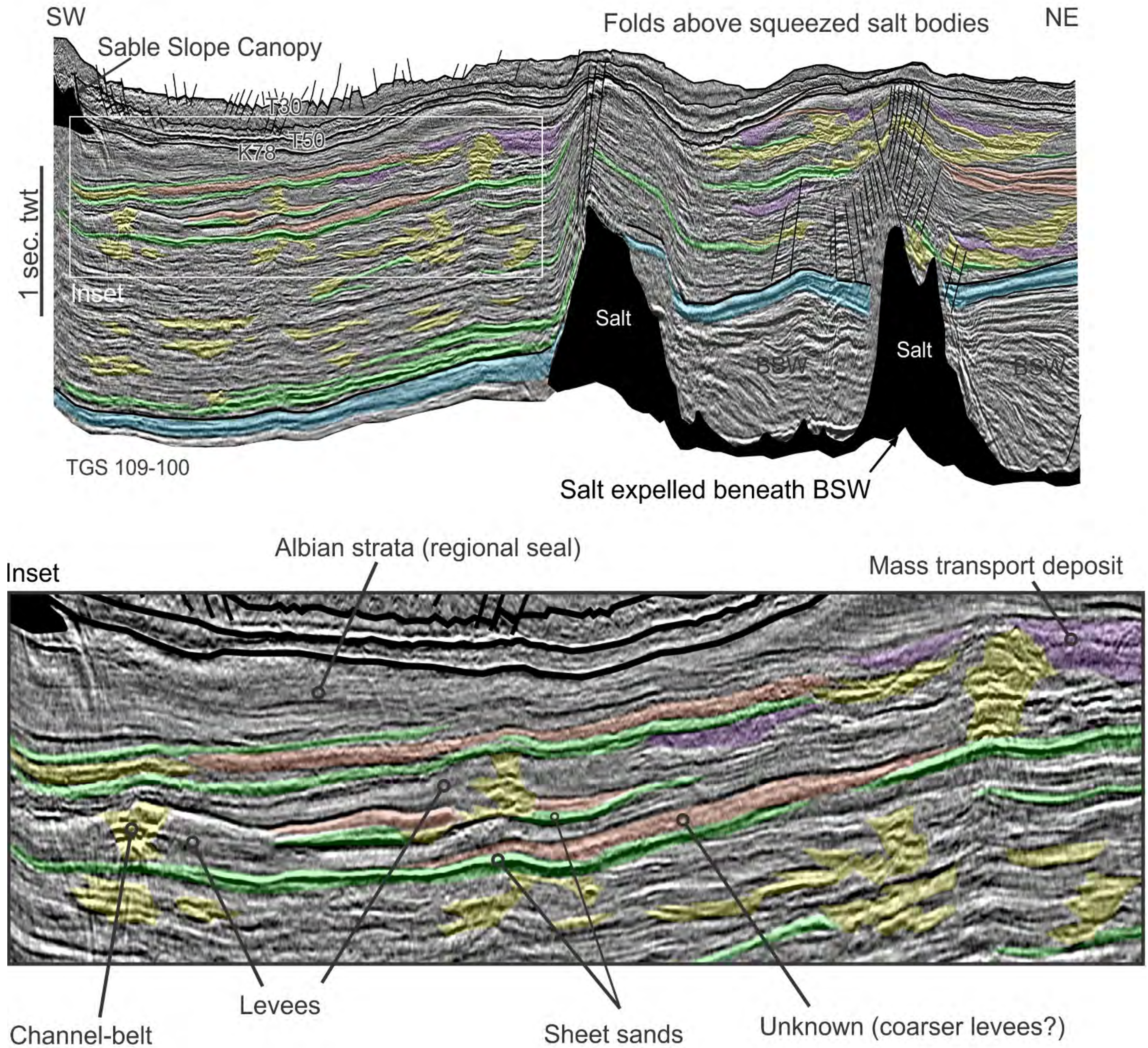


Figure 13. Representative strike-oriented 2D seismic profile located seaward of the Sable Slope Canopy, where the absence of salt overhangs substantially improves seismic imaging. Coloured overlays show the different deepwater seismic facies recognized seaward of the Sable Delta. Inset show close-up view of sand-prone channel-belts (yellow) flanked by levees, with potential sheet sands corresponding to lobe deposits identified in green. Blue identifies approximate Cretaceous-Jurassic boundary. See figure 8 for line location.

shales that drape the Upper Cretaceous Eagle chalk reservoirs. On the slope, most deepwater wells have encountered thick successions of claystone and shale. Potential seals are expected both locally within turbidite-dominated intervals, associated with stacked reservoir-seal pairs, but also regionally, during periods of particularly fine-grained sedimentation that took place across wider areas of the slope. In particular, the Albian to Cenomanian succession above the K101 marker on the slope shows very little evidence for turbidite sand deposition, and is interpreted to be a shale or clay dominated succession. For traps located below the Sable Slope Canopy, salt is also likely to act as an effective regional seal.

Potential Source Rocks

Numerous produced fields and significant discoveries in the areas of Parcels 6, 7, and 8 demonstrate that an effective source rock is present in the shelfal parts of the Sable Subbain (see Smith et al. 2014). Most of these discovered hydrocarbons have been tied to Tithonian deltaic shales containing a mix of Type II to III organic matter (Fowler et al. 2020). For example, up to 5% TOC type II to III source rocks were encountered in Tithonian strata in Louisbourg J-47 (OETR 2011), east of Parcel 8. On the slope, Tithonian source rocks are also widely considered the primary source interval for hydrocarbons encountered in Annapolis G-24, Newburn H-23, and Aspy D-11/D-11A (Fowler 2020). They are interpreted to be linked to Upper Jurassic delta systems that supplied ample terrigenous material to the slope. Such source rocks are likely to be mainly gas-prone, consistent with the phase of hydrocarbons discovered on the slope so far. Petroleum system modelling shows that Tithonian source rocks would be in the oil to dry gas window across much of the Sable Subbasin, while reaching maturity in the Late Cretaceous to Late Cenozoic (OERA 2016).

There has also been speculation that a deeper Lower Jurassic oil-prone marine source rock could be present along the Scotian margin (OETR 2011). Geochemical typing of oil samples in wells along the rift-shoulder (e.g. Mic Mac J-77) provides the clearest evidence for a deeper (Lower Jurassic?) restricted-marine marly source rock (Fowler 2020), but these source intervals have not been demonstrated to be widespread. If a Lower Jurassic source rock is present beneath the eastern Scotian Slope, its deep burial depth probably means it is overcooked and gas-prone. Together, these observations suggest that the source rocks in the Call for Bids NS22-1 area will mainly expel gas and condensate.

Ongoing Research

A number of additional geoscience studies are currently under way that may also be of interest to the reader. In particular, the Nova Scotia Department of Natural Resources and Renewables and the Offshore Energy Research Association (now Net Zero Atlantic) have funded several projects on the Scotian margin focused on plate tectonics, deep crustal modeling using refraction data, paleoclimate, paleobathymtery and tectonic evolution of the Central Atlantic conjugate margin. Project descriptions for for these ongoing studies can be found on the OERA website here: https://oera.ca/research-portal

Most of these projects are scheduled to be completed in early 2023 while Call for Bids NS22-1 is still open.

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