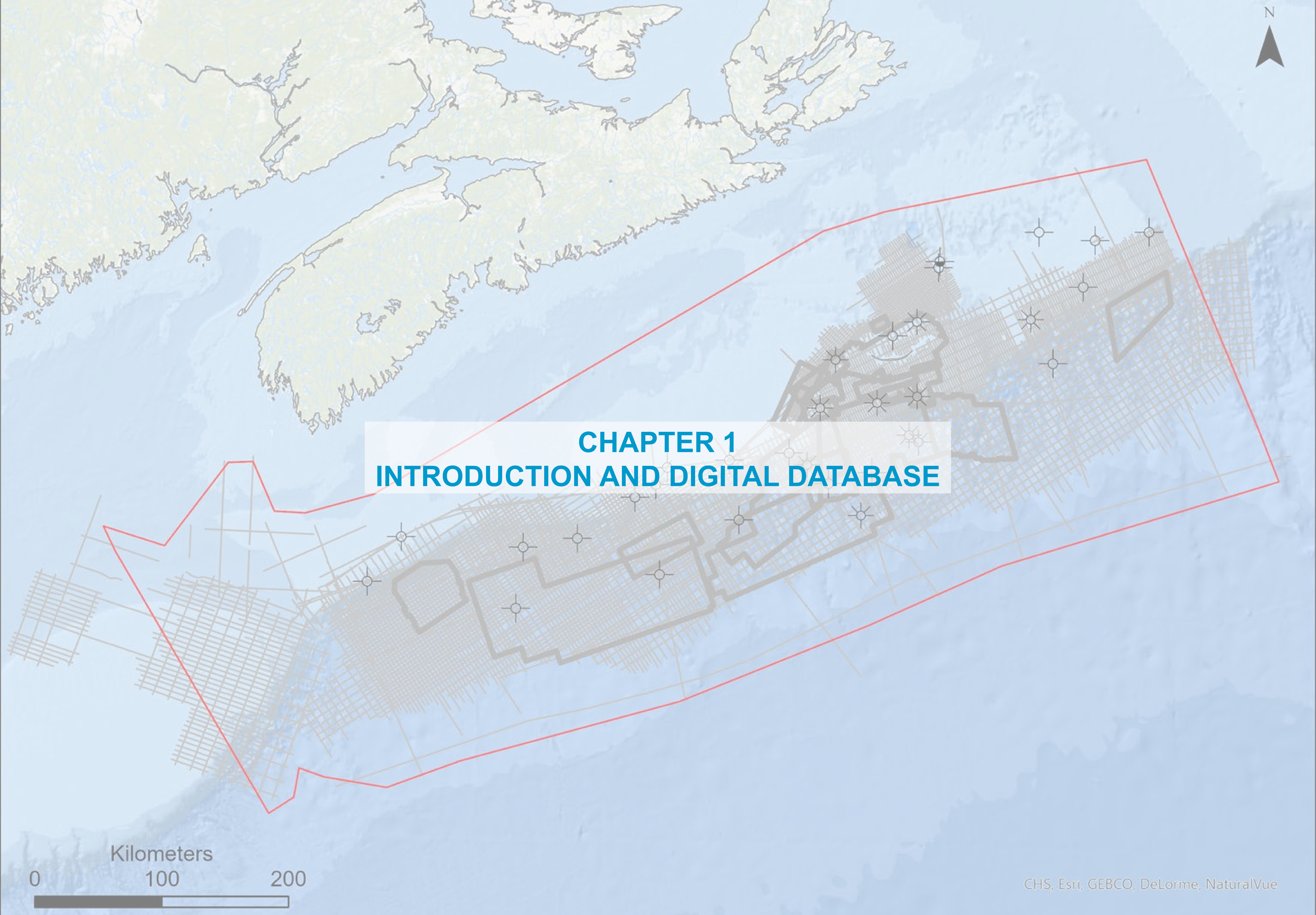
CHAPTER 1
INTRODUCTION AND DIGITAL DATABASE



Introduction

The Scotian Basin has been explored since the 1960s. With 24 significant discoveries, extensive 2D and 3D seismic data, and over 200 wells, the basin has yielded a cumulative production of approximately 2.1 TCF of gas and 45 MBO from 8 now decommissioned fields, plus a P50 resource of approximately 2 TCF and 28 MBO in 15 currently stranded Significant Discovery Licenses (CNSOPB 2021, 2022A, 2022B, and Smith et al, 2014).

To attract renewed exploration interest in offshore Nova Scotia, this study aims to produce a definitive reference document and dataset (the Integration Atlas) highlighting the province's offshore petroleum potential. It has integrated the past twelve years of data and research undertaken since the publication of the 2011 Play Fairway Analysis and will comprise new workflows, including Beicip Franlab's updated picture of Nova Scotia's potential, for the petroleum exploration community.

The Integration Atlas was conceived by the Province of Nova Scotia Department of Natural Resources and Renewables as a collaboration between leading Scotian Basin researchers in government, university, and contractor roles to provide key inputs for a Beicip-Franlab team to integrate and develop a revised assessment of Nova Scotia's offshore petroleum systems. For the integration atlas project, the Beicip-Franlab team recommended and developed a new sequence stratigraphic framework, petroleum systems synthesis, and select lead volumetric calculations for the whole Scotian Basin building on previous assessments and latest exploration results. Significant collaborators include:

•CNSOPB (seismic interpretation and sediment delivery to the deep water);

•Stratum Reservoir (source rock distribution, quality and uncertainty);

•Nova Scotia Natural Resources and Renewables (seismic attribute analysis for reservoir potential; Jurassic petroleum system assessment and AVO analysis); and

•Other international researchers supporting the parallel PaGeo research program (see Appendix 4), as well as technical advisors including Matt Luheshi, Janice Weston, Andrew MacRae, Andrew Bishop, Bill Richards, and Martin Fowler.

The Integration Atlas study area is covered by approximately 79,000 km of 2D and 42,300km² of 3D seismic data (Figure 1).

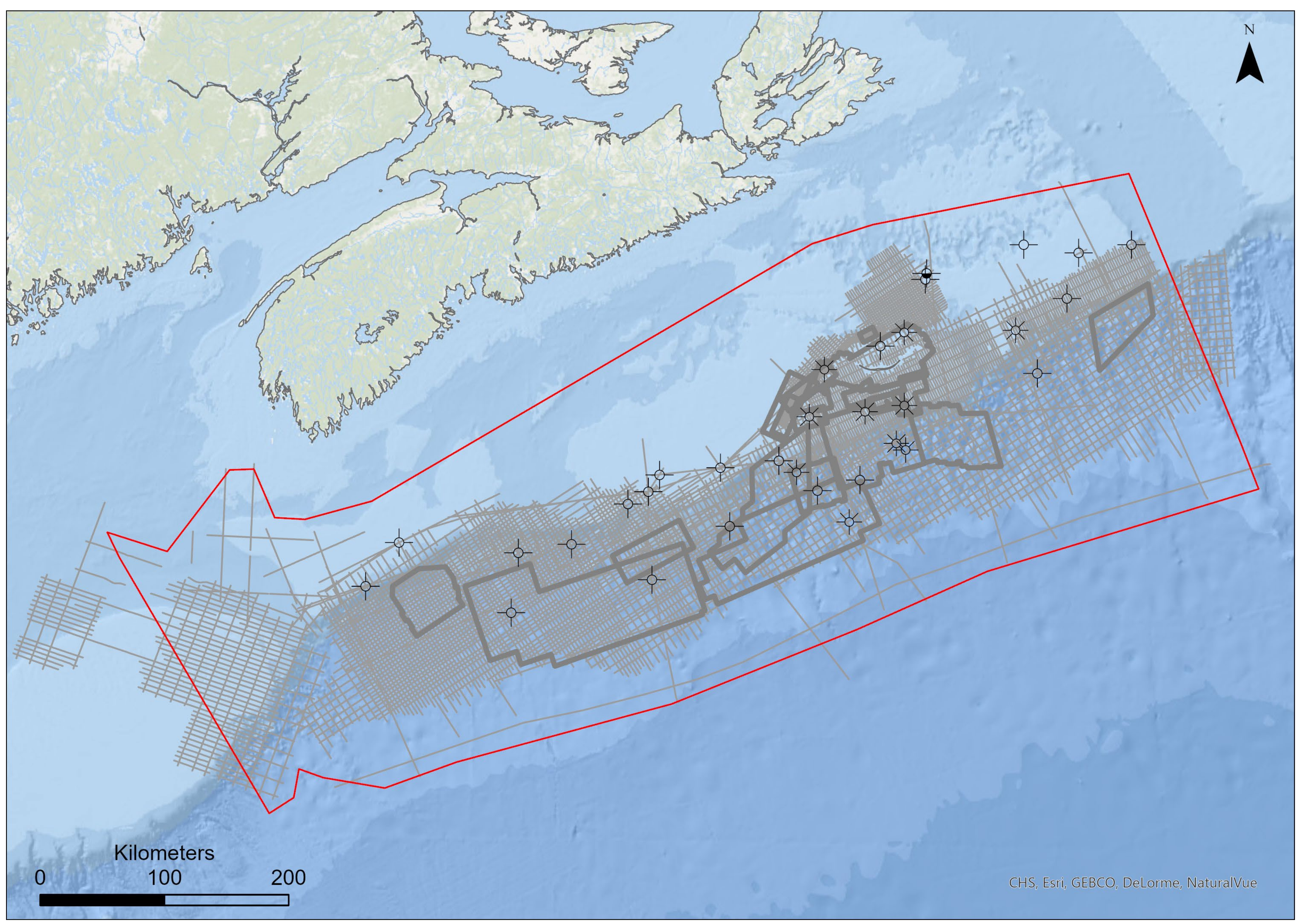


Figure 1: Integration Project outline in red with 2D and 3D seismic and key wells used in this project.

Integration Project

A principal objective of the Scotian Basin Integration Atlas project was to take lessons learned and work completed in the decade since the 2011 Play Fairway Analysis (PFA) was published and to create an updated review of Nova Scotia's potential for the petroleum exploration community. Integration of data and interpretation from new high quality 3D seismic and 3 deep water wells drilled by Shell & BP in the last decade (i.e. post the 2011, 2015 and 2016 studies published by NRR) provide significant uplift and insight further to previous studies.

The Scotian Basin Integration Atlas project began in March 2022 and was completed in June 2023. The work was organized in three sequential phases:

1) A regional review to update Nova Scotia and Beicip-Franlab's 2011, 2015 & 2016 PFAs for all of Nova Scotia's deep water and key shelf areas, including detailed sequence stratigraphic and gross depositional environment analysis

2) Identification of Areas of Interest (AOI) for an analysis component based on a regional update of GDE and CRS maps. This was completed by a joint team of experts consisting of staff from Nova Scotia/OERA, CNSOPB and Beicip-Franlab. These AOIs were subjected to a more detailed analysis and workup by Beicip-Franlab.

3) A detailed evaluation of the top 10 leads identified and the creation of an atlas synthesis of (1) and (2), similar to previous PFA studies. Publication of the Atlas is accompanied by digital layers of the component inputs and outputs.

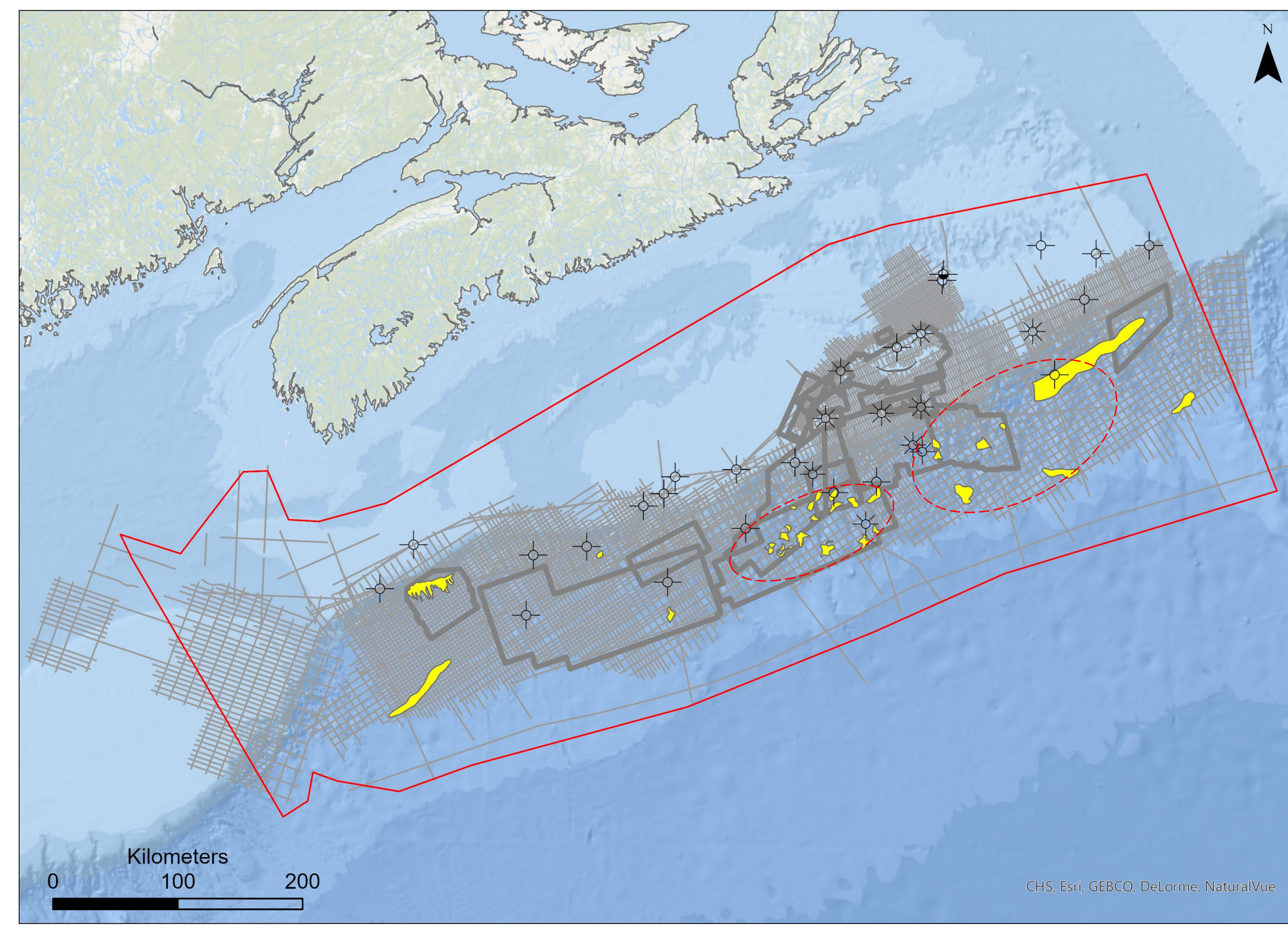


Figure 2: Integration Project outline in red with top leads (yellow) overlain on the 2D and 3D seismic and key wells used in this project.

3D seismic surveys

19 (Nineteen) 3D seismic surveys have been used for the Scotian Basin Integration Atlas (2023). The seismic data were all provided in the time domain, except for Tangier 3D data delivered in depth. These 3D seismic surveys are:

Name	Program Number	Vintage	Operator
Abenaki	NS24-E043-001E	2002	Encana Corporation
Alma	NS24-M003-006E	1997	Mobil Oil Canada Properties
Barrington	NS24-P003-004E	2020	Pancanadian Petroleum Limited
Blueberry	NS24-E043-004E	2003	Encana Corporation
Chebucto	NS24-E040-001E	2001	ExxonMobil Canada Limited
Cree	NS24-E030-001E	2001	ExxonMobil Canada Limited
Huckleberry	NS24-P003-002E	2000	Pancanadian Petroleum Limited
Marathon	NS24-M005-001E	2003	Marathon Canada Limited
Marmoa	NS24-M007-007E	1998	Mobil Oil Canada Properties
North Triumph	NS24-M003-006E	1997	Mobil Oil Canada Properties
Penobescot	NS24-N011-001E	1991	Nova Scotia Resources Limited
Sable MegaMerge	NS24-M003-003E,006E,007E,009E,0010E	2001	ExxonMobil Canada Limited
Shelburne	NS24-S006-003E	2013	Shell Canada Limited
Stonehouse	NS24-E043-002E	2003	Encana Corporation
Tangier	NS24-B071-001E	2014	BP
Thrumcap	NS24-S006-001E,002E	2001	Shell Canada Resources Limited
Torbrook	NS24-P003-002E	2000	Pancanadian Petroleum Limited
Veritas	NS24-V003-002P,003P,004P	2001	Veritas Seismic
Weymouth	NS24-P003-004E	2001	Pancanadian Petroleum Limited

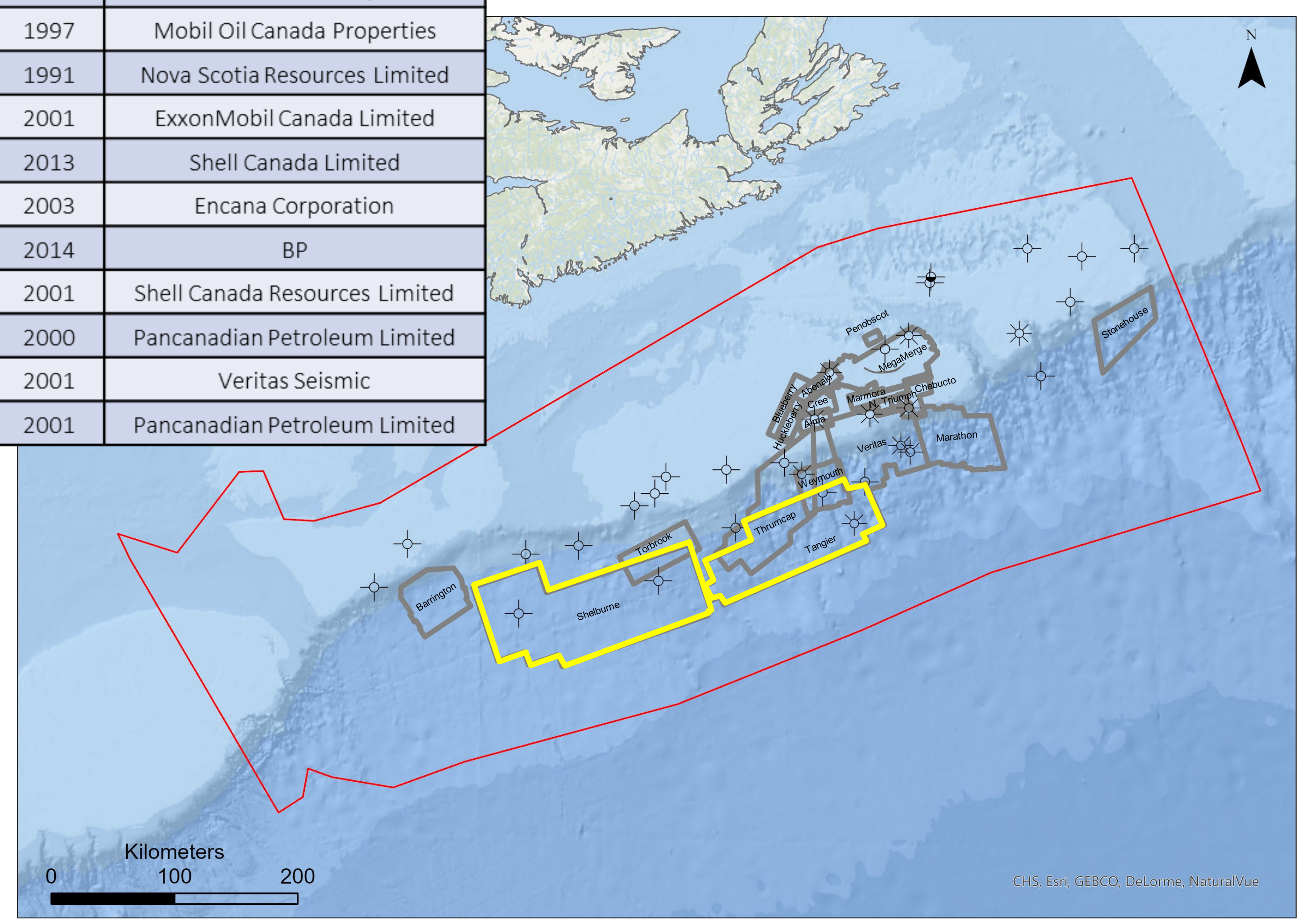


Figure 3: Integration Project outline in red with the 19 3D seismic surveys used in this project. The Modern WAZ 3D Surveys, Shelburne and Tangier, are outlined in yellow.

2D Seismic surveys

Several 2D seismic surveys have also been used in the Atlas. The seismic data were all provided in the time domain. These 2D seismic surveys are:

1) TGS NOPEC selected 2D lines (2010 reprocessing)
2) NovaSpan 2D (NS24-G075-003P)
3) Penobscot 2D (8620-N011-001E)
4) 83 MGR (8620-S014-006E)
5) TGS 2D Regional (NS100/109)
6) The Dales (NS24-P003-003E)

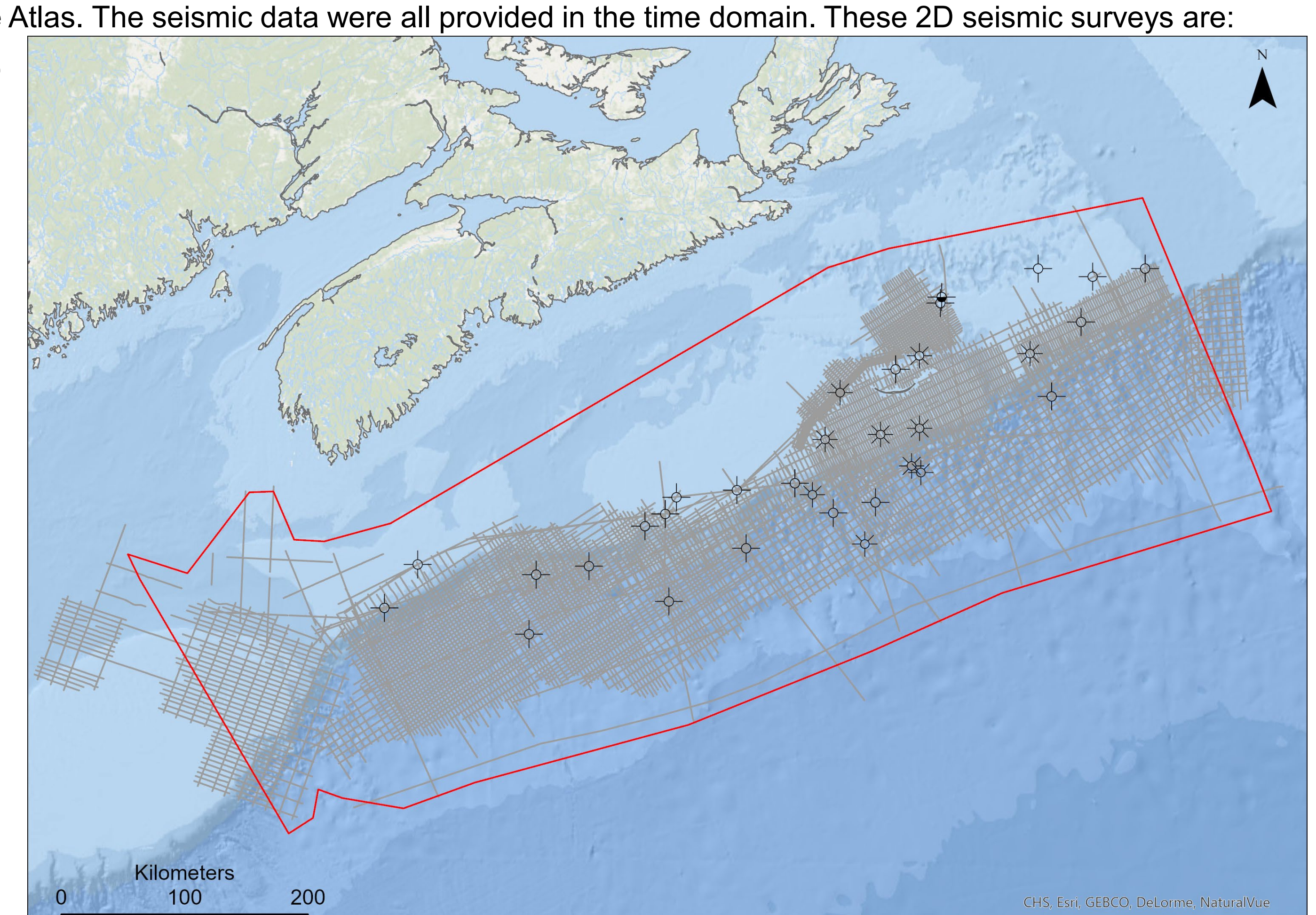
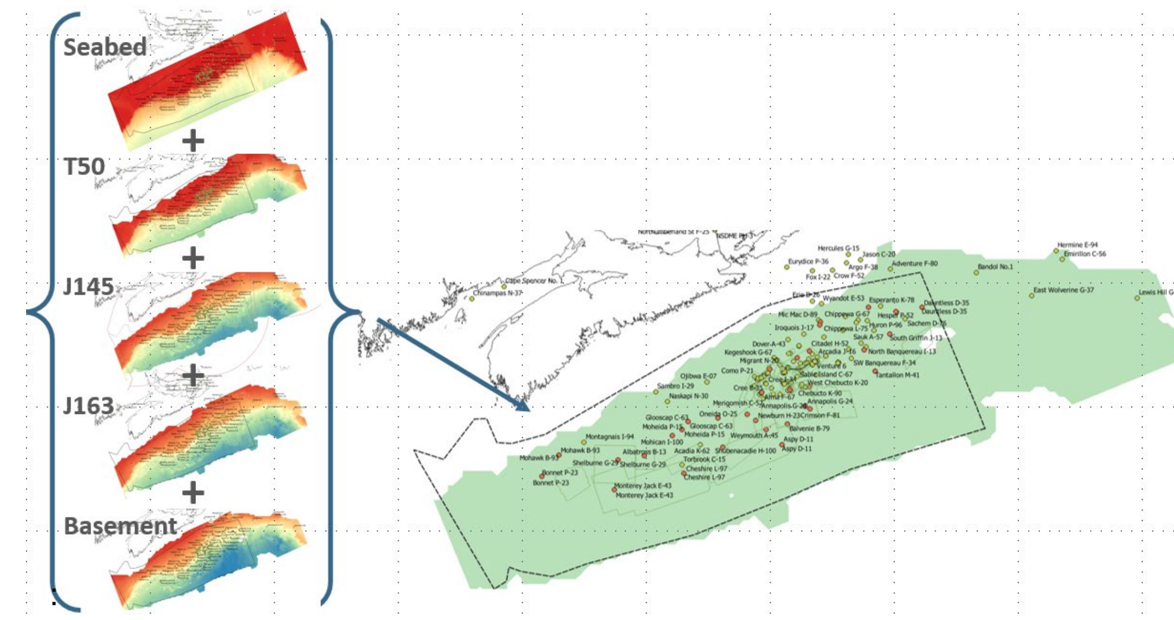


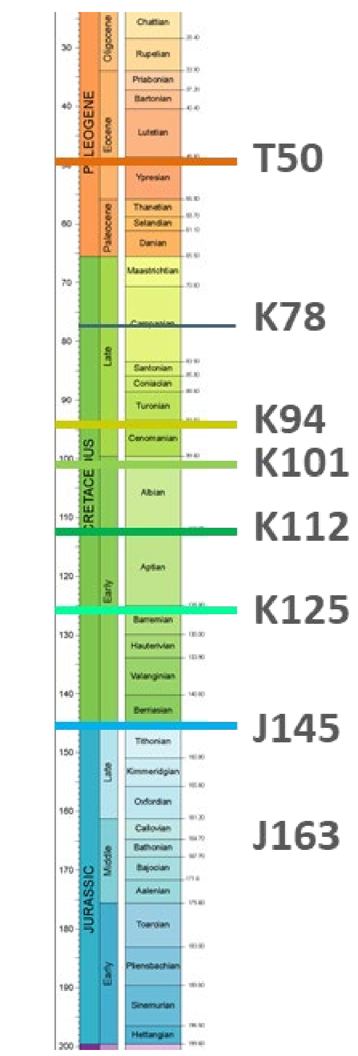
Figure 4: Integration Project outline in red with the six 2D seismic surveys used in this project. The Jebco and Georges Bank surveys in the west was utilized in the 2015 PFA (several horizons from this project are incorporated in the current study).

Seismic horizons

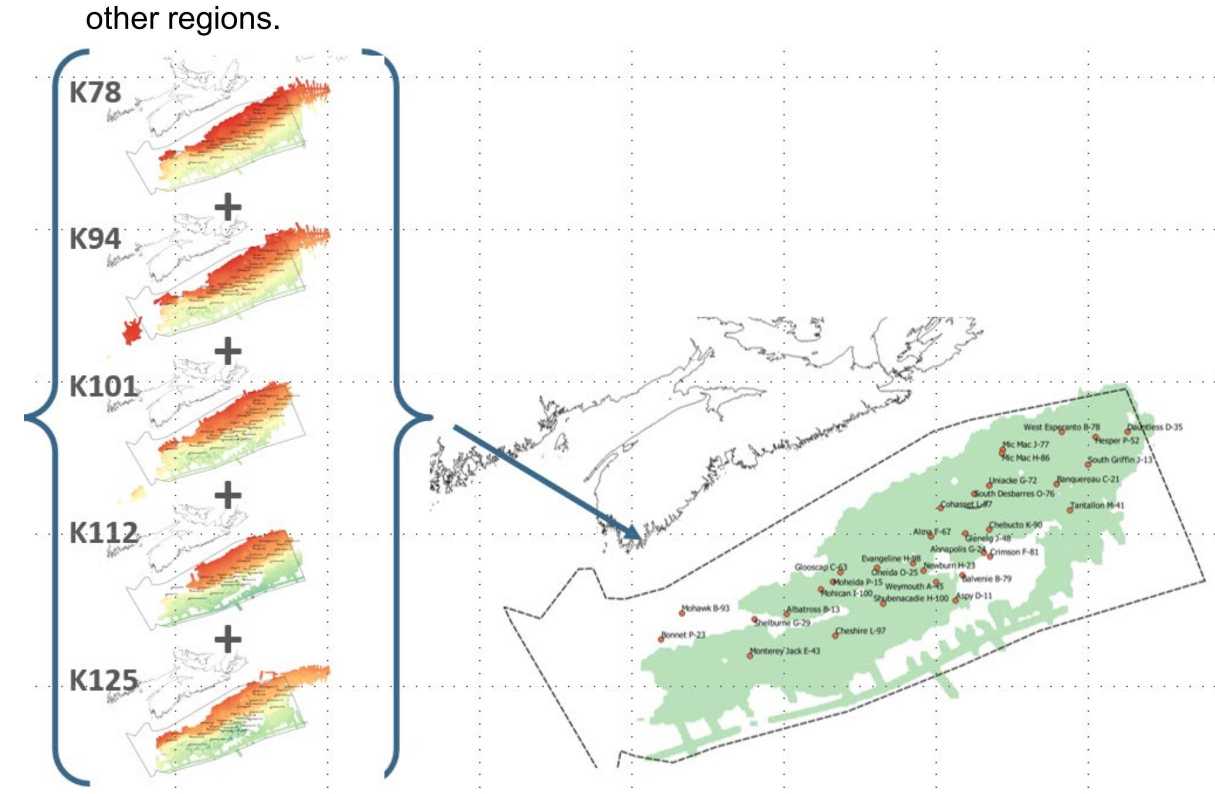
The following horizons were delivered in the time domain by the Canada Nova Scotia Offshore Petroleum Board (CNSOPB, see Chapter 2): Top Basement, J163, J145, K125, K112, K101, K94, K78 and T50 (Deptuck and Kendell, 2023).

- The following horizons were delivered in almost the whole study area





- The remaining horizons (K78, K94, K101, K112 and K125) were delivered in a limited part of the Study area. These were subsequently completed by the CNSOPB in the SW and by Beicip-Franlab in the other regions.



The CNSOPB also delivered valuable horizons related to the salt in the time domain. These included the top and the base of the autochthonous salt, allochthonous salt in the central slope, canopy salt in the central slope, and shallowest salt in the Banquereau region, as well as the top of the salt diapirs in the western Scotian slope, and the corresponding salt polygons at the intersection of the salt with each of the delivered interpreted horizons.

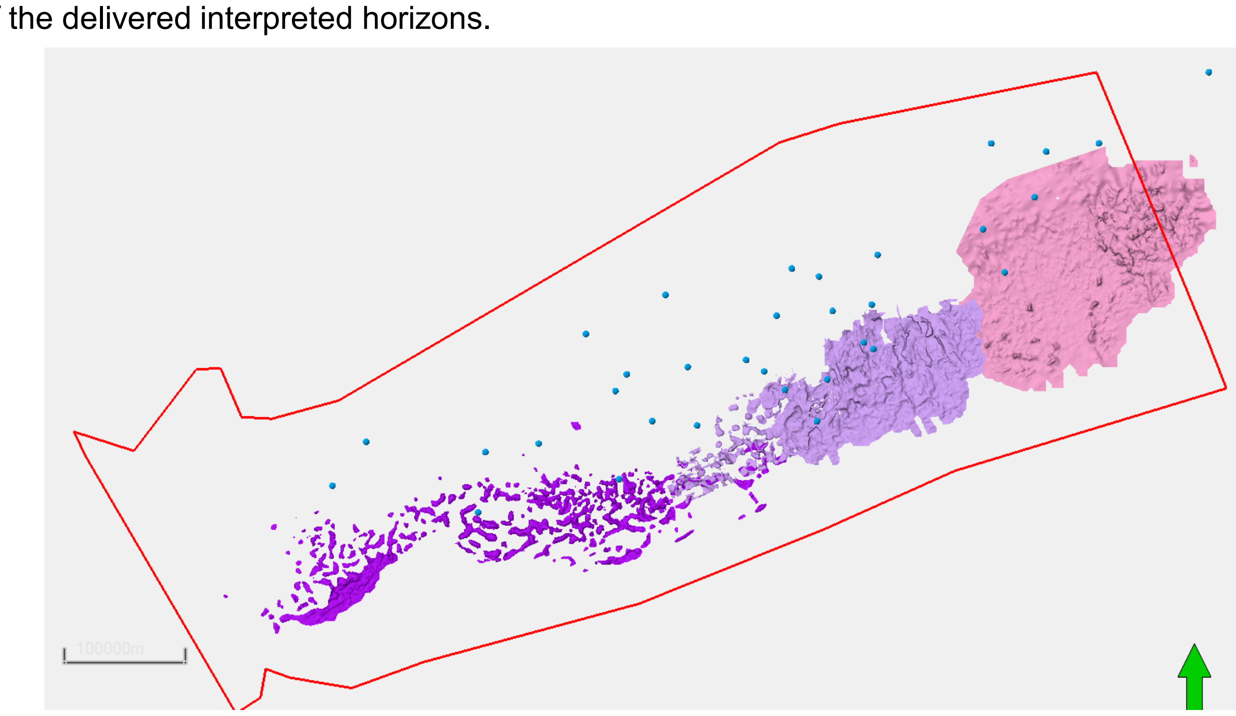


Figure 5: Integration Project outline in red with CNSOP Salt horizons.

Wells

The 2023 Scotian Basin Integration Atlas used all the key wells shown in Figure 6. These were the wells used in the 2011 Nova Scotia Play Fairway Analysis, plus three more recent exploration wells, namely Monterey Jack E-43 and Cheshire L-97 drilled by Shell and Aspy D-11 drilled by BP.

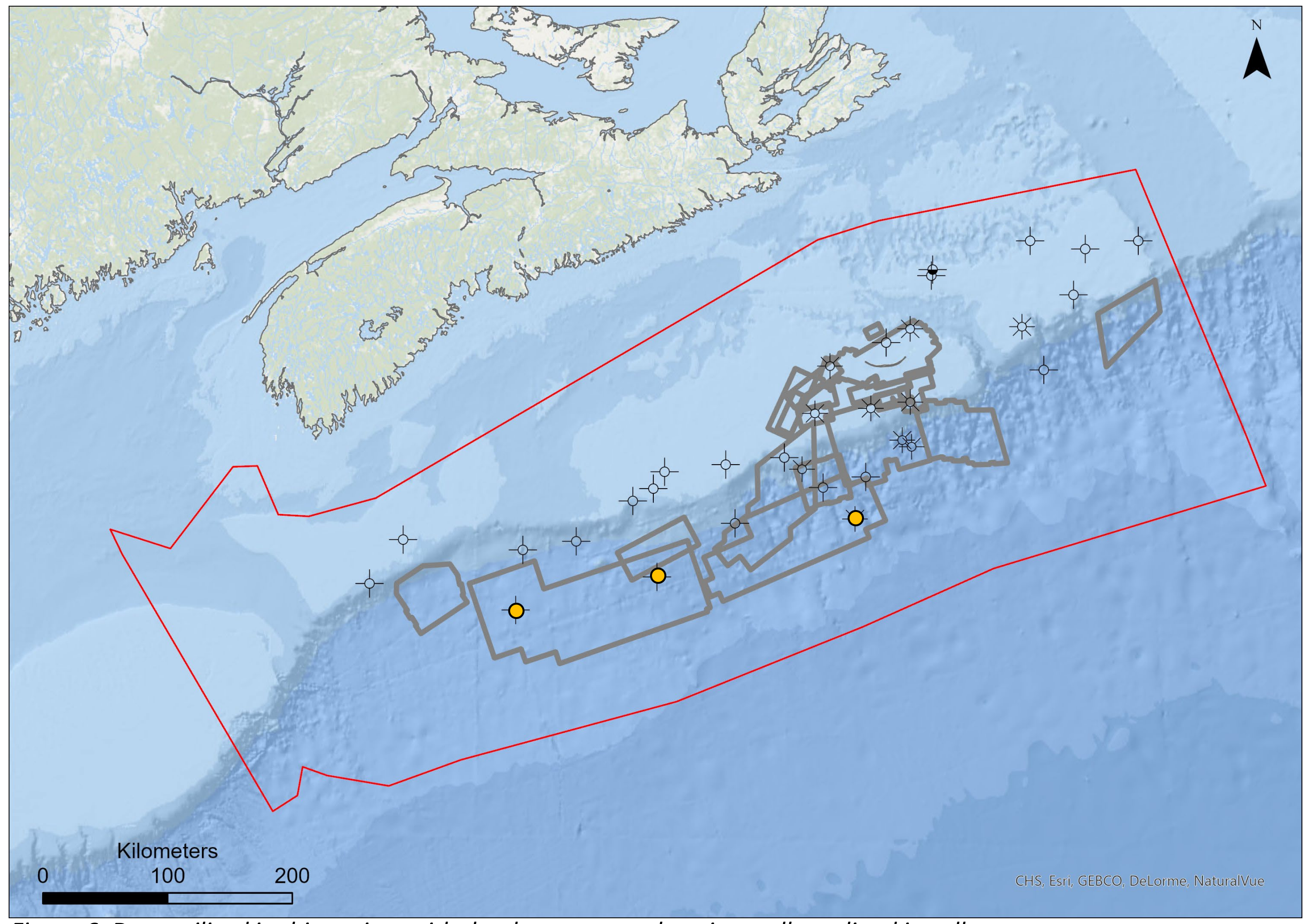


Figure 6: Data utilized in this project with the three new exploration wells outlined in yellow.

Well Name	Spud Date	Rotary Table (m)	Water Depth (m)	Total Depth (m)
Albatross B-13	11-Dec-80	24.4	1335	4,046
Alma F-67	1-Dec-79	24	68	5,054
Annapolis G-24	16-Apr-98	36	1678	6,182
Aspy D-11	21-Apr-14	31	2771	6,458
Aspy D-11A	18-Aug-14	31	2771	7,400
Balvenie B-79	5-Jul-99	25	1803	4,750
Banquereau C-21	1-Dec-77	27	83	4,991
Bonnet P-23	13-Jan-80	25	135.5	4,336
Chebucto K-90	5-Jan-80	22.8	86.2	5,235
Cheshire L-97	22-Oct-11	31.7	2141.5	6,832
Cheshire L-97A	26-Jul-12	31.7	2141.5	7,068
Cohasset L-97	12-Jul-74	32.9	21.6	4,872
Crimson F-81	17-Jun-00	24	2091.5	6,676
Dauntless D-35	25-Apr-67	29.9	69.2	4,741
Eagle D-21	21-Apr-68	29.9	51.2	4,660
Evangeline H-98	7-Aug-80	20.1	174	5,044
Glenelg J-48	21-Feb-79	24	82	5,148
Glooscap C-63	6-Aug-79	22.9	122	4,542
Hesper P-52	21-Aug-80	40.5	44.5	5,679
Mic Mac J-77	24-Mar-66	25.9	62.8	3,886
Mohawk B-93	2-May-66	31.4	117	2,126
Moheida P-15	17-Nov-72	29.9	111.9	4,298
Mohican I-100	26-Dec-67	29.9	153.4	4,393
Monterey Jack E-43	24-Sep-12	31.7	2149.5	5,266
Monterey Jack E-43A	27-Nov-12	31.7	2149.5	6,692
Newburn H-23	21-May-98	24	977	6,070
Oneida O-25	15-Nov-65	25.9	82.3	4,120
Primrose F-41	29-Jan-69	29.9	58.6	2,592
Shelburne G-29	30-Mar-81	24	1153.5	4,005
Shubenacadie H-100	4-Nov-78	24	1476.5	4,200
South Desbarres O-76	16-Apr-80	23.7	69	6,039
South Griffin J-13	7-Jan-80	39.6	63.4	5,911
Tantallon M-41	14-Feb-82	24	1516	5,602
Uniacke G-72	8-May-79	23.4	152.9	5,735
West Esperanto B-78	21-Aug-78	23.3	92	5,703
Weymouth A-45	26-Oct-99	25	1689.7	6,520

Biostratigraphic markers of these wells, were available for this study. In addition, nine other wells wells were also included (Figure 7, Mohawk B-93, Mohican I-100, Moheida P-15, Uniacke G-72, South Desbarres O-76, Oneida O-25, MicMac J-77, MicMac H-86 and Banquereau C-210).

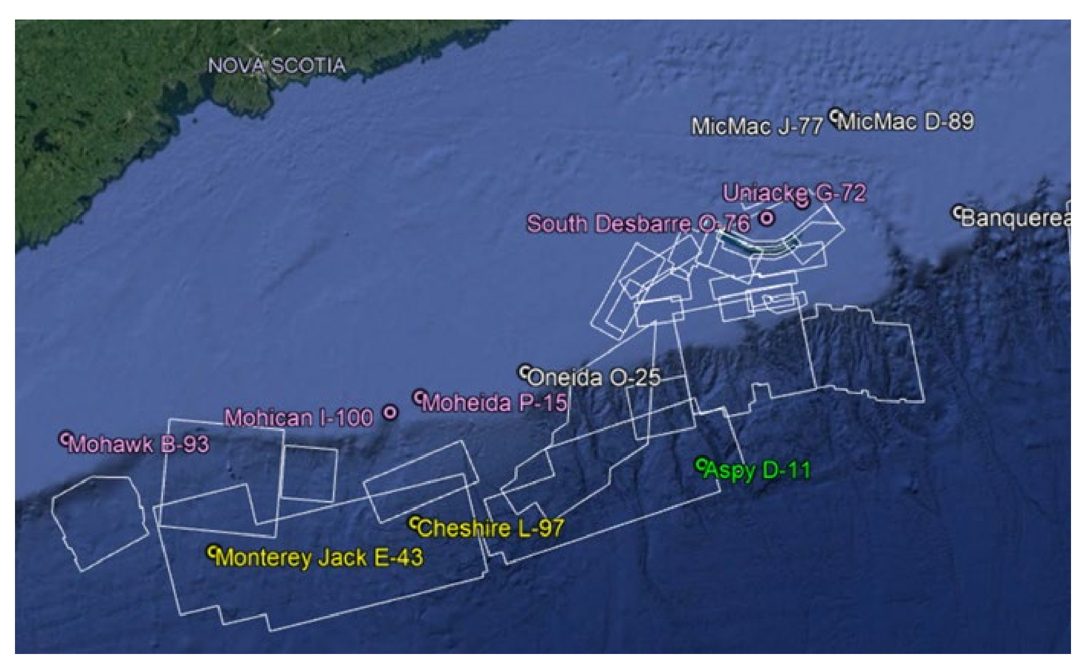


Figure 7: The 3 recent drilled wells in yellow (Shell), green (BP) and the nine additional wells used in this study.

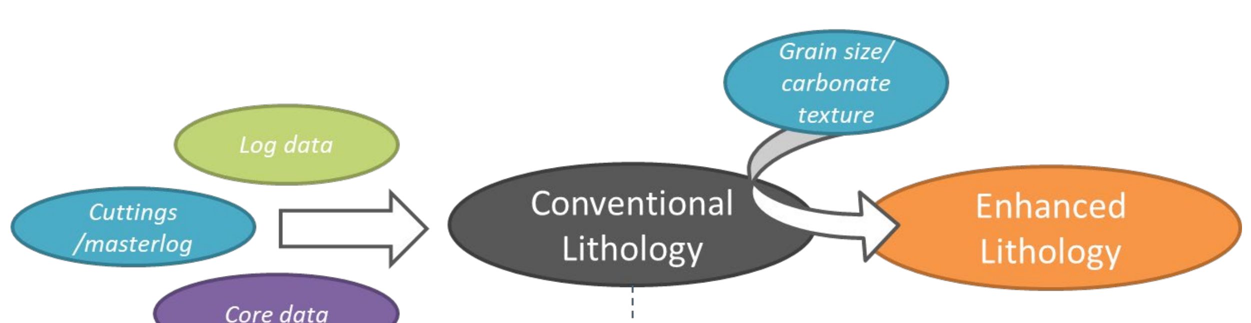
Electrofacies Definition

Lithologies were defined in 32 key wells as follows:

- 20 wells from former 2011 PFA study
- 3 new wells
- 9 wells added for completeness

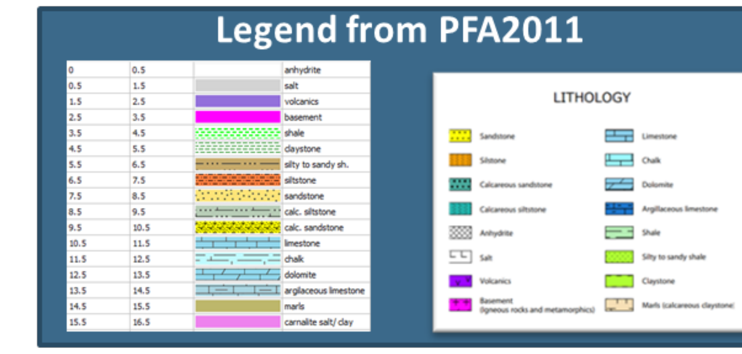
Methodology for lithology definition: 2 lithology curves created

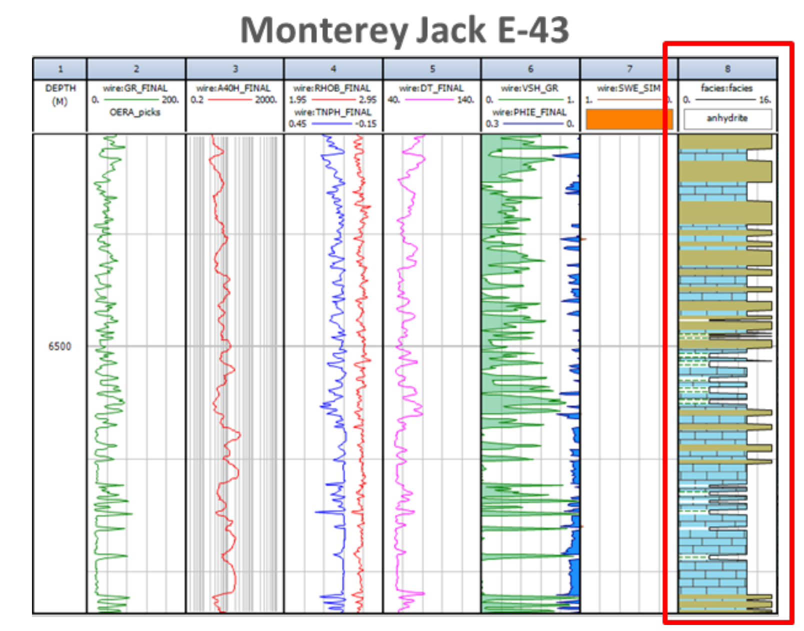
- Conventional curves (cf PFA2021)
- Additional curves with textural/grain size information

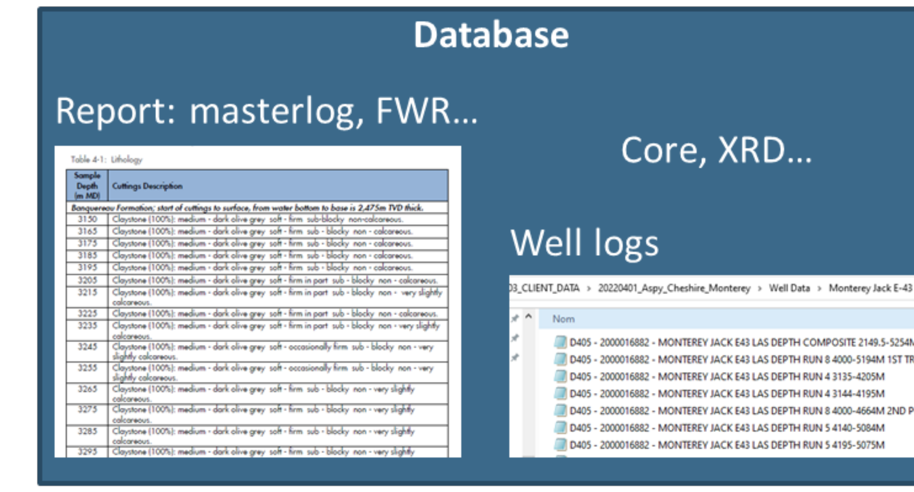


Lithology digitized from PFA 2011 in 20 wells

Methodology extended to 12 other wells: Monterey Jack E-43, Cheshire L-97 and Aspy D-11 and 9 other wells for their location.



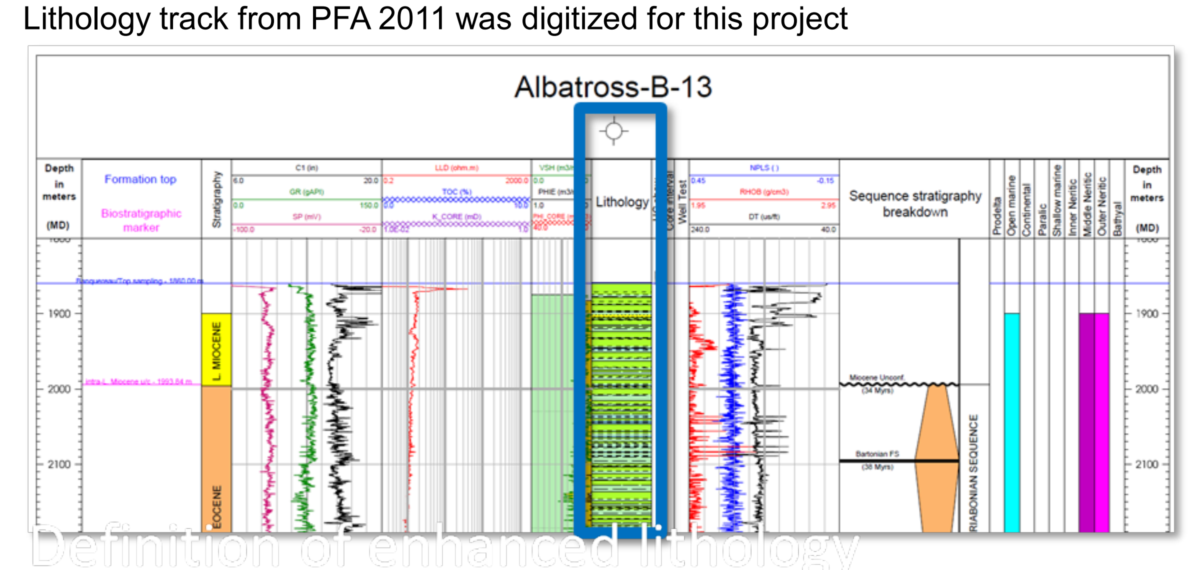


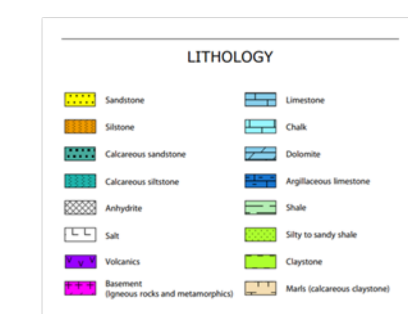


Definition of conventional lithologies

Lithologies of 20 wells were evaluated during PFA 2011:

- Methodology from PFA 2011 was based on core descriptions, reports on mineralogical variations, cuttings and log variations.
- More than 16 lithologies were identified
- Lithology track from PFA 2011 was digitized for this project



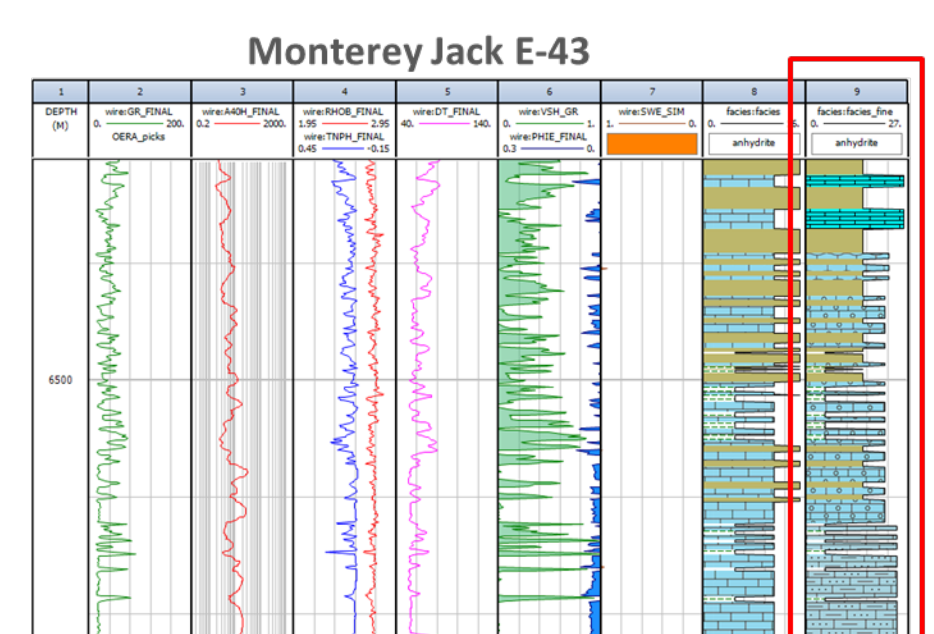


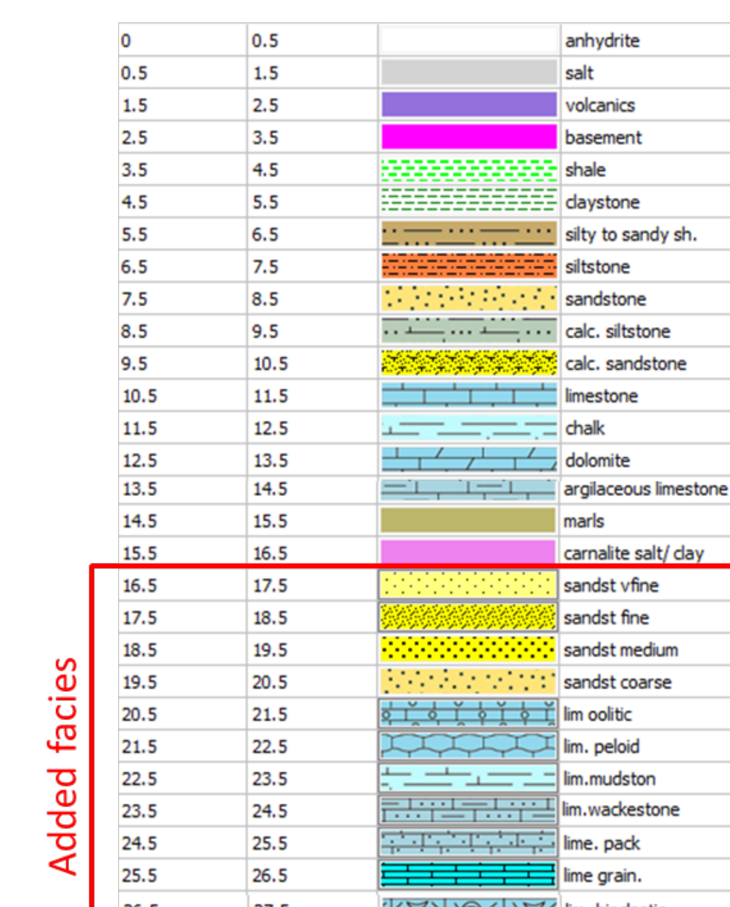
Definition of enhanced lithologies

Methodology for enhanced lithology definition:

- Lithology variation from conventional lithology
- Addition of textural information and grain size

Enhanced lithology extended to all 32 wells





Velocity Model

In past Play Fairway Analysis (PFA) projects (2010-2021), velocity models were variously developed to allow time-to-depth conversion of interpreted seismic. By 2021, OERA / NSDRR had a collection of legacy PFA regions of interest with different stages of interpretation and velocity models.

To make use of these past projects and updated interpretations from the CNSOPB (in time) for different parts of the margin, the OERA / NSDRR were faced with the general challenge of creating an integrated and internally consistent time-to-depth or velocity model conversion.

This study created a regional time-to-depth velocity model that integrated diverse inputs and reconciled inconsistencies in a systematic way to support approximate, yet reasonable depth-converted seismic interpretations across offshore Nova Scotia. This updated velocity cube was used to depth convert all the seismic TWT maps used in this current study. A full, detailed workflow can be seen in Appendix 6.

Database

A rectangular area – the AOI – delimits the zone where the velocity model was constructed. It measures 358 x 1224 km along a WSW-ENE main direction (structurally the main N68 'strike' direction), delimiting a 438,000 km² surface, and covers the whole offshore Nova Scotian margin plus a large part of the Laurentian sub-basin belonging to the province of Newfoundland and Labrador.

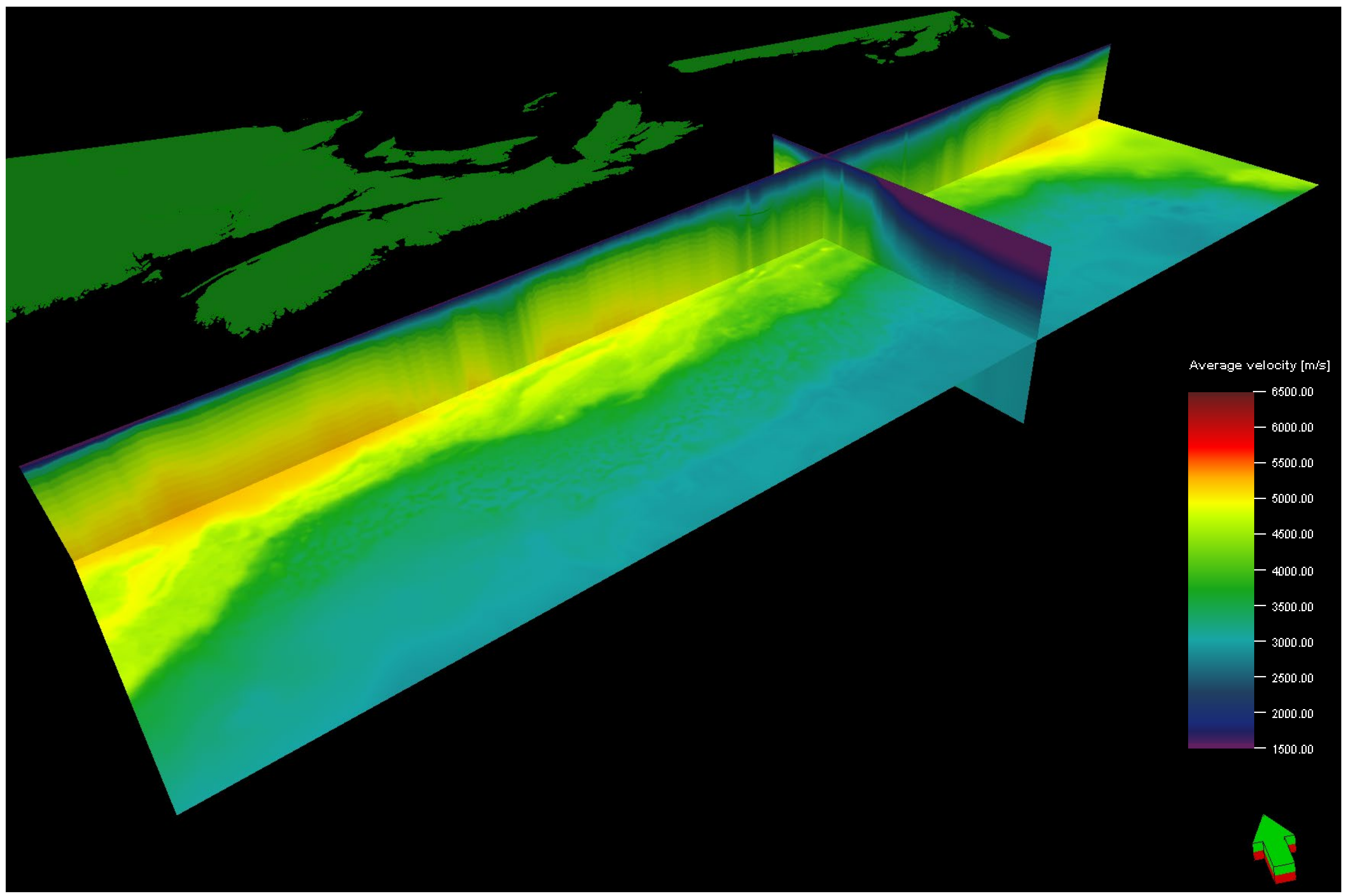


Figure 8: Sample of Average velocity model.

A total of 40 wells were included. These wells had diverse data sets (these included checkshot or VSP data, sonic log and geological markers). Data coverage was not uniform.

Seismic processing velocities were divided into six 2D surveys and four 3D cubes.

The AOI encompasses five gridded main horizons. Three sets of salt horizons divide the salt area into diapirs and canopies. They were QCed to get extended horizons that do not cross each other.

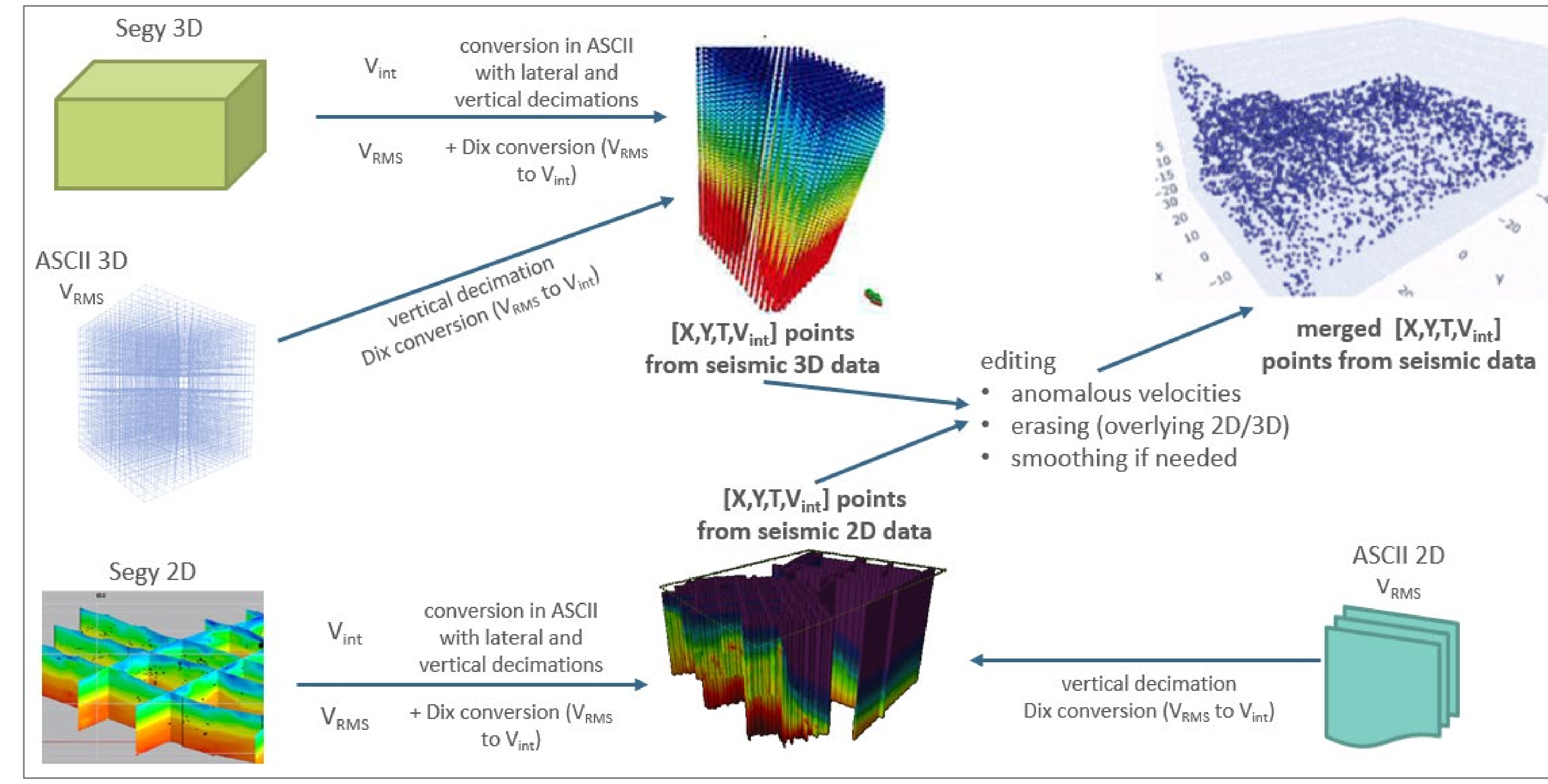


Figure 9: Phase one methodology.

Methodology

Phase 1 (Figure 9): Creation of a merged set of [X,Y,T,V_{int}] *data* points from various sources of raw seismic velocities. Different kind of editing (erasing, cropping, smoothing, upscaling) *was* done before merging.

Phase 2 (Figure 10): 3D interpolation of seismic velocities *using* a stratigraphic model built using all the horizons *(some editing was done).* Different zones of layering are set between the edited horizons: regular layering in the sedimentary/reservoir zones, constant layer/velocity in the salt and water.

Phase 3 (Figure 10): Co-kriging of the calibrated well velocities with the seismic velocity cube. Such co-kriging preserves the calibrated TZ laws, consequently no further residual correction would be necessary (the residuals are corrected/estimated previously to the co-kriging). Interval velocities Vint were converted to average velocities Vavg for domain conversion described in the subsequent plate.

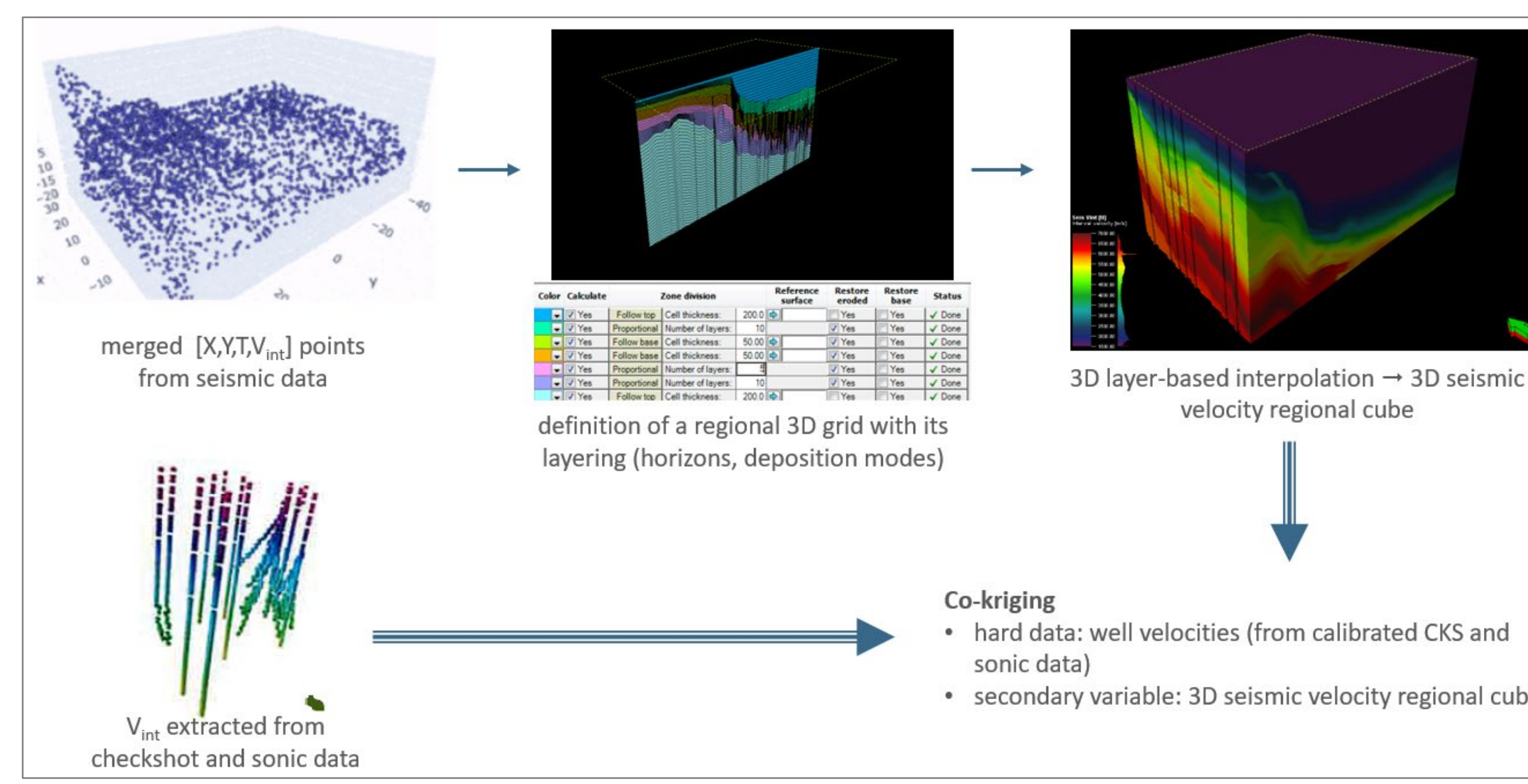


Figure 10: Phase two and three methodologies.

Horizon Conversion and Residual Analysis

Horizons were converted to depth using the following formula: Depth = V_{avg}(TWT)*TWT*0.5

Depth conversion was conducted within Petrel. The resulting depth surfaces were checked against corresponding markers at available wells. There were several sources of uncertainty and potential differences due to

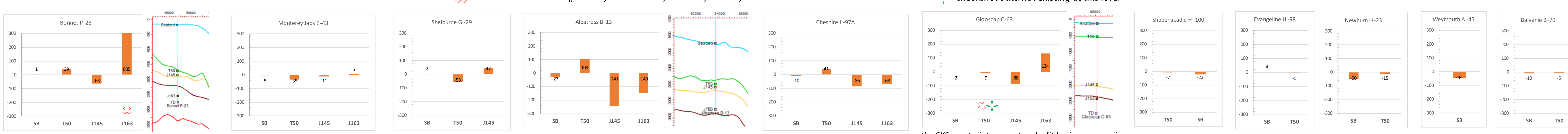
- Possible mismatches between the supplied mapped horizons in time and their corresponding geological markers at wells. The supplied TWT surfaces were converted to depth as is (i.e. no editing was done to correct for any local differences at wells)
- Errors/uncertainties in the regional time grids due to merging surfaces from different vintages of mapping
- Another potential source of errors is the assumption of a constant water velocity of 1500 m/s – this may also contribute to any discrepancies between horizon and well depths.

The following graphs show the depth residual in m after conversion: residual = $Zss_{converted\_horizon}$ - Zss_{marker}. The wells are displayed from West (left) to East (right) and gathered in 3 groups:

- The 23 wells with TZ from checkshot. TZ data from check shot surveys were taken as ground truth and thus not all the seismic horizons can be fitted accurately. The largest residuals are illustrated with comments on the relevant TWT section with the horizons used for the velocity modelling.
- The 6 wells with sonic log. Only Hermine E-94 and Emerillon C-56 have markers coincident with the corresponding interpreted horizons (or vice versa). The depth residuals in the 4 remaining wells cannot be appraised with reliability
- The 11 wells without any TZ recorded. The velocities were "stretched and squeezed" in some intervals between two horizons to better fit the markers and horizons, but without necessarily reaching a "perfect match" through strongly deformed velocities from the first co-kriging results. Indeed, as the horizons may also be incorrect, forcing a perfect fit through non-geological velocities is often unsuitable.

not taken into account (probably horizon interpretation problem)

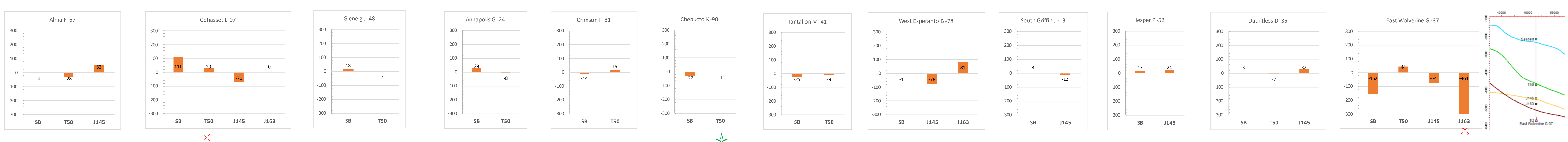
checkshot data not existing at this level



the CKS constraints cannot make fit horizon conversion with such J163 marker (→ horizon problem?)

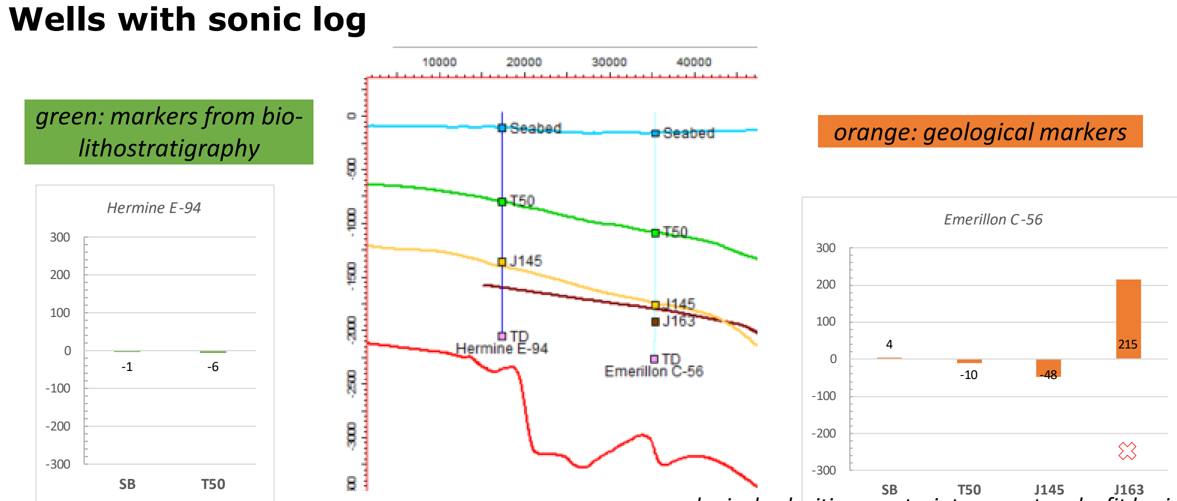
the CKS constraints cannot make fit horizon conversion with such T50-J145 marker nearness (→ horizon problem)

the CKS constraints cannot make fit horizon conversion with such J145-J163 marker position (→ horizon problem)



the CKS constraints cannot make fit horizon conversion with such J163 marker (→ horizon problem)

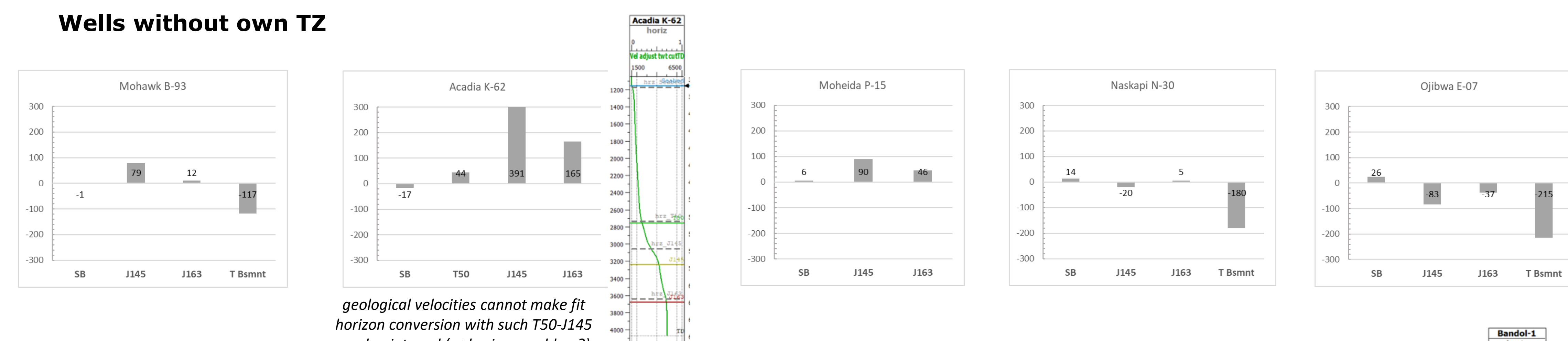
Wells with sonic log



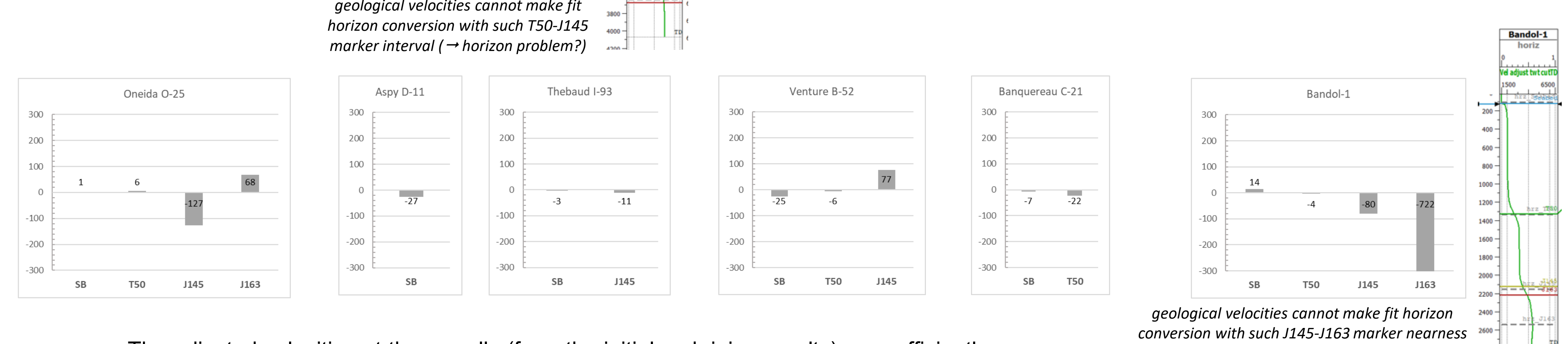
geological velocities constraints cannot make fit horizon conversion with such J145-J163 horizon nearness (→ horizon problem)

NB: the 4 remaining wells in NL, namely Petrel A-62, Kittiwake P-11, Puffin B-90 and Heron-73 have too large discrepancies between horizons and roughly estimated markers to get significant depth residuals.

Wells without own TZ



geological velocities cannot make fit horizon conversion with such T50-J145 marker interval (→ horizon problem?)



geological velocities cannot make fit horizon conversion with such J145-J163 marker nearness (→ horizon problem?)

The adjusted velocities at these wells (from the initial co-kriging results) are sufficiently fitted: their residuals are in the same range as for wells with recorded checkshot.