Velocity model

Final report

Prepared for:

BC Oil and Gas Research and Innovation Society (BC OGRIS)

British Columbia Energy Regulator (BCER)

Version 1.0

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Executive summary

The British Columbia Energy Regulator (BCER) engaged Nanomentics to develop a velocity model for the North East British Columbia (NEBC) region. The objective was to construct a model using publicly available well logs to enhance the understanding of subsurface velocity distribution and to aid in the location of natural and induced seismicity.

The model development process involved selecting and preparing sonic log data, followed by a quality assessment to ensure data reliability. A total of 442 well logs containing P-wave velocity information and 112 well logs with S-wave velocity were parsed during the data preparation process. To preserve the dataset quality, noisy information that could not be effectively treated with smoothing was removed. The final 3D velocity model was constructed for the area of interest, incorporating key geological features such as horizon top surfaces. Additionally, a 1D average velocity model was extracted by averaging the 3D model across the study area.

We thank BC Oil and Gas Research and Innovation Society (BC OGRIS) for their financial support to this project. We thank the BC Energy Regulator (BCER) for help in accessing and providing the input data to the models and review of the results throughout the project.

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Introduction

The British Columbia Energy Regulator (BCER) has requested Nanomentics to develop a velocity model for the North East British Columbia (NEBC) area. The objective was to construct a velocity model using publicly available wells logs, tops, and geological horizons.

This enhanced velocity model aims to improve upon the existing simple 1D regional model, allowing for more precise seismic event localization. By refining event locations, the model will contribute to a better understanding of regional seismicity, including both natural and induced events, and enable more accurate hazard assessments. The study area covers approximately 180 km × 120 km and involves the evaluation of public log files.

Methodology

The model workflow includes the selection and preparation of sonic log data, followed by a thorough quality assessment to ensure data reliability. Noisy information that could not be effectively treated with smoothing was removed to maintain data quality. Finally, a 3D model was developed for the area of interest, incorporating the characteristics of horizon top surfaces. Additionally, a 1D average velocity model was extracted.

The following sections will outline the workflow steps (Figure 1), methodology, and assumptions.

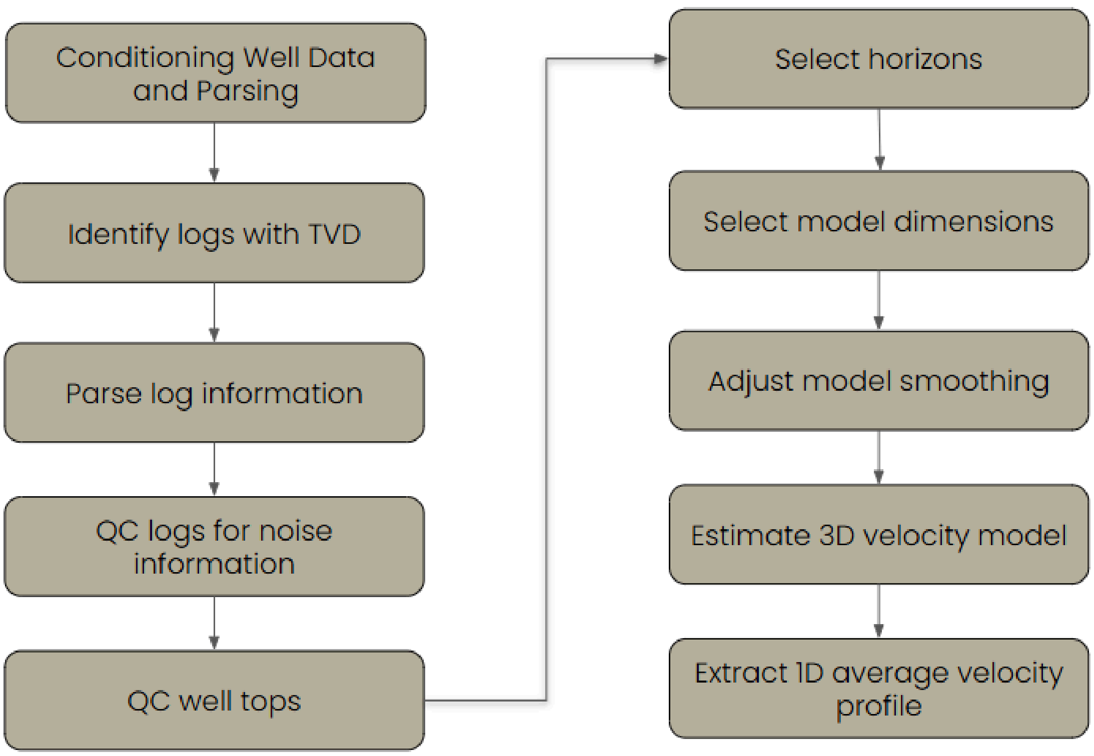

Figure 1. Model building workflow.

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Conditioning Well Data and Parsing

In the initial phase of the investigation, the comprehensive dataset from the BCER comprised approximately 185 GB of LAS files containing well data for all drilling activities across British Columbia. Alongside these files, a CSV file was obtained which documented all reported wells in the province, including unique well identifiers (WA#), precise latitude/longitude coordinates, and elevation data. Due to inconsistencies in the geospatial information across the LAS files (stemming from variations in reporting and geographic datum) data was merged between LAS file metadata with the CSV data based on the unique well identifiers. This integration was necessary to validate the spatial locations of each well, thereby enabling a more reliable geographic assessment of the dataset.

Following the data consolidation, the focus shifted to the north Montney zone targeted for velocity model development. The shapefile for the zone was plotted with all wells located within a 10 km radius (Figure 2). This spatial filtering reduced the dataset to a manageable subset of LAS files. Given that sonic data was not uniformly reported, we then systematically reviewed the LAS files within this region to identify those that contained the appropriate sonic headers. The process involved scanning thousands of files and subsequently categorizing the identified files into those with P-wave and S-wave information. This careful parsing resulted in a refined dataset, further organized by differentiating true vertical depth (TVD) from measured depth (MD) (next section), and would allow for subsequent data cleaning and velocity model building workflow.

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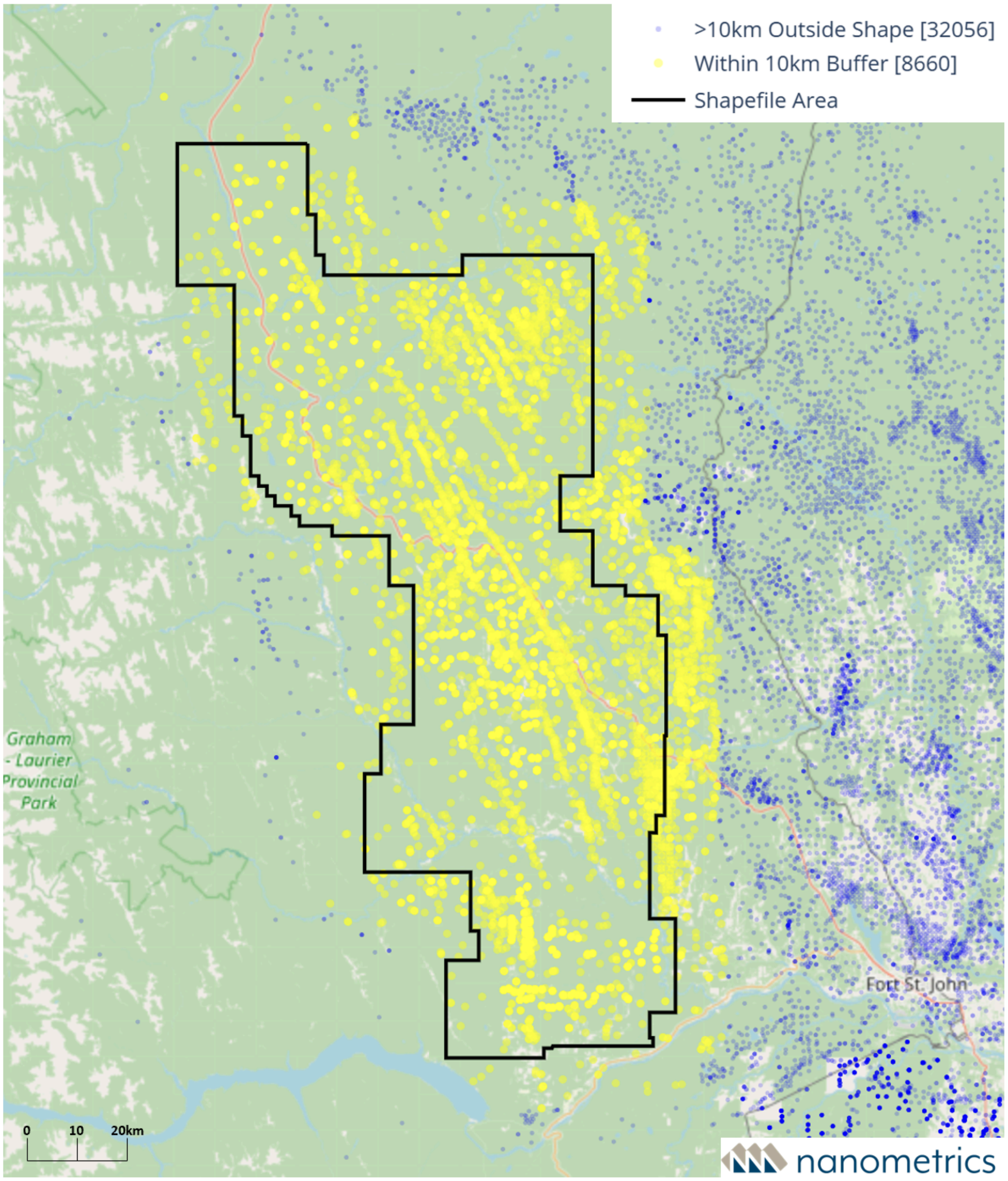

Figure 2: Map of LAS files provided, wells that were located within the target area to be further parsed for P-wave and S-wave sonic velocities.

True Vertical Depth log files

The initial database consisted of files containing True Vertical Depth (TVD) and Measured Depth (MD) data. For velocity model building, TVD data was used to ensure an accurate depth representation of the subsurface. Since TVD accounts for the true vertical positioning of horizons top, it provides a more reliable basis for integrating velocity information, reducing distortions that could arise from well deviations in MD measurements. TVD logs accounted for 45% of the available data (Figure 3). In total, 483 logs containing P-wave information and 119 logs with S-wave velocity information were selected for the velocity model-building process.

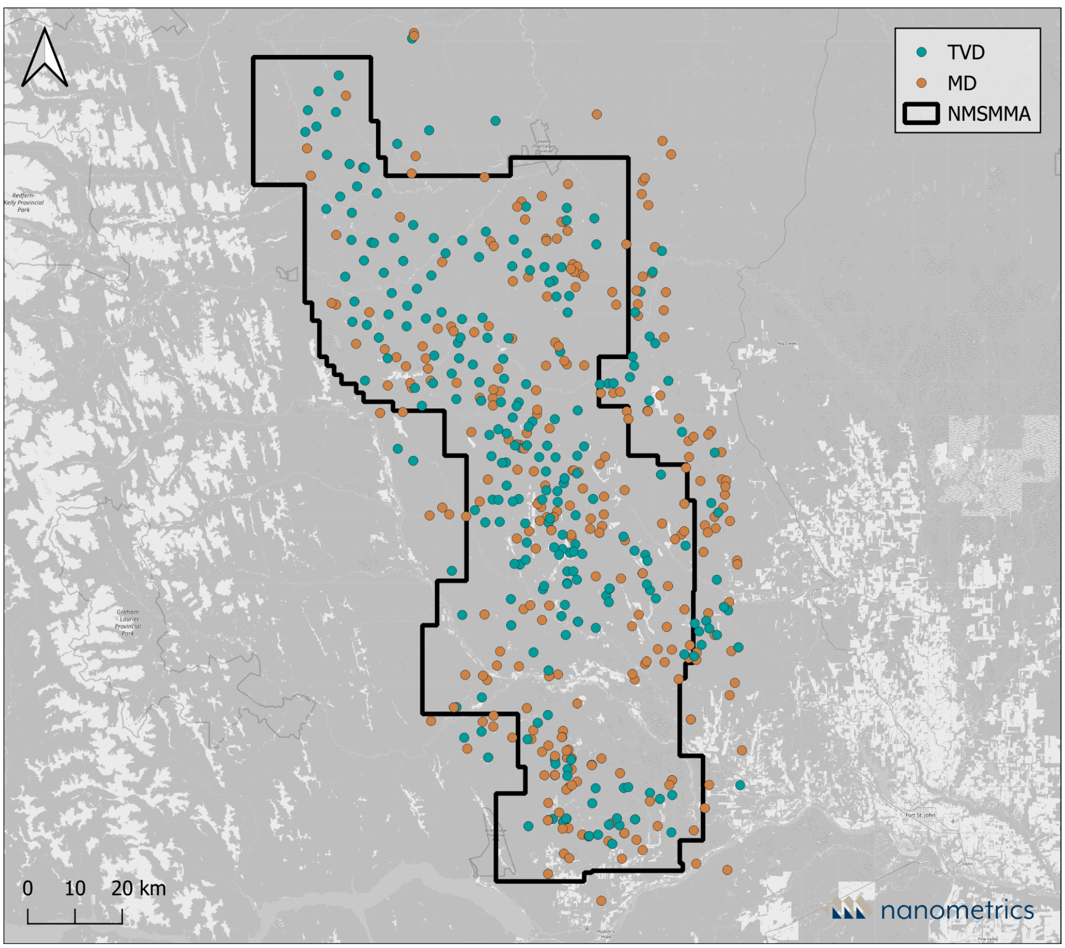

Figure 3. Map of the provided logs classified by depth information (TVD or MD).

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Parsed files

The logs database consisted of multiple formats, requiring a structured parsing approach to standardize the data. The parsing process involved identifying and converting different file types to a uniform format suitable for analysis. Of the total TVD files, more than 90% were successfully parsed and analyzed. The parsing process included extracting key attributes such as well location (latitude and longitude) and reference elevation, velocity data, and well top information. In total, 554 log files were parsed, including:

- 442 logs with P-wave velocity information;
- 112 logs with S-wave velocity information.

Figure 4 presents a map displaying the parsed log distribution. After the parsing process, a good coverage of the Area of Interest (AOI) was achieved, ensuring the availability of information across the entire region.

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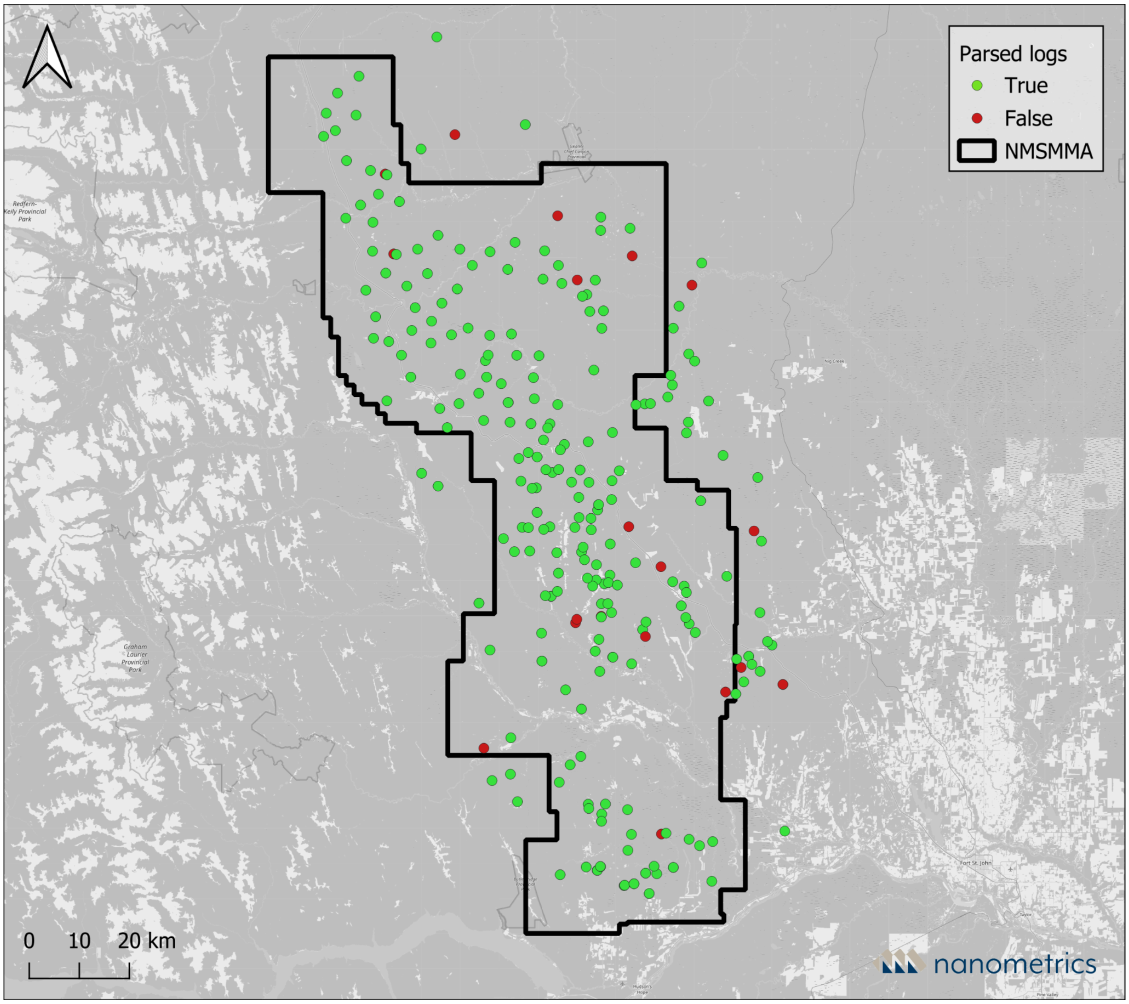

Figure 4. Map of the Area of Interest and location of parsed files (True points).

Quality control - logs

After parsing, the logs underwent a quality control assessment to ensure data reliability and consistency. This process aimed to identify the depth coverage of the files and conduct a pre-model analysis, flagging any data that needed to be removed from the database to prevent potential compromises in model quality. The following information was observed:

For logs containing P-wave information (Figure 5):

- TVD ss: [-1100, 1750] m;
- 442 logs;

- There is good agreement between the logs in the depth range of [-750, 400] m, even though the velocities are being considered over a large area.

For logs containing S-wave information (Figure 6):

- TVD ss: [-1100, 1750] m;
- 112 logs;
- There is good agreement between the logs in the depth greater than > 1500 m, even though the velocities are being considered over a large area.

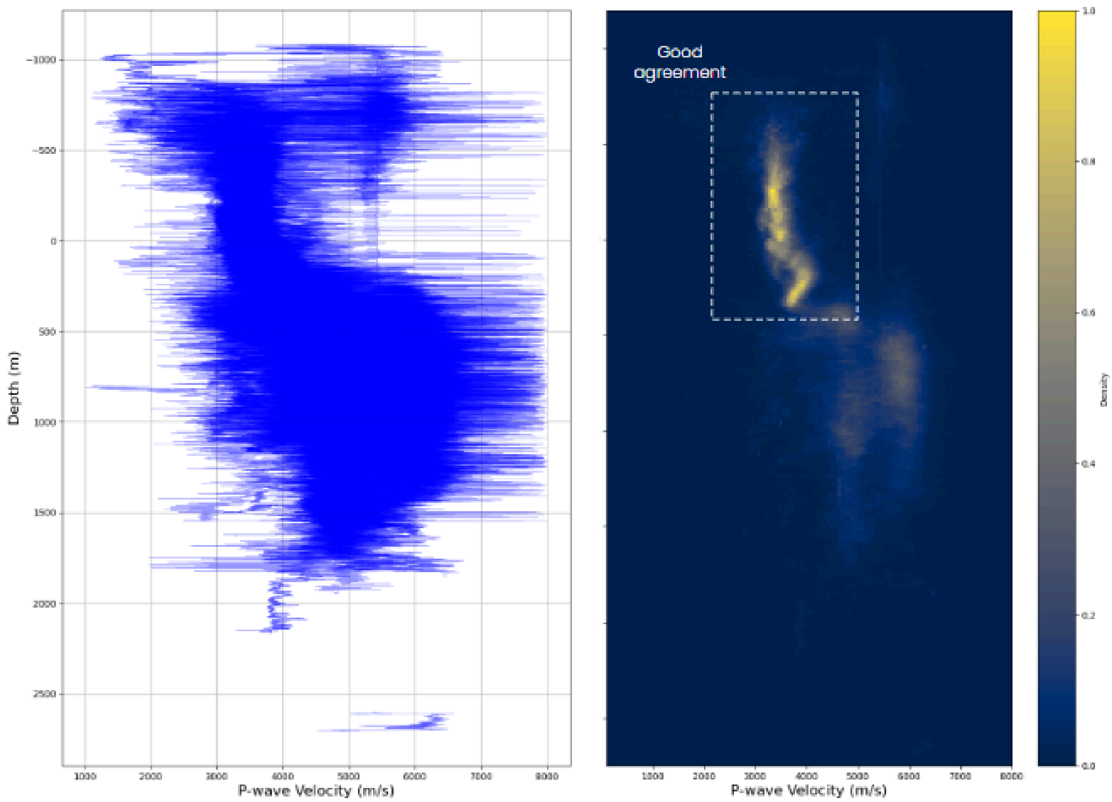

Figure 5. Stacked log profile information - P-wave.

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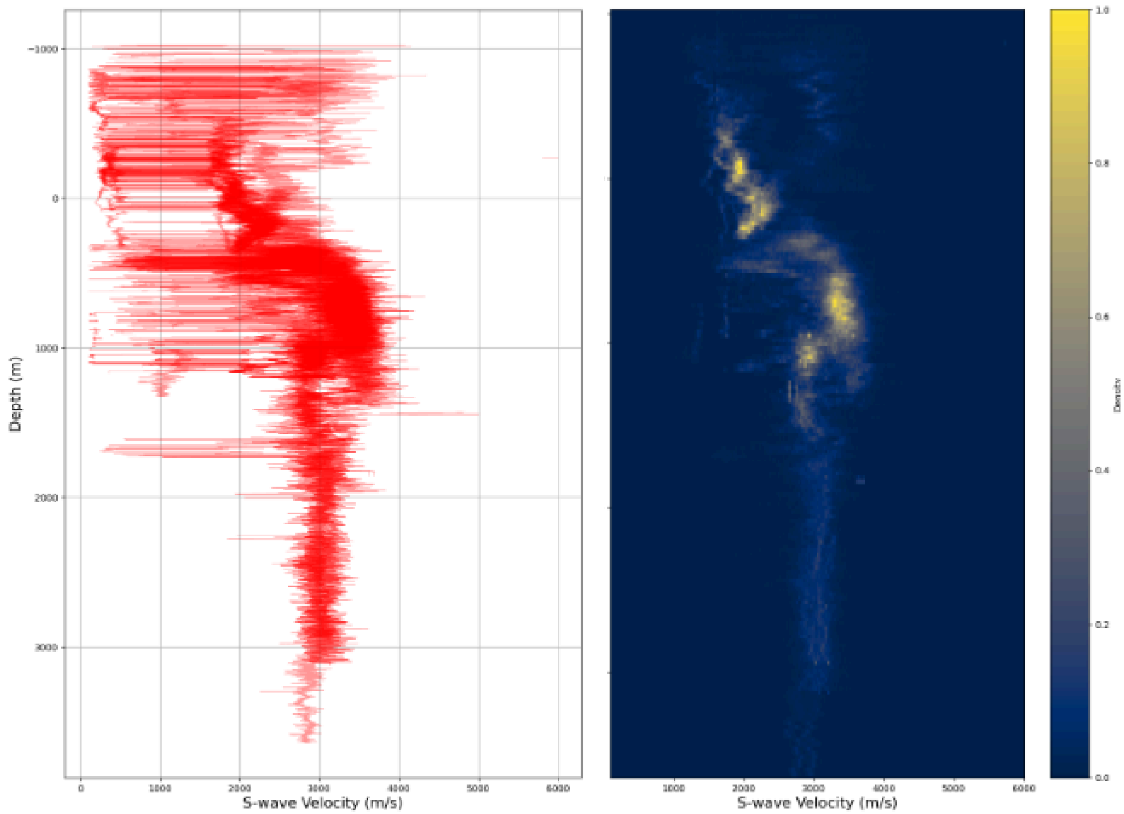

Figure 6. Stacked log profile information - S-wave.

Some logs exhibit higher noise levels, which can impact the model quality. For instance, as shown in Figure 7, two logs located 1.3 km apart exhibit significant differences in their profiles. This discrepancy is particularly evident at depths between 750 and 1000 meters, where one profile shows a velocity variation with an amplitude change of 2000 m/s, while the other presents a variation of 5000 m/s. To mitigate the impact of noisy measurements, all plots were analyzed, and if a noisy range could not be effectively smoothed, it was disregarded to maintain data reliability. Consequently, a total of 18 logs had horizons removed or were entirely excluded from the modeling process to ensure the quality of the final dataset.

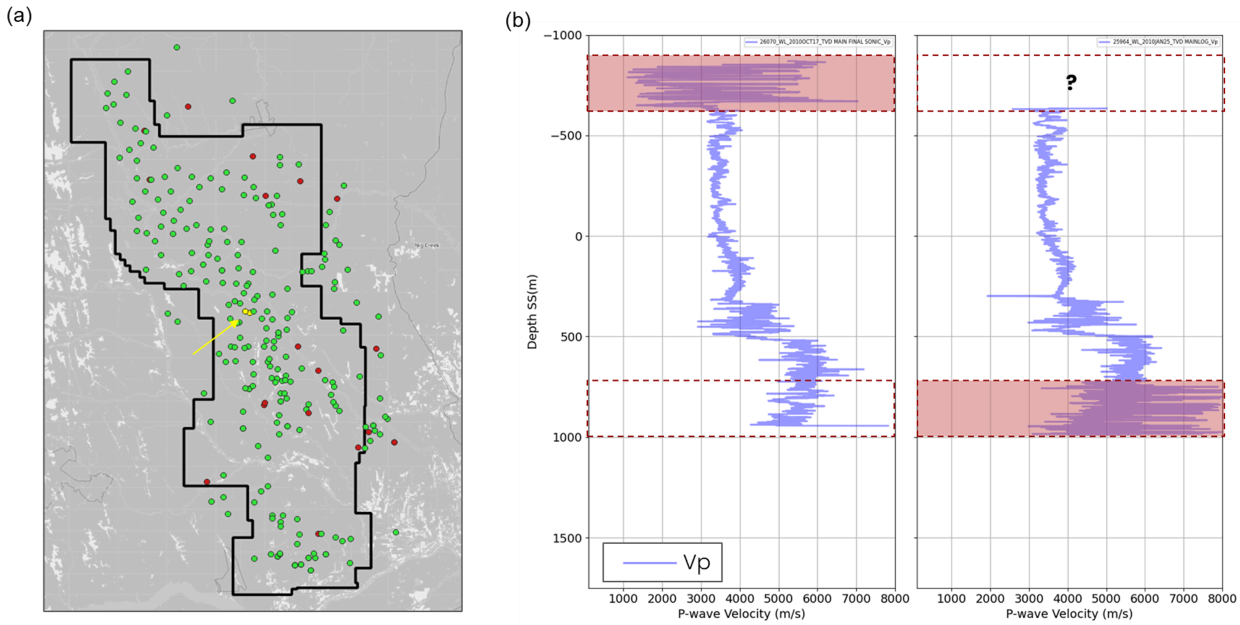

Figure 7. Noise levels were observed in nearby logs. (a) sonic logs location. (b) sonic logs P-wave velocity profile confrontation.

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Quality control - well tops and extension

The well tops were parsed (Figure 8) and subjected to a quality control process to identify and resolve any discrepancies within the available data. This validation ensured consistency and accuracy before integrating the information into the modeling workflow.

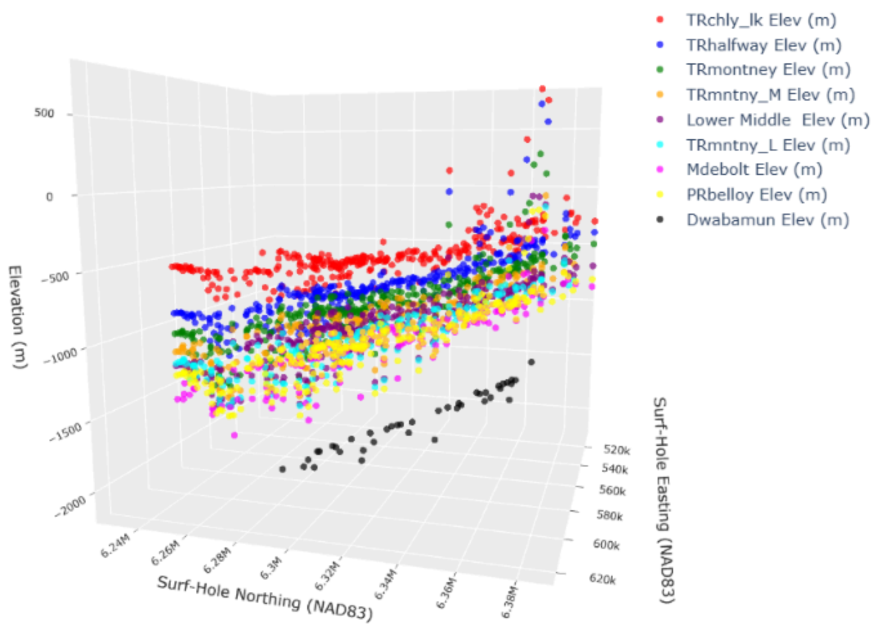

Figure 8. Plot of the well top information.

Additionally, the depth extension of the wells was assessed, revealing that most of the available data falls within the -1000 m to 1000 m depth range (Figure 9).

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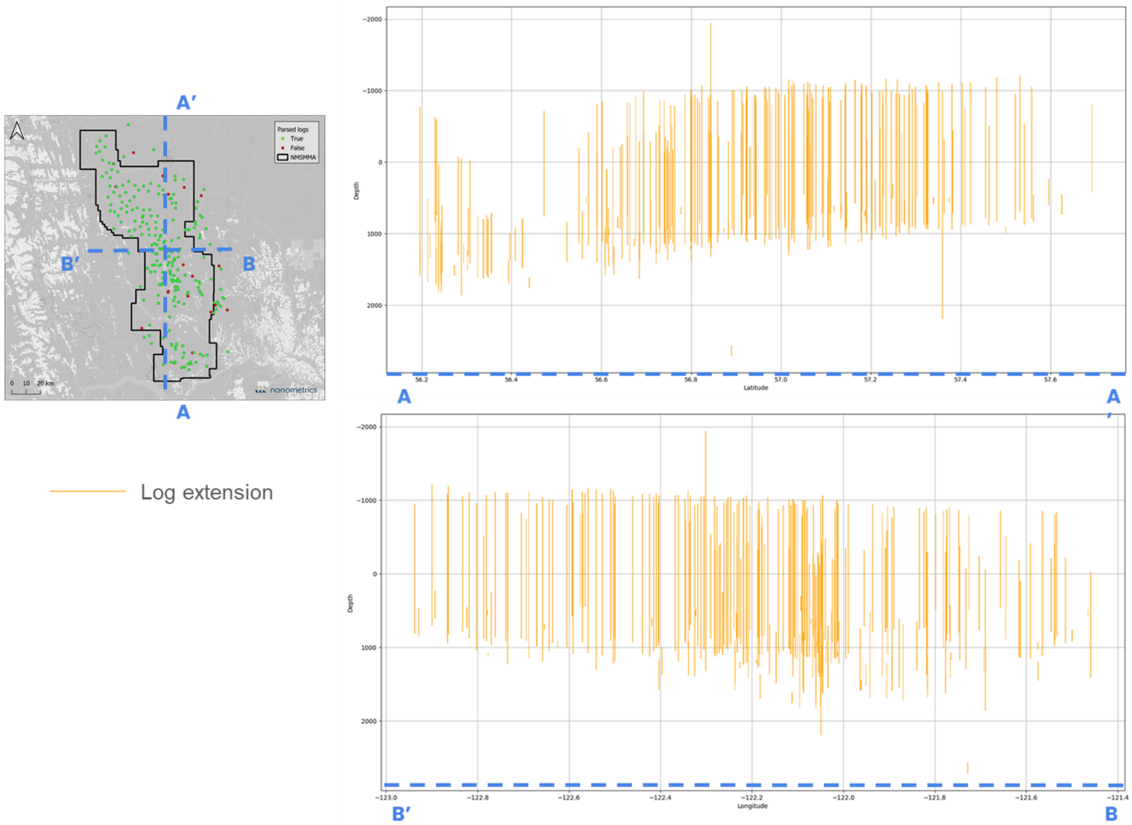

Figure 9. Sonic logs depth (in meters) extension.

Horizon surface

The velocity model was constructed and the structural horizon surfaces and formation tops were incorporated into the model to ensure agreement with actual Earth's subsurface velocities and their physical complexity.

Based on the tops information, eight horizons were identified. The selection methodology considered their spatial continuity, ensuring they extended across the entire Area of Interest. Additionally, their consistency with the available sonic log data was assessed. The horizons were required to align with velocity changes observed in the logs and to be intersected by a sufficient number of logs.

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After analysis, the model building process considered 3 horizon surfaces (Figure 10):

- Triassic Charlie Lake Formation (TRchly)
- Triassic Montney Formation (TRmontney)
- Mississippian Debolt Formation (Mdebolt)

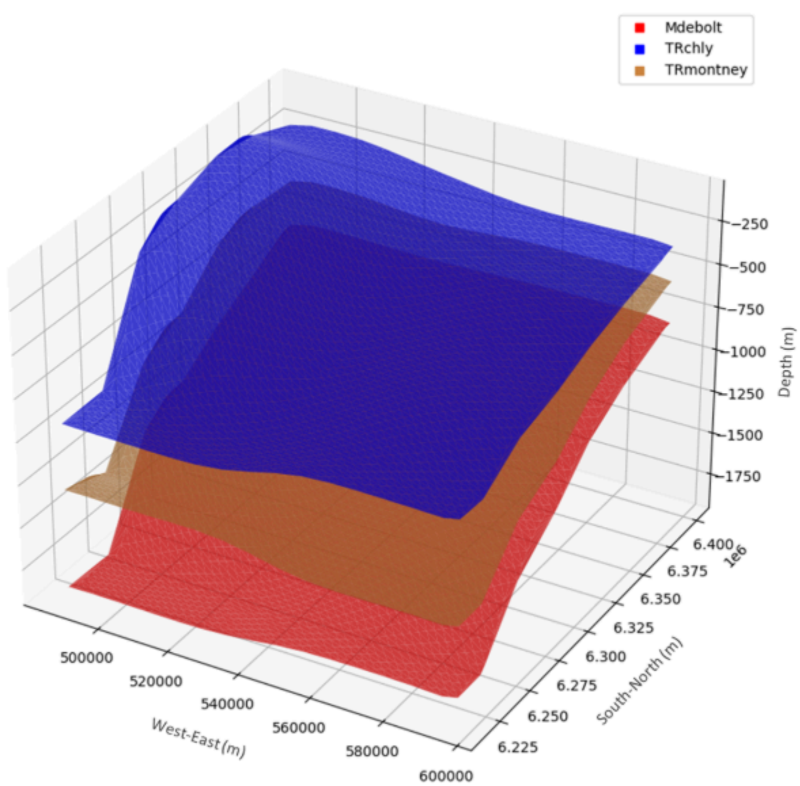

Figure 10. Selected surface horizons.

Model dimensions

The model dimensions were selected to encompass the area of interest while maximizing the use of available data. To achieve this, a 3D grid space was defined, allowing for the integration of nearby velocity information (Figure 11). The following inputs were incorporated:

- Coordinate System: NAD83 UTM Zone 10N (EPSG: 26910);
- Grid size: 16,683,744 points

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- Geographical Limits:
    - Longitude: -123.22° to -121.39°;
    - Latitude: 56.08° to 57.73°.
- Depth Range: -2,000 m to 20,000 m.
    - Zero depth represents sea level, with depth values as positive.

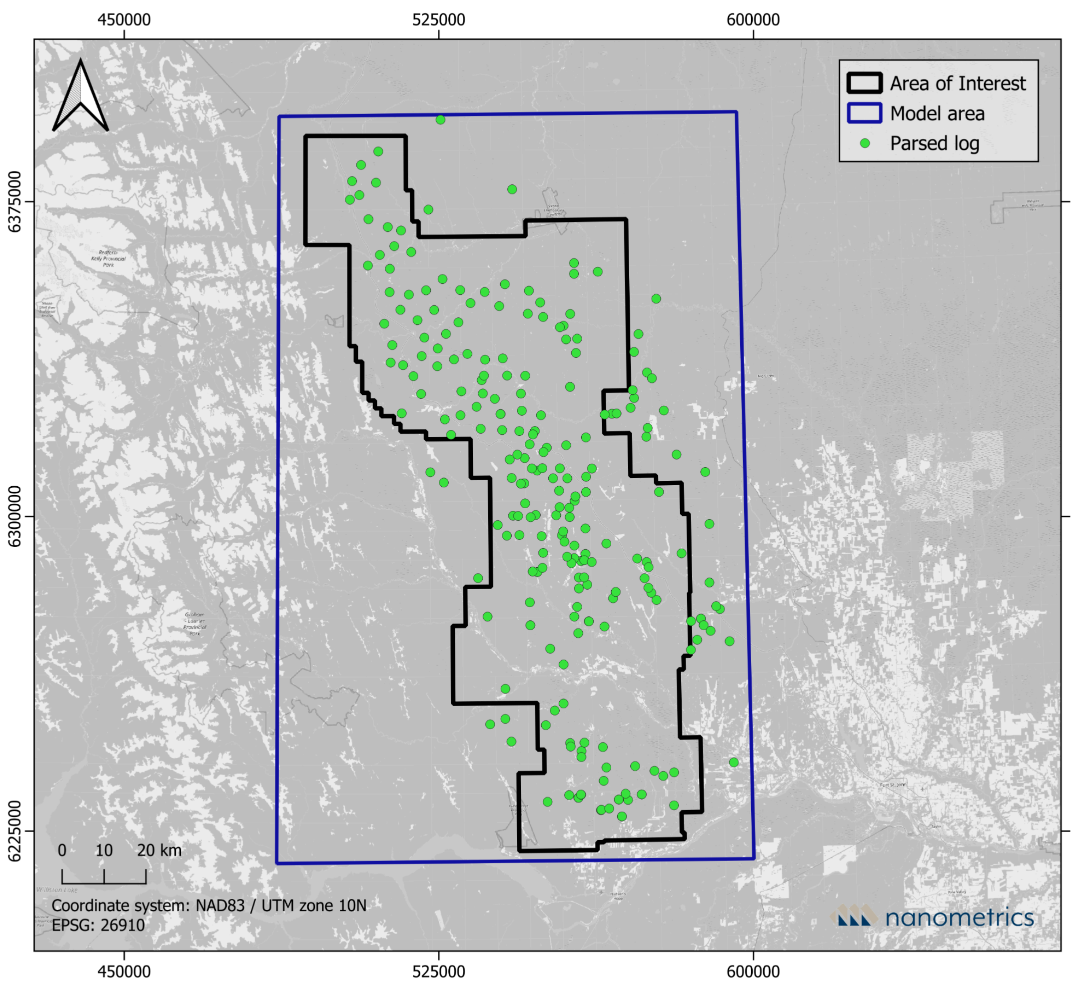

Figure 11. Map of the Area of interest and modeled area (EPSG: 26910).

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Model smoothing

The smoothing window, implemented as a moving average, was applied to the log data to reduce noise and enhance the overall trend of each velocity profile. Various window sizes were tested to determine the most suitable parameter, and a window size of 25 m was selected as the optimal choice for preserving main velocity variations while minimizing noisy fluctuations (Figure 12).

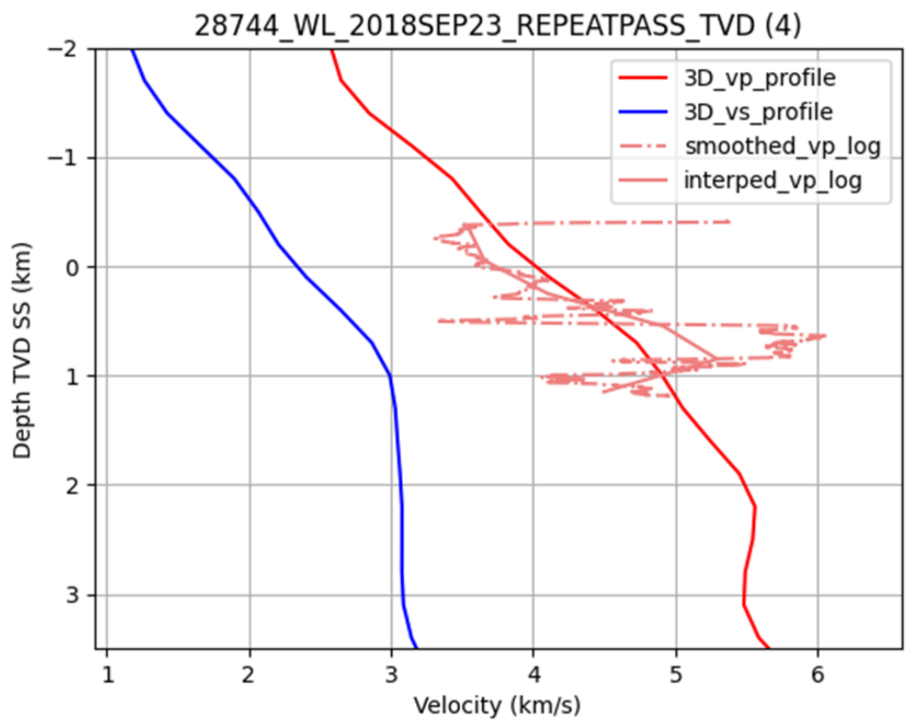

Figure 12. Example of a smoothed P-wave velocity profile and the interpreted velocity information.

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Results

3D velocity model

The final 3D volume is constructed by assembling the interpolated layers of the model. Finally, a 3D smoothing algorithm to further reduce sharp velocity contrasts.

Cross-sections were extracted from the 3D model, revealing a good agreement between the interpolated velocities and the three selected horizons. Figures 13 and 14 display cross-sections of the modeled area in the south-north and west-east directions. The figures present data down to a depth of 6,000 meters. Although the final model extends to 20,000 meters, velocities below 6,000 meters remain near constant. Therefore, the plots focus on regions with greater velocity contrasts.

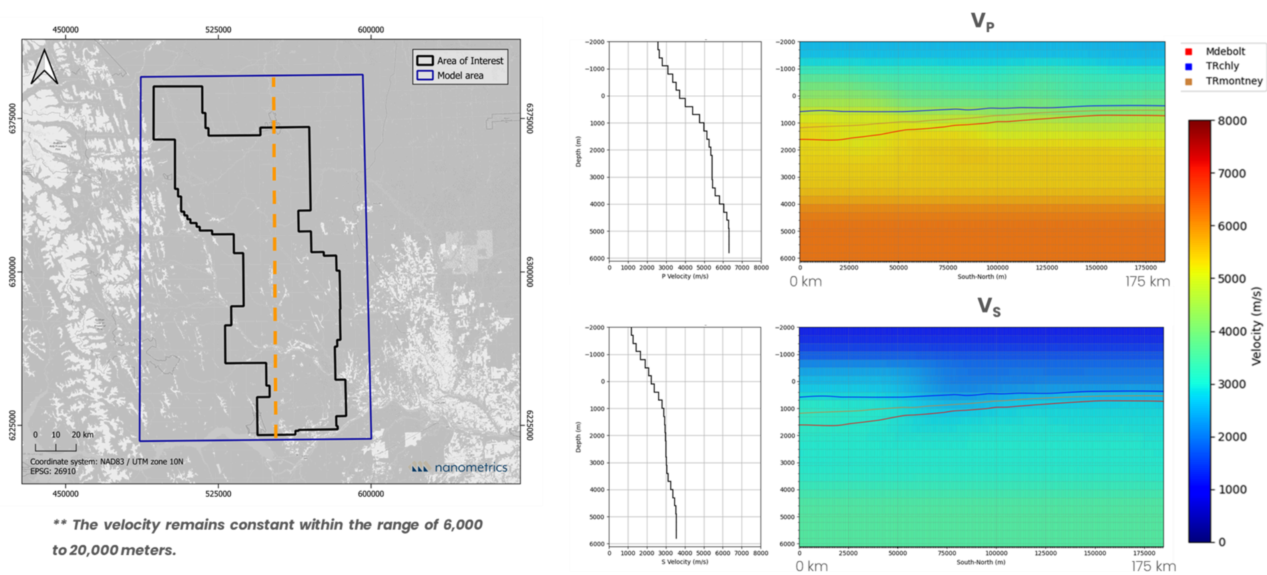

Figure 13. South-north cross-section of the 3D velocity model.

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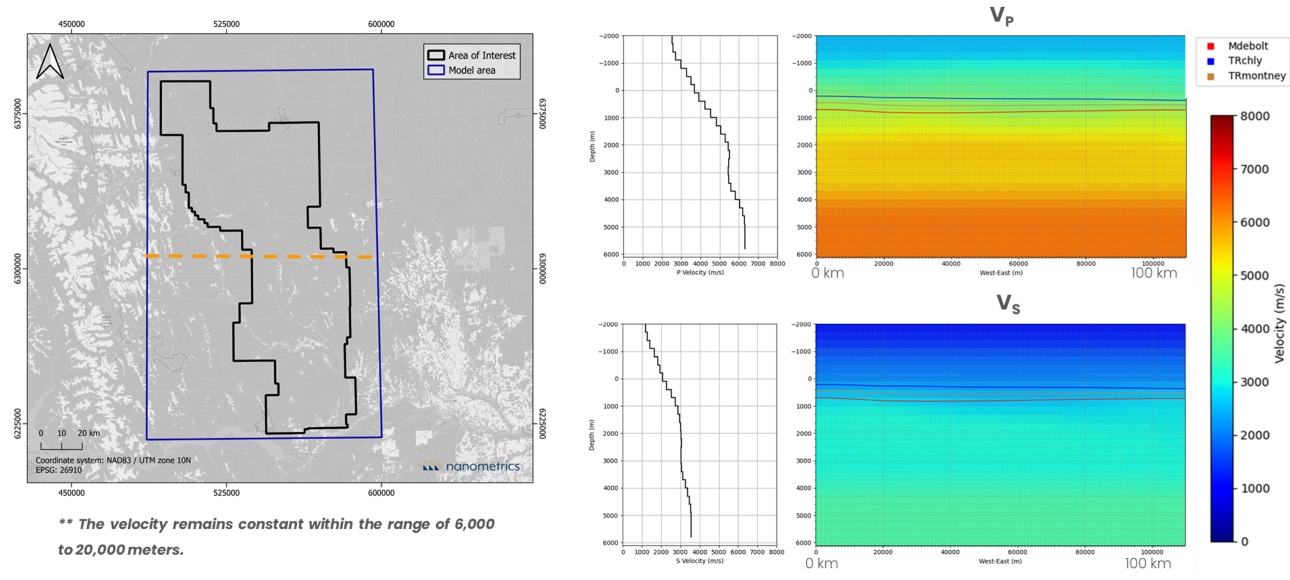

Figure 14. West-east cross-section of the 3D velocity model.

Additionally, depth slices were generated for sonic logs intersecting the 3 horizons. Figures 15-16 illustrate the interpolated velocities across each horizon surface. Notably, a high density of data points is observed at these intersections, which was a key criterion for their selection, ensuring a robust velocity result across the modeled area.

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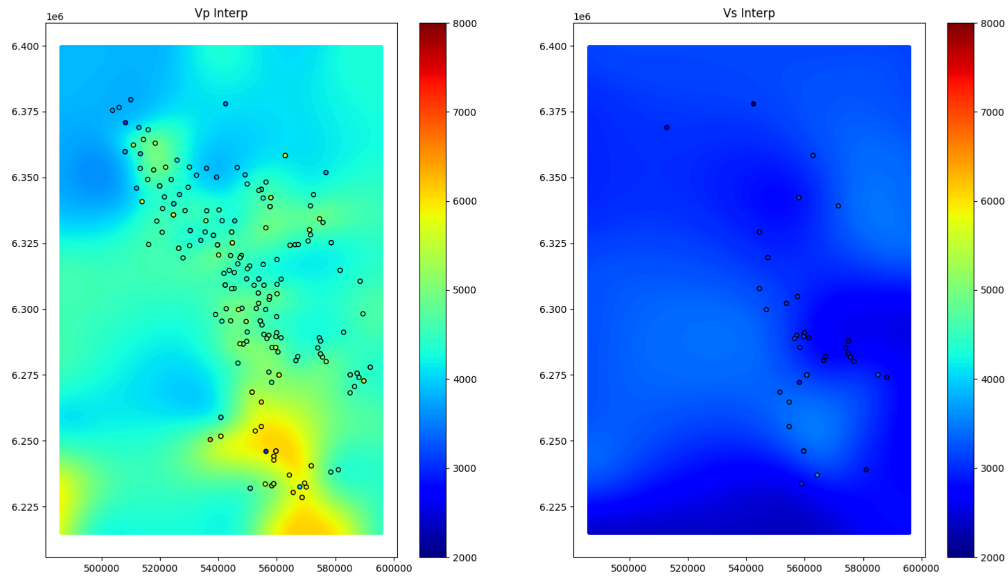

Figure 15. Interpolated velocity [m/s] at horizon Triassic Charly Lake Formation (TRchly).

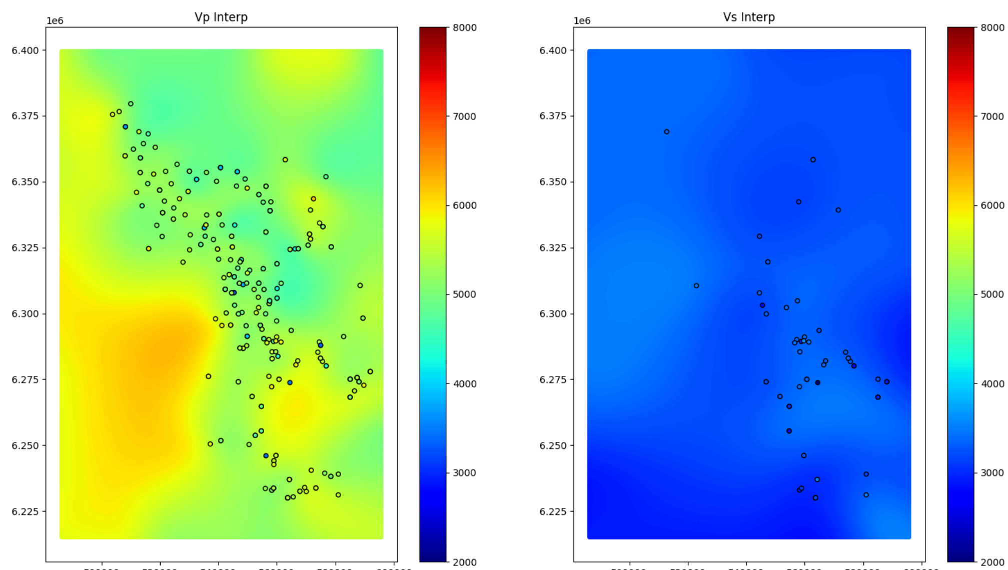

Figure 16. Interpolated velocity [m/s] at horizon Triassic Montney Formation (TRmontney).

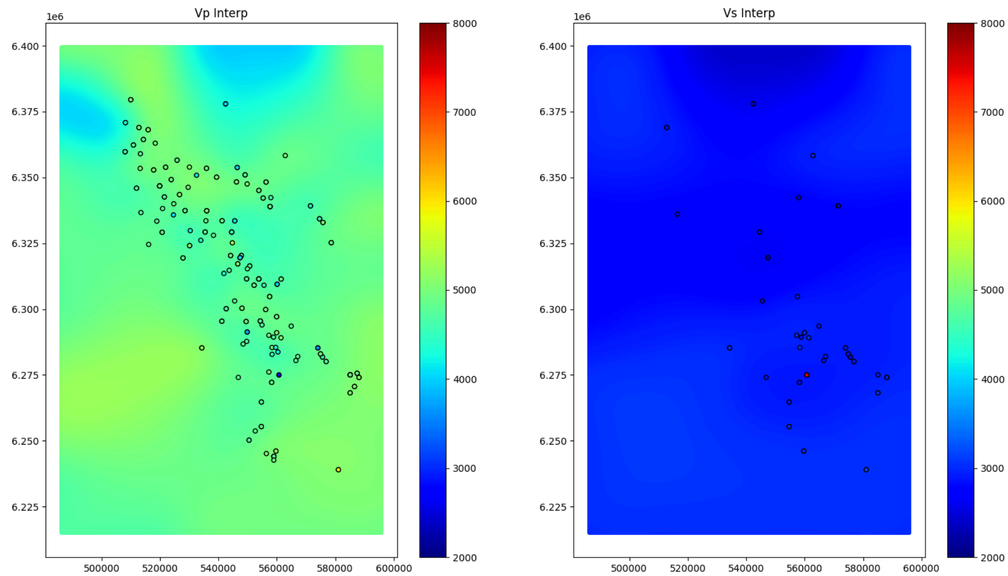

Figure 17. Interpolated velocity [m/s] at horizon Mississippian Debolt Formation (Mdebolt).

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1D average velocity model

A 1D velocity profile (Figure 18) was extracted as the average of the 3D model across the entire modeled area, providing a representative velocity structure for the region.

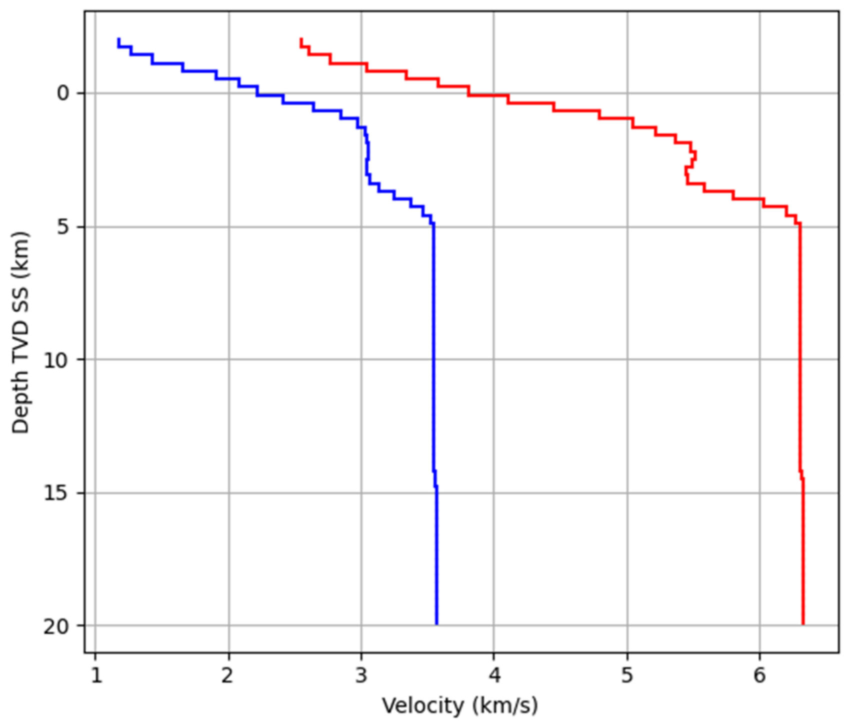

Figure 18. 1D average velocity profile.

Model consistency

Since no seismic event catalog was provided for testing or calibrating the model, its consistency was evaluated using data acquired at the Kiskatinaw Seismic Monitoring and Mitigation Area (KSMMA) (Figure 19). This comparison served as an additional quality control step, ensuring that the velocity model aligns with observed seismic data and provides reliable velocity estimates for the region.

A good agreement can be observed between the 1D average velocity profile and the KSMMA model (Figure 20), particularly at depths greater than 5 km. This consistency reinforces the reliability of the generated model in capturing the regional velocity structure. However, it is important to note that the KSMMA model has a lower resolution compared to the generated 1D model, which may account for some differences in finer-scale velocity variations.

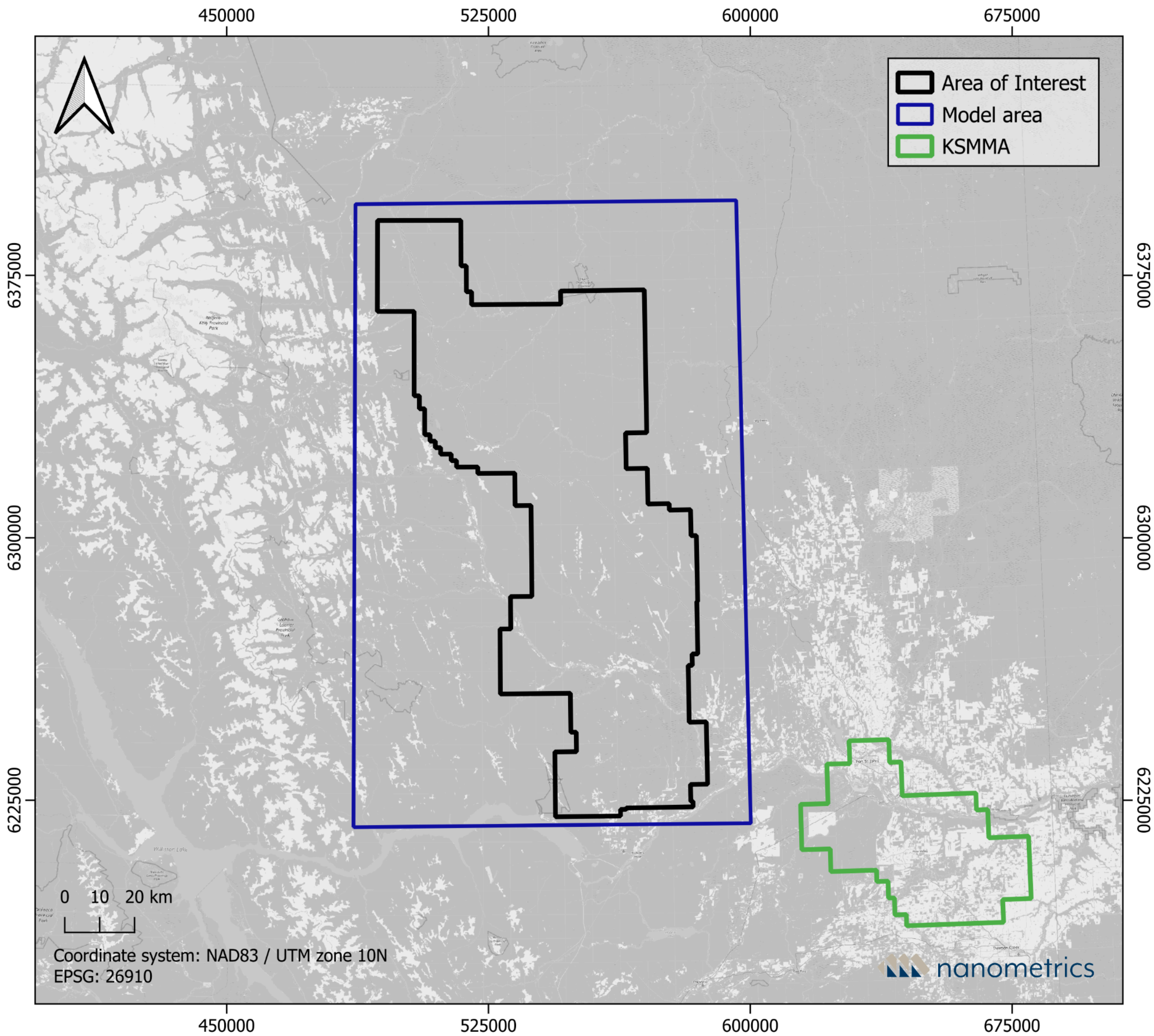

Figure 19. Map of the model area and Kiskatinaw Seismic Monitoring and Mitigation Area (KSMMA).

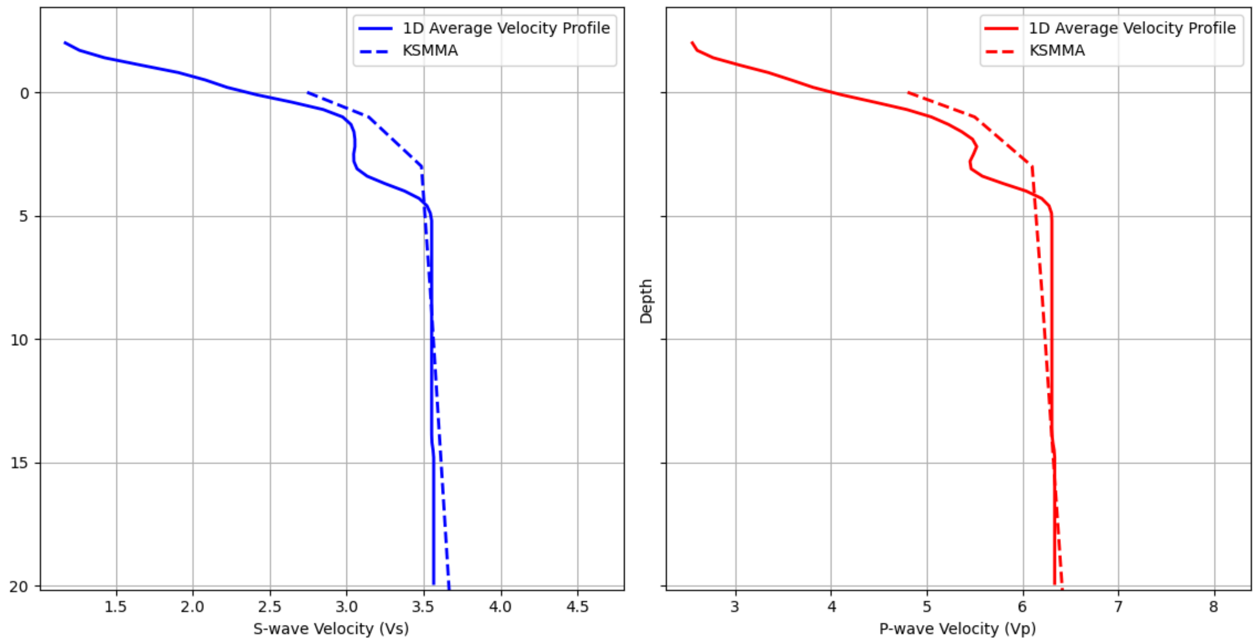

Figure 20. Confrontation between 1D average velocity model and KSMMA model.

Conclusions

More than 400 compressional and 100 shear sonic logs, guided by 3 horizon top surfaces, were used to construct a 3D velocity model for North East British Columbia (NEBC) area.

A 1D velocity model is obtained from averaging the 3D model across the area of Interest. The performance of the 1D model is comparable with the 3D model and provides similar advantages over the existing models.

No seismic event catalog was provided for testing or calibrating the model.

In addition to this report, the following deliverables were provided:

- 3D P-wave velocity model in ASCII format;
- 3D S-wave velocity model in ASCII format;
- 1D P-wave velocity model in ASCII format; and
- 1D S-wave velocity model in ASCII format.

Acknowledgements

Nanometrics acknowledges BCOGRIS funding this project and enabling the public release of its results. We also extend our thanks to the BCER and various oil and gas operators whose freely available online data was incorporated into this study.