AER/AGS Model 2017-04

3D Geological Model of Coal Zones in Southern and Central Alberta − Methodology

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Abstract

The three-dimensional (3D) geological model of Upper Cretaceous−Paleogene coal zones covers approximately 308 000 km^2 of central and southern Alberta and excludes an area representing the approximate extent of Cordilleran deformation.

The model provides an updated view of coal zones in Alberta and contributes to the 3D Provincial Geological Framework Model of Alberta. The model includes coal zones of the Scollard, Wapiti, Horseshoe Canyon, and St. Mary River formations as well as the Belly River Group. The modelled coal zones and their correlative equivalents in this succession include: 1) Ardley; 2) Carbon-Thompson; 3) Daly / Weaver / Garden Plain; 4) Wayne / Rockyford Standard; 5) Basal Drumheller; 6) Lethbridge; 7) Taber; and 8) Mackay. Each of these coal zones have been modelled using an iterative approach with an Alberta Geological Survey (AGS) geologist providing input at each stage to create a model that honours both the input data and the conceptual understanding of coal zones within the Upper Cretaceous−Paleogene strata of the Alberta Plains.

This report summarizes the methodology used to create the 3D model of coal zones and provides information about workflows and parameters required to reconstruct this model. Inputs and procedures needed for model construction are discussed in detail and include: 1) compiling source data delineating each coal zone; 2) filtering (QA / QC) source data through geostatistical analysis; 3) interpolating geostatistically filtered data to create surfaces for each coal zone; 4) manipulating each interpolated surface to honour the geological relationships of coal zones in 3D space; and 5) evaluating uncertainty to ensure the interpolated surfaces for each coal zone are of sufficient quality to be used as inputs for the model construction phase.

Information about the 3D model construction procedures and parameters is also provided, as several decisions were made during development of the geological model in Schlumberger’s Petrel 2015 (Petrel). These model construction decisions include: model parameters (i.e., geometry and grid increment), the grid discretization based on the ordering of interpolated surfaces, and the layering relationships that were imposed to create the final 3D coal model.

Outputs from the 3D model are a series of deconstructed-model products that are provided as maps in the appendices of this report and digital data published and available for download on the AGS website.

The standard format of the deconstructed-model digital data available for download includes

- a tab-delimited tabular dataset of stratigraphic picks and point data used to create the model,
- a deconstructed-model dataset composed of discrete and continuous model horizons as Esri format grids and zone model extent shapefiles, and
- an iMOD model dataset package.

All of the standard format digital datasets can be viewed in iMOD (Section 7.2), an open-source software, enabling users to visualize, rotate, slice, explode, and toggle data on and off in 3D. The iMOD software provides end users with an interactive geospatial environment where they can manipulate 3D geological models and import their own geospatially referenced subsurface and surface data.

1 Introduction

The three-dimensional (3D) model of coal zones (referred to as the 3D coal model in this report) provides an updated view of coal occurrences in Alberta, as rendered from available data sources showing the distribution, spatial continuity, elevation, and thickness of coal zones at a regional scale (approximately 1:500 000). This model uses the results of years of coal work in Alberta (e.g., Allan, 1921; Nurkowski, 1985; Chen et al., 2005) and includes all available surface and subsurface data housed at the Alberta Energy Regulator / Alberta Geological Survey (AER/AGS) as well as new AGS interpretations, which were used to infill areas of sparse data or verify existing datasets. There are significant coal resources in Alberta and this model seeks to increase the understanding of coal occurrences in the Alberta Plains and contribute to the 3D Provincial Geological Framework Model, a geological model of Alberta's subsurface (AGS, 2016; Branscombe et al., 2018).

The 3D coal model is built within the Alberta part of the Interior Plains (Pettapiece, 1986) with the boundaries defined as the Canada-USA border to the south, the Saskatchewan-Alberta border to the east, and the deformation edge of the Rocky Mountain Foothills to the west (Figure 1). Data outside these boundaries are not included in the model. The northern boundary is a generalized boundary that encompasses all the currently modelled coal zones in Upper Cretaceous−Paleogene bedrock strata. The model covers approximately 308 000 km^2 of central and southern Alberta and is generated from the bedrock topography surface down to the coal zones occurring at the base of the Belly River Group with a minimum elevation of -1150 m asl.

This modelling effort is a compilation of a substantial amount of work from previous workers. The 3D coal model is built in Schlumberger's Petrel 2015 (Petrel) by assembling available legacy AGS data (e.g., Beaton et al., 2002; Beaton, 2003; Pana, 2007a, b), corporate data holdings at the AER, new interpretations compiled by AGS geologists, and shallow subsurface datasets (e.g., mining information, and water well and legacy borehole records) of varying quality and spatial coverage. These datasets were compiled and used to build each coal zone in an iterative approach with an AGS geologist providing input at each stage to improve model outcomes. The collaborative nature of the project was important to ensure the 3D coal model provided a consistent reconstruction of coal zones within the Upper Cretaceous−Paleogene strata (not including coal zones in the Mannville Group) and a reasonable representation of a collective conceptual geological understanding of coal zones in the Alberta Plains.

1.1 Objectives

This report documents the methodology used to construct the 3D coal model and provides information about the spatial distribution of modelled coal zones and input data used. The modelling workflow and the parameters used to render the coal zones in 3D are also outlined to ensure that the model is reproducible and can be easily updated as new data becomes available, or our understanding of the subsurface improves with further information or interpretations. Final products from this model are a series of digital datasets of model horizons, extents, and a stratigraphic picks database published on the AGS website.

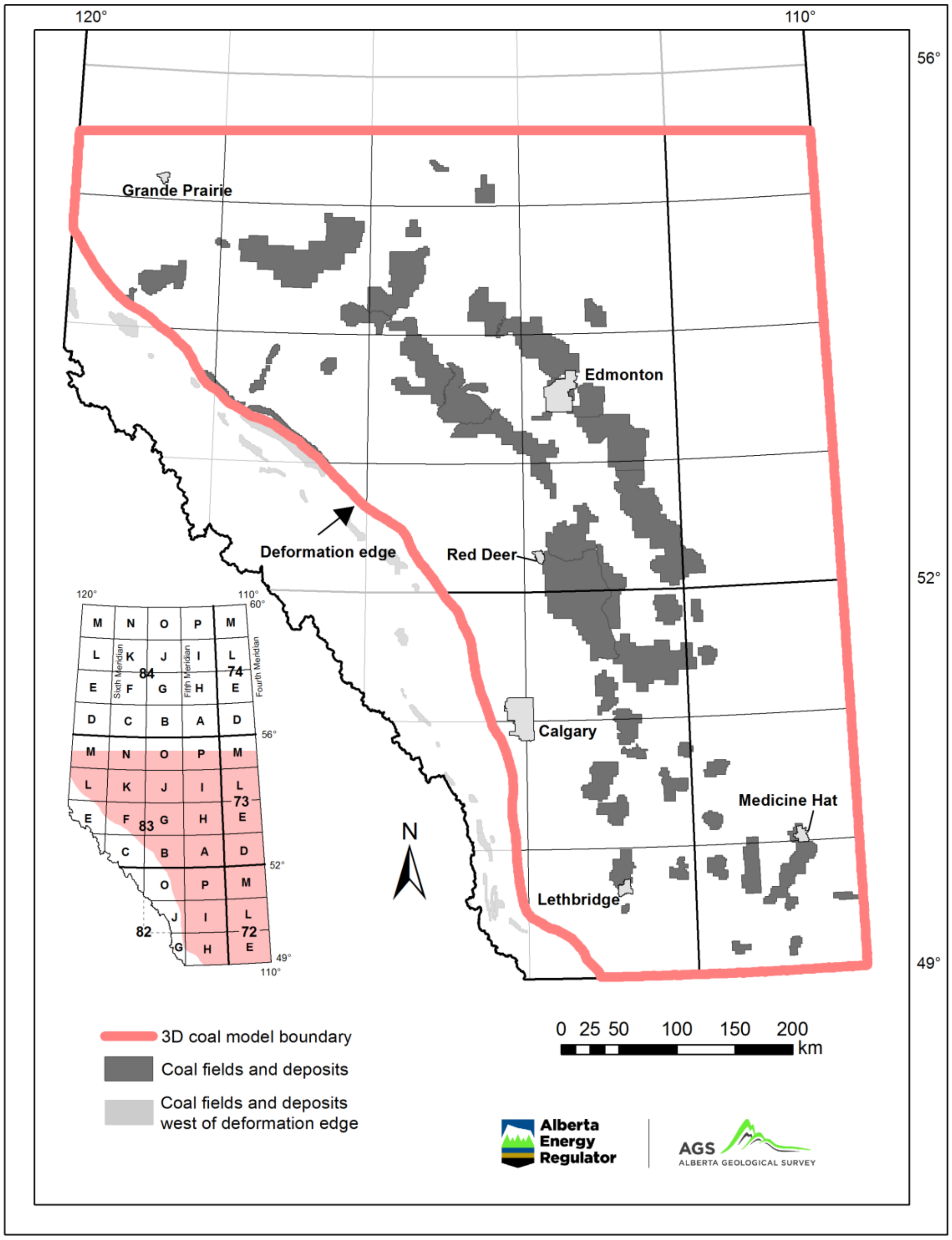

Figure 1. Map of the 308 000 km^2 3D coal model domain. Coal fields and deposits in the central and southern portions of the province are also shown (from Smith et al., 2008). Model is limited to the west by the deformation edge.

2 Stratigraphic Framework

The interval of interest for the 3D coal model includes coal zones within Upper Cretaceous–Paleogene strata. Coal zones in this succession include intervals in the Scollard, Wapiti, Horseshoe Canyon, and St. Mary River formations as well as the Belly River Group (Figure 2). Within these stratigraphic units, coal zones cover great lateral distances, and vertically contain packages of interbedded coal seams and inorganic partings. There is no defined minimum or maximum thickness of intervening interbedded sediment, resulting in coal zones of varying thickness (Beaton et al., 2002).

All foreland strata in Alberta including coals zones are dipping west towards the deformation edge (Figure 1). Faulting may occur close to the deformation edge; however, no structural component is included in this model. Stratigraphic picks were used to define the top and base of coal zones, which in some cases may include fault offsets. However, the magnitude and orientation of faulting was not examined, and this model is considered a simplified non-structural model.

Within the Upper Cretaceous–Paleogene succession 8 coal zones were modelled (Generalized Model Column; Figure 2) by combining stratigraphic data from 11 discrete coal zones. Grouping was implemented to ensure that modelled coal zones did not vertically intersect each other due to the close proximity of data from adjacent coal zones, and to align with the conceptual geological understanding of coal zones presented in previous studies. Not all coal zones were grouped; however some coal zone grouping was appropriate at a regional scale. Three specific scenarios were used to group coal zones including where: 1) stratigraphic picks defining the top and base of a two or more coal zones had a close vertical proximity to one another (e.g., Weaver grouped with Garden Plain and Wayne grouped with Rockyford Standard); 2) the stratigraphic data for a coal zone was confined to a geographic location (e.g., coalbed methane areas) rather than the geological distribution of the coal zones (e.g., Daly grouped with Weaver and Garden Plain); or 3) previous studies had grouped the zones together (e.g., Daly-Weaver; Beaton et al., 2002) and this grouping was carried forward into this modelling effort.

Some coal zones lying in different parts of the Alberta Plains are considered lateral equivalents in this model: the named coal zones in the Horseshoe Canyon Formation and Belly River Group are considered lateral equivalents of unnamed coal zones in the St. Mary River and Wapiti formations, respectively. The unnamed coal zones are herein named 'St. Mary River Coals' and 'Wapiti Coals' (Figure 2) to reflect the formation the coal zone is located within. The nomenclature used for the coal zones in this 3D coal model utilizes the named coal zones in the Scollard and Horseshoe Canyon formations as well as the Belly River Group for clarity and ease of communicating the results. Figure 2 provides the coal zone nomenclature and grouping used for the 3D coal model and throughout this report.

Discrete and economically important coal zones also exist within the Paskapoo Formation (Demchuk and Hills, 1991), however, these— along with coal seams in the Alberta Rocky Mountains and Foothills —are considered beyond the scope of this model. Coal zones in the Lower Cretaceous Mannville Group are also not included as part of this report, but are considered prospective work that could be completed in future modelling efforts. The stratigraphic units (i.e., Scollard, Wapiti, Horseshoe Canyon, and St. Mary River formations as well as the Belly River Group) that contain the modelled coal zones (Figure 2) are also not included in the 3D coal model. Figure 2 shows these geological formations or groups as undifferentiated zones, as this model and report were compiled to show only the location of Upper Cretaceous−Paleogene coal zones in 3D space. This report does not include a description of the geological background of coal zones or any other geological unit. Refer to Nurkowski, 1985, Dawson et al., 1994, 2000, Beaton et al., 2002, and Hamblin, 2004 for further geological information on coal zones within Upper Cretaceous −Paleogene strata.

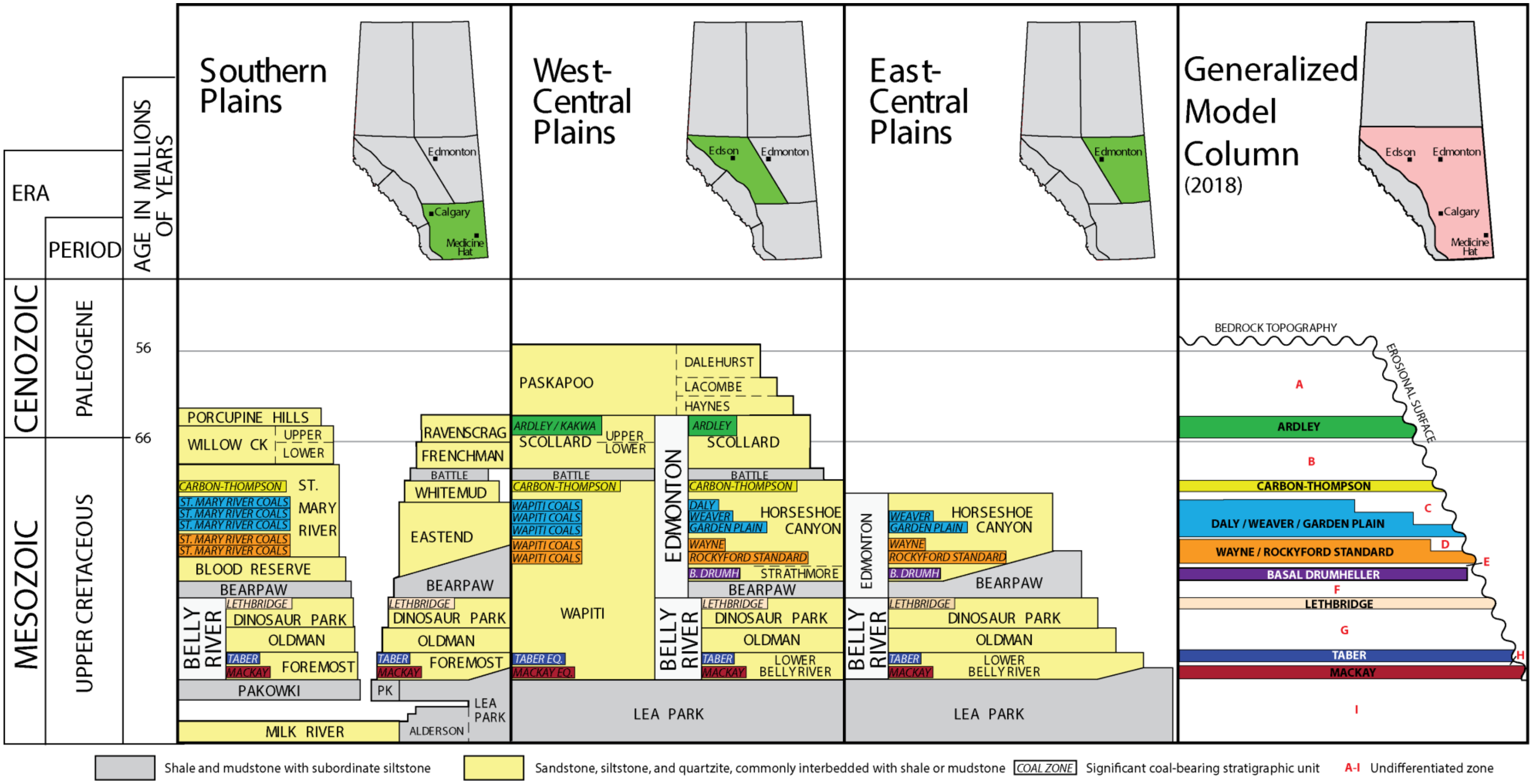

Figure 2. Generalized model column for the 3D coal model (modified from AGS, 2015). Coal zones with the same colour are considered lateral equivalents or have been grouped together to form one modelled coal zone. Basal Drumheller is abbreviated to B. DRUM. Geological units younger than the Paskapoo Formation are not included.

3 Model Definitions

Construction of the 3D coal model utilized a variety of input datasets defining the top and base of a coal zone and the completed model produced output datasets in a variety of formats (Figure 3). This definitions section provides a common terminology for model inputs versus model outputs. The authors use a standardized terminology to ensure the way a coal zone is generated, stored, and visualized at the AGS is the same way we define it herein.

Common Terminology

- **3D simple grid:** A simplified process/step when creating 3D grids with no faults in Petrel.
- **3D geocellular grid:** A 3D geological model divided into cells/voxels resulting from the 3D simple grid process.
- **Discrete surface:** An interpolated surface that does not span the entire model extent.

Model Inputs

- **Source data:** A set of unfiltered, original, multisource point data defining the stratigraphic pick of a zone top or base. These data include geospatial coordinates (x, y) and elevation (z) information. Most of the data are from well boreholes and have a unique well identifier (UWI); however, a UWI is not provided for outcrop or lineament sampled data.

- **Input filtered data:** A set of geostatistically filtered, multisource point data defining the stratigraphic pick of a zone top or base. These data include UWI, geospatial coordinates (x, y) and elevation (z) information. This dataset excludes outliers and erroneous data captured in the *source data*. The outliers and erroneous data were eliminated in a series of successive culls to reduce global uncertainty (Section 5.2).

- **Input extent:** A set of discrete polygons or polylines delineating a coal zone top or base zero-edge, subcrop-edge, or other GIS information outlining a coal zone top or base and attributed with elevation (z) values.

- **Interpolated surface:** A discrete gridded surface interpolated in modelling software over the geospatial extent of a coal zone top or base from *input filtered data* and *input extents/lineament(s)* (if applicable). Defines the elevation (z) of a coal zone top or base and is manipulated where necessary to eliminate crossovers with adjacent *interpolated surfaces* and/or to honour unconformities. *Interpolated surfaces* are considered primary input data for the construction of a 3D model and are used for constraining the top and base of a model as well as the discretization of the model within. Each *interpolated surface* is defined as a particular type to define the relationship to other contacts (e.g., erosional, conformable, etc.), which ensures that the geospatial and temporal relationships of all coal zone tops and bases are honoured.

- **Geo-edge:** A set of polygons or polylines used to constrain (or clip) an *interpolated surface* to areas where the coal zone is present, as defined by a zero-edge and/or subcrop-edge. *Geo-edges* are primarily defined by the geologist or geomodeller based on the distribution of coal zone stratigraphic picks and/or from external supporting data such as previously published literature.

- **Continuous surface:** A gridded surface generated from discrete *interpolated surfaces* and modelled to span the entire model extent (Figure 1). Although a coal zone may only exist in part of the province, the surface must be modelled to cover the entire province to ensure the zone is completely sealed for continuous-style model construction. To do this, the geomodeller merges the discrete surface with the nearest coal zone surface or unconformity (i.e., the bedrock topography) if the discrete surface is subcropping or outcropping.

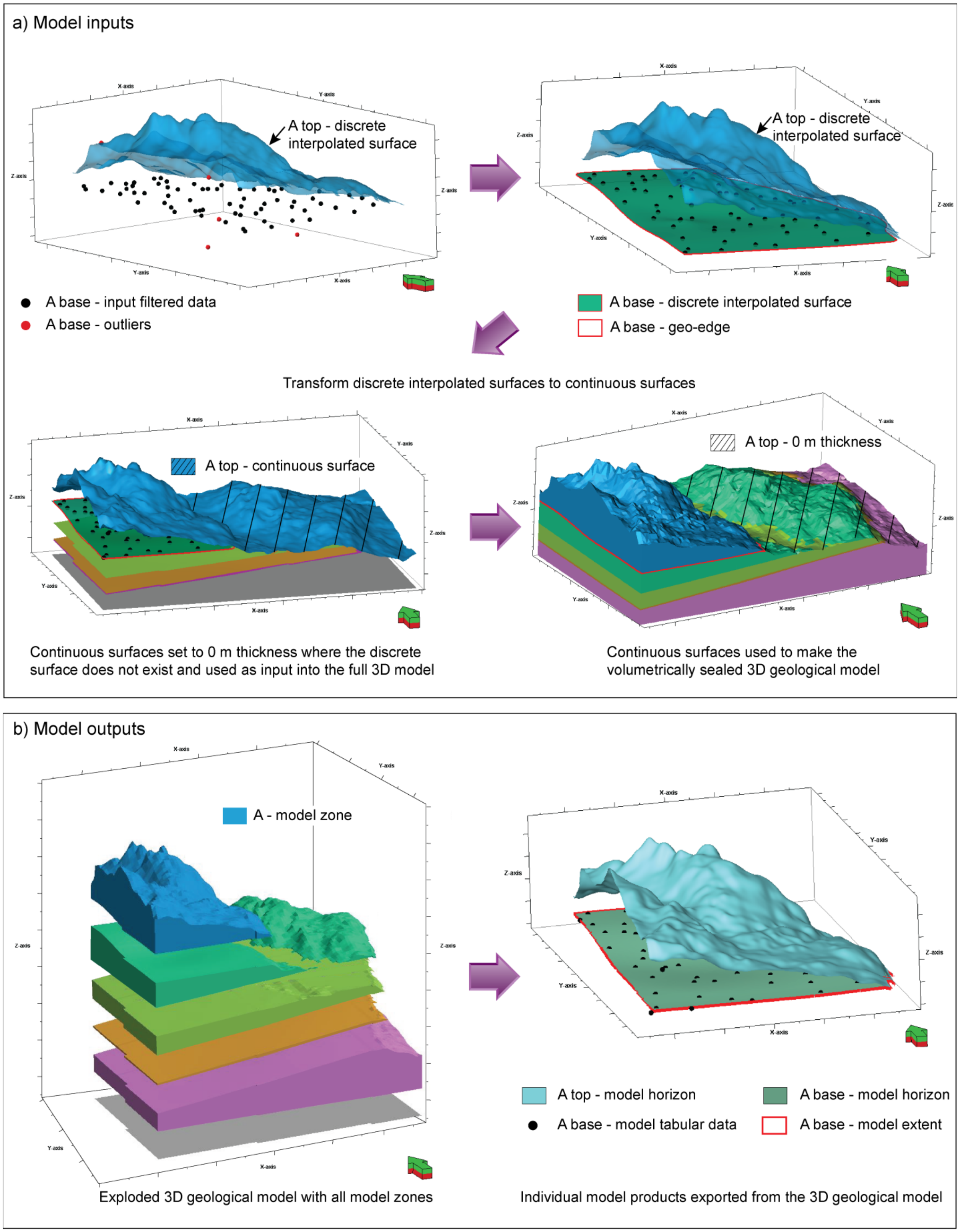

Figure 3. (a) model inputs and (b) model outputs for example coal zone A top and base. All images are shown at 45x vertical exaggeration.

Model Outputs

- **Model tabular data:** The set of finalized stratigraphic picks dataset selected from the *input filtered data* with lowest global uncertainty; published with UWI, geospatial coordinates (x, y), elevation data (z), and dataset source for coal zone tops and bases as a point dataset.

- **Model extent:** A polygon that defines the boundary of a coal zone top or base *model horizon* and attributed with elevation (z) values.

- **Model horizon:** A grid that represents the 3D distribution and elevation of a coal zone top or base. It captures the geospatial extent and elevation (z) values of discrete *interpolated surfaces*; however where sufficient minimum vertical 3D geocellular grid cell sizes are not achieved (e.g., <1 m) the horizon does not exist. The collection of all model horizons partitions the 3D geocellular grid into a series of *model zones*.

- **Model zone:** defines the vertical resolution of the 3D simple grid between top and base *model horizons*.

- **Model:** The combination and construction of all model zones in correct stratigraphic sequence.

4 Modelling Workflow

Each of the defined model inputs are part of a workflow used to generate the 3D coal model outputs. The workflow for the 3D coal model aligns with the workflow developed for the 3D Provincial Geological Framework Model (Branscombe et al., 2018) to ensure consistency in the modelling approach and products produced by the AGS.

There are several technical components of the 3D modelling workflow used to create the coal model. Each technical part of the modelling workflow is outlined in Figure 4 and grouped into six main parts:

Part 1: Input Data and Stratigraphic Framework (Section 5.1)

a) compile all source data (input points, lineaments, and extents)
b) combine multisource input data defining the top and base of each zone
c) establish conceptual geological model(s) and convey to geomodeller(s)
d) done by geologists and geomodellers

Part 2: Geostatistical Analysis (Section 5.2)

a) geostatistically filter source data
b) achieve stabilization of global uncertainty
c) completed by geomodellers

Part 3: Input Surface Interpolation and Manipulation (Sections 5.3 and 5.4)

a) create interpolated surfaces for tops and bases of zones
b) manipulate interpolated surfaces to honour unconformable surfaces
c) manipulate interpolated surfaces to ensure no crossovers with adjacent surfaces
d) manipulate interpolated surfaces to geo-edges (if applicable)
e) assess alignment with conceptual model(s)
f) completed by geomodellers

Part 4: Uncertainty Analysis (Section 5.5)

a) provide uncertainty analysis for interpolated surfaces
b) completed by geomodellers

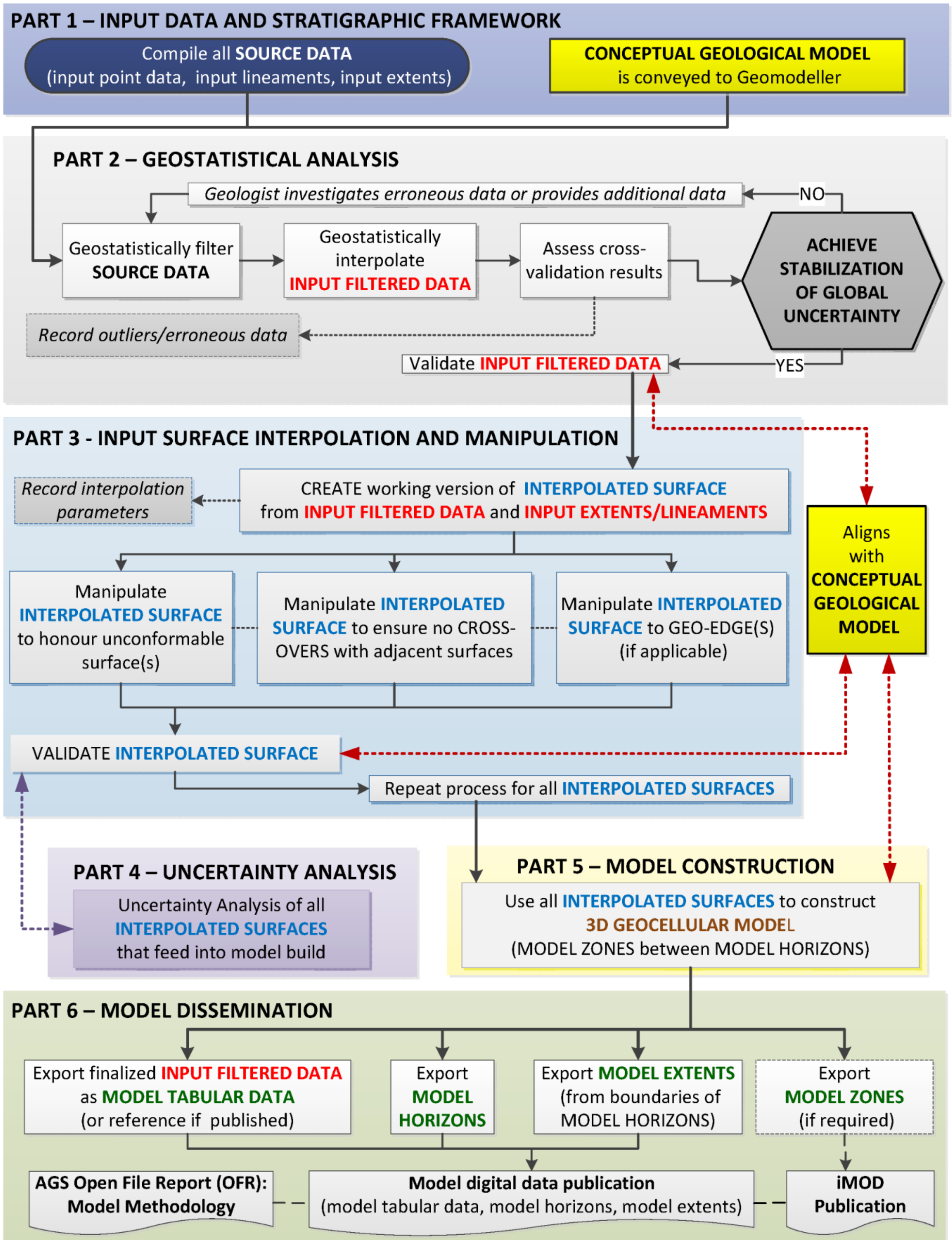

Figure 4. Generalized workflow followed to construct a 3D model at the AGS (Branscombe et al., 2018). Steps taken to publish model products are also included.

Part 5: Model Construction (Section 6)

a) generate a 3D geological model of all zones from specified input parameters
b) completed by geomodellers

Part 6: Model Dissemination (Section 7)

a) disseminate deconstructed 3D model outputs
b) disseminate iMOD package for 3D visualization of model
c) completed by geomodellers

Parts 1–5 of the workflow (Figure 4) were performed iteratively to reduce model error and optimize input parameters. Several rounds of geostatistical analysis were implemented to filter and reduce errors in the source data for the creation of interpolated surfaces representing a coal zone top or base. Draft 3D models were also created iteratively to ensure model parameters were chosen to correctly render the volumetrically sealed 3D coal model. All data filtering and parameter selection were recorded at every step to ensure reproducibility and transparency of the 3D coal model.

Each iteration of an interpolated surface or the 3D model was evaluated visually with the help of an AGS geologist to ensure the model outputs adhered to both the conceptual geological understanding of coal occurrences in the Alberta Plains and the stratigraphic framework outlined in Figure 2. Feedback from geologists was also an important component of the 3D modelling workflow, as they were able to verify suspicious data with external sources (e.g., resource maps or models), published literature (e.g., Beaton et al., 2002) or provide additional data in areas of sparse control.

The following sections provide details about the technical parts of the workflow and all parameters needed to reproduce the 3D coal model.

5 Model Inputs

The methodology used to create the 3D coal model relies on a series of model inputs, which were created following parts 1–4 of the workflow outlined in Figure 4. Inputs included geostatistically filtered data from subsurface and shallow (near-surface and surface) data sources and interpolated surfaces generated from these data in Petrel, which represent a coal zone top or base. The following sections provide information about the input data and interpolated surfaces, as well as the surface manipulations applied to ensure the thickness, geometry, and lateral extent of a coal zone top or base was appropriate for input into the 3D coal model (Section 6). An effort was also made to assess the uncertainty of each interpolated surface prior to the model construction phase.

5.1 Input Source Data

The first part of the modelling workflow included compiling all available source data for each coal zone top and base (part 1; Figure 4). Three types of source data were typically used including: subsurface, surface, and near-surface information. Multisource subsurface datasets included elevation (z) data with stratigraphic pick data that were allocated to a coal zone with no lithological descriptions provided while surface and near-surface datasets included lithological descriptions that identified coal lithologies in 3D space. The ratio of subsurface, surface, and near-surface information differ between coal zones (see data distribution maps; Appendix 1) and the quality of these data types also varied. All quality differences in these datasets were accounted for during the surface interpolation (part 3 and discussed in Section 5.3).

5.1.1 Subsurface Datasets (Coalbed Methane and Other Coal Data)

Subsurface datasets were used to constrain coal zones buried in the subsurface. Stratigraphic picks for coal zones in subsurface datasets were originally identified on geophysical logs based on the log signature and correlated within Upper Cretaceous−Paleogene stratigraphic units and exported as elevation (z) values.

The subsurface dataset was composed of variable quality data from multiple sources. The originators of this data included: 1) coalbed methane (CBM) datasets from the AER corporate database; 2) legacy AGS CBM data (e.g., Beaton et al., 2002); and 3) recent data generated by the AGS for coal characterization studies (i.e., Ardley coal zone) or new AGS interpretations to infill data gaps or verify the quality of existing datasets housed at the AER/AGS. Recent data generated by the AGS were considered the highest quality data along with new AGS interpretations, as these data were verified by AGS geologists. The CBM data from the AER corporate database was the next most reliable dataset, followed by legacy AGS data that had not been checked for accuracy in 3D space prior to this modelling effort.

5.1.2 Surface (Mining and Outcrop) and Near-Surface Datasets (Water Wells and Alberta Research Council Shallow Boreholes)

Coal occurrences at surface or described in the shallow subsurface (i.e., approximately 0–500 m below land surface) are generally located along the eastern extent of a coal zone where coal occurrences are not deeply buried. The abundance of surface and near-surface data helped delineate shallow coal occurrences and aided in the identification of the subcrop edge of coal zones at the bedrock topography interface (Figure 5).

Surface and near-surface datasets were obtained from different sources. The surface dataset consisted of lithological descriptions from mining operations and outcrop investigations, while near-surface datasets included lithological descriptions from both water-well records and Alberta Research Council (ARC) coal investigations. Surface data from mining and outcrop investigations were obtained by AER from different sources and over several decades. The original dataset obtained by AER consisted of tops and bases of individual coal samples cumulating in over one million data points. This massive number of samples was managed for the 3D coal model through a simplification process, which combined several successive coal sample records per x,y location that had <5 m of intervening bedrock strata into one coal interval. The simplified coal intervals per x,y location were then grouped as one coal zone. The near-surface coal data differed from the surface data, as the near-surface data represented the extraction of coal descriptions from a selected collection of water-well records (AEP, 2015) and shallow coal boreholes (ARC/AGS; extracted April 2015). No simplification of coal descriptions was required for this dataset.

Because the surface and near-surface data simply represented coal lithologies in 3D space, steps were taken to allocate the coal lithologies to a specific coal zone, as no coal zone was designated for these datasets. Surface and near-surface coal lithologies were selected and allocated to a coal zone if they were located within a reasonable tolerance (approximately 20 m) of an interpolated surface (Section 5.3) for a coal zone top or base, as generated from the subsurface datasets (Section 5.1.1). Using this method, the selected coal lithologies were allocated to a specific coal zone and visually checked to ensure these datasets fit within the proper formation. Overall, these data were considered lower quality than the subsurface datasets, as they were derived from lithological descriptions providing a delineation of the coal, rather than a discrete coal zone. However, the addition of this data for the creation of an interpolated surface greatly improved the subcrop edge of many of the coal zones.

All described subsurface, surface, and near-surface datasets were combined for each coal zone for geostatistical analysis. However, prior to geostatistical filtering, first-order analysis was implemented on the source data to remove any points that were considered erroneous. Source data that deviated more than 100 m from the trend of the rest of the data points were removed from the source data, as coal zones are typically flat-lying features and source data that were obviously erroneous were not considered for use in the model. Source data that were significantly above or below the trend of another coal zone were also removed or checked by a geologist to verify their accuracy. Once these erroneous data were removed from the source data these data were then geostatistically filtered.

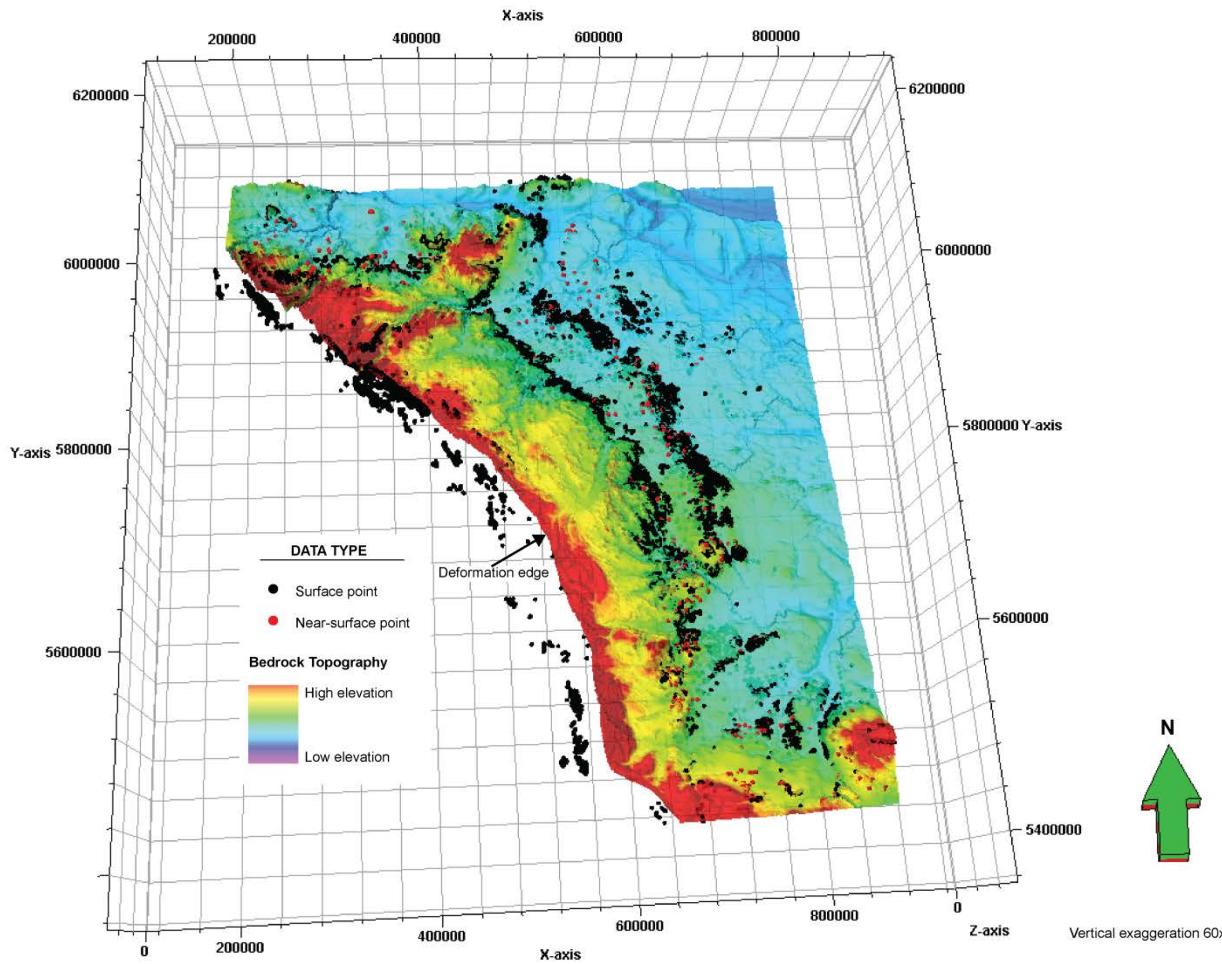

Figure 5. Plan-view map showing the distribution of surface and near-surface data delineating a coal lithology as encountered in a near-surface borehole or at a surface mining operation. Data west of the deformation edge were not included in the model. Axes are labelled with NAD 1983 10TM AEP Forest coordinates.

5.2 Geostatistical Analysis

Geostatistical filtering of source data from subsurface, surface, and near-surface datasets was performed for the top and base of each coal zone in ArcGIS 10.1. Several iterations of filtering and outlier removal were performed to achieve stability in the global uncertainty (part 2; Figure 4). The source data were geostatistically interpolated using ordinary kriging in the Geostatistical Analyst Extension of ArcGIS 10.1. In the interpolation a local first-order trend was removed to account for the westward dip of the Upper Cretaceous−Paleogene strata towards the deformation edge. Once the short-range variation in the residuals was modelled and the trend was added back into the prediction to achieve a final result, cross-validation results were calculated for each coal zone top or base to identify possible outliers in the data, which were typically caused by errors in unit conversion (e.g., feet to metres), unflagged deviated wells, kelly bushing elevation issues, or a misidentification of a coal zone.

Cross-validation was used to successively filter data that deviated from an interpolated surface and were considered outliers (geostatistically filtered source data are now considered input filtered data; see model definitions; Section 3). For example, where data were 40 m above or below the interpolated surface (as shown from the cross-validation results) these points were removed and a second interpolation and culling procedure took place. This culling procedure was done successively with the goal of achieving stabilization of global uncertainty, as assessed by the root mean square error (RMSE). The RMSE shows the difference between the predicted interpolated surface values and measured values from the input filtered data (MacCormack et al., 2013). With each round of culling the cross-validation errors were eventually reduced to the point that the RMSE would not change with any more removal of points and was as low as possible (see Section 5.5). All parameters from the geostatistically analysis were recorded and outliers were compiled for future reference.

The input filtered data were checked by an AGS geologist for any noticeable errors. The geologist would check suspicious data points or provide new data to increase density of data in areas that lacked certainty. Once the input filtered data was accepted by both the geomodeller and geologist and verified as aligning with the conceptual geological understanding of coal zones, the data were imported into Petrel for surface interpolation.

5.3 Input Surface Interpolation

The input filtered data that was prepared in ArcGIS was imported into Petrel resulting in 16 top and base interpolated surfaces (part 3; Figure 4) to define 8 discrete coal zones (Figure 2). Each coal zone top and base was first interpolated independently of any other coal zone or erosional surface (Table 1). The interpolated surfaces needed to be independently interpolated to ensure selection of interpolation parameters were optimized for the input filtered data for each coal zone top and base (e.g., to allow implementation of different data quality weighting between coal zones; Appendix 1) and the surface could be visually assessed for potential errors. These interpolated surfaces were rendered at a 500 m grid cell size over the entire 308 000 km^2 extent of the coal model (Figure 1).

Where applicable the input filtered data was modelled using the convergent interpolator algorithm in Petrel (Table 1). An advantage of this algorithm is that datasets can be assigned a quality ranking with high-quality data having a greater weight than lower quality data. This gridding algorithm also tends to produce more geologically realistic results for interpolated surfaces. In cases where interpolated surfaces of differing coal zones were close together, the conformal gridding algorithm (a variant of the convergent interpolator) was used to ensure no surface crossovers occurred (Table 1). The conformal gridding algorithm allows bounding interpolated surfaces (i.e., coal zones existing above and/or below) to be defined. Defining the bounding interpolated surface(s) ensured the resulting interpolated surface was modelled adjacent to other coal zones in a vertical sequence with limited surface crossovers.

For both the convergent interpolator and the conformal gridding algorithms the quality of the source data was assessed to categorize and weight the data during surface interpolation. Higher quality data were more heavily weighted in the interpolation and lower quality data were used as secondary data with less weighting. Weighting the data produced more accurate interpolated surfaces, as higher quality data were used primarily to constrain the interpolated surface, and lower quality data were used to fill in data gaps where no high-quality data existed. See Appendix 1 for a list of the data weighting that was used during interpolation.

Once interpolated surfaces were built independently in Petrel, the surfaces and input filtered data were again visually assessed for errors and outliers. An isopach grid was also calculated between a coal zone top and base to ensure that no large thicknesses were depicted from a few randomly distributed points. If errors in the input filtered data were found these data were removed from the input filtered dataset and a new interpolated surface was generated. All interpolated surfaces were also visually assessed for accuracy by the geomodeller and geologist to ensure the coal zones were modelled according to the conceptual geological understanding of coal zones in the Alberta Plains.

Table 1. Interpolation procedures used in Petrel for each interpolated surface.

Interpolated Surface	Interpolation Method	Bounding Interpolated Surfaces
Ardley top	Convergent interpolation	n/a
Ardley base	Convergent interpolation	n/a
Carbon-Thompson top	Convergent interpolation	n/a
Carbon-Thompson base	Convergent interpolation	n/a
Daly / Weaver / Garden Plain top	Conformal gridding	Carbon-Thompson base (*above*); Wayne / Rockyford Standard top (*below*)
Daly / Weaver / Garden Plain base	Conformal gridding	Daly / Weaver / Garden Plain top (*above*); Wayne / Rockyford Standard top (*below*)
Wayne / Rockyford Standard top	Conformal gridding	Basal Drumheller top (*below*)
Wayne / Rockyford Standard base	Conformal gridding	Wayne / Rockyford Standard top (*above*); Basal Drumheller top (*below*)
Basal Drumheller top	Conformal gridding	Lethbridge top (*below*)
Basal Drumheller base	Conformal gridding	Basal Drumheller top (*above*); Lethbridge top (*below*)
Lethbridge top	Conformal gridding	Basal Drumheller base (*above*);
Lethbridge base	Conformal gridding	Lethbridge top (*above*); Taber top (*below*)
Taber top	Conformal gridding	Lethbridge base (*above*); Mackay top (*below*)
Taber base	Conformal gridding	Taber top (*above*); Mackay top (*below*)
Mackay top	Convergent interpolation	n/a
Mackay base	Convergent interpolation	n/a

*All surfaces were built with the convergent interpolator first and any surface crossovers were reduced with a second round of interpolation using the conformal gridding algorithm.

5.4 Input Surface Manipulation

To use the interpolated surfaces as input into the 3D coal model (Section 6) a series of manipulations were applied to each interpolated surface to ensure that: 1) coal zones were truncated at major unconformities (or erosional surfaces; Figure 2); 2) the areal extent of the coal zone was limited to geo-edges; 3) no crossovers occurred with adjacent surfaces; and 4) minimum coal zone thicknesses were maintained (part 3; Figure 4).

The first manipulation that was applied to each interpolated surface included truncating all surfaces at the bedrock topography surface (where applicable). This was necessary as each interpolated surface was originally modelled across the entire study area (Figure 1) and in areas where the interpolated surface and the bedrock topography intersected, a subcrop edge was delineated. Truncating the coal zones at the bedrock topography surface was important as it represents a major unconformity in the model (Table 2).

Geo-edges were used to constrain interpolated surfaces to areas where coal zones were interpreted to be present. Geo-edges were individually delineated for each coal zone (Table 2), but were constructed following a similar set of criteria. The criteria that were used to construct a geo-edge included using the

Table 2. Interpolated surface manipulations.

Interpolated Surface	Truncated at Bedrock Topography Surface?	Geo-Edge Construction	Interpolated Surface Crossovers?	Minimum Thickness Applied?
Ardley top	Yes; eroded portion made equal to the bedrock topography.	- Combined subcrop edge with zero edge. - Zero edge defined by 'not deposited or eroded stratigraphic picks' in southern reaches of the unit (near Calgary), the deformation edge, and a polyline created to encompass all data points to the north.	- Yes; Ardley base.	- No
Ardley base	Yes; used as subcrop edge.		- Yes; Ardley top.	- Yes; moved 1 m down where Ardley top and base interpolated surfaces were crossed or minimum thicknesses (1 m) were not achieved.
Carbon-Thompson top	Yes; eroded portion made equal to the bedrock topography.	- Combined subcrop edge with zero edge. - Zero edge defined by the deformation edge and a polyline created to encompass all data to in the north and south. - The southern boundary (just south of Calgary) was based on previous studies (i.e., Beaton et al., 2002).	- Yes; Carbon-Thompson base.	-No
Carbon-Thompson base	Yes; used as subcrop edge.		- Yes; Carbon-Thompson top.	- Yes; moved 1 m down where Carbon-Thompson top and base interpolated surfaces were crossed or minimum thicknesses (1 m) were not achieved.
Daly / Weaver / Garden Plain top	Yes; eroded portion made equal to the bedrock topography.	- Combined subcrop edge with zero edge. - Zero edge defined by the deformation edge and a polyline created to encompass all data to in the north and south. - Northern boundary does not extend past the northern extent of the Bearpaw Formation (from Map 600, Prior et al., 2013).	- Yes; Daly / Weaver / Garden Plain base	- No
Daly / Weaver / Garden Plain base	Yes; used as subcrop-edge.		- Yes; Daly / Weaver / Garden Plain top	- Yes; moved 1 m down where Daly / Weaver / Garden Plain top and base interpolated surfaces were crossed or minimum thicknesses (1 m) were not achieved.
Wayne / Rockyford Standard top	Yes; eroded portion made equal to the bedrock topography.	- Combined subcrop edge with zero edge. - Zero edge defined by the deformation edge and a polyline created to encompass all data to in the north and south. - Northern boundary does not extend past the northern extent of the Bearpaw Formation (from Map 600, Prior et al., 2013).	- Yes; Wayne / Rockyford Standard base	- No
Wayne / Rockyford Standard base	Yes; used as subcrop edge.		- Yes; Wayne / Rockyford Standard top	- Yes; moved 1 m down where Wayne / Rockyford Standard top and base interpolated surfaces were crossed or minimum thicknesses (1 m) were not achieved.

Basal Drumheller top	No	- No subcrop edge used and only zero edges define the geo-edge. - Central and southern portions of the zero edge defined by the limits of the Strathmore Member of the Horseshoe Canyon Formation (where the Bearpaw Formation is present). - Polyline created to encompass all data to in the north. - Eastern boundary constrained to the zero edge of the Bearpaw Formation (from Map 600, Prior et al., 2013).	-Yes; Basal Drumheller base	- No
Basal Drumheller base	No		-Yes; Basal Drumheller top	- Yes; moved 1 m down where Basal Drumheller top and base interpolated surfaces were crossed or minimum thicknesses (1 m) were not achieved.
Lethbridge top	Yes; eroded portion made equal to the bedrock topography.	- Combined subcrop edge with zero edge. - Zero edge defined by the deformation edge and a polyline created to encompass all data. - Zero edge also informed by previous studies (i.e., Beaton et al., 2002).	Yes; Lethbridge base	- No
Lethbridge base	Yes; used as subcrop edge.		Yes; Lethbridge top	- Yes; moved 1 m down where Lethbridge top and base interpolated surfaces were crossed or minimum thicknesses (1 m) were not achieved.
Taber top	Yes; eroded portion made equal to the bedrock topography.	- Combined subcrop edge with zero edge. - Zero edge defined by the deformation edge and a polyline created to encompass all data. - Zero edge also informed by previous studies (i.e., Beaton et al., 2002).	Yes; Taber base	- No
Taber base	Yes; used as subcrop edge.		Yes; Taber top	- Yes; moved 1 m down where Taber top and base interpolated surfaces were crossed or minimum thicknesses (1 m) were not achieved.
Mackay top	Yes; eroded portion made equal to the bedrock topography.	- Combined subcrop edge with zero edge. - Zero edge defined by the deformation edge and a polyline created to encompass all data. - Southern boundary constrained to the zero edge of the Pakowki Formation where the Belly River Group does not exist (from Map 600, Prior et al., 2013).	Yes; Mackay base	- No
Mackay base	Yes; used as subcrop edge.		Yes; Mackay top	- Yes; moved 1 m down where Mackay top and base interpolated surfaces were crossed or minimum thicknesses (1 m) were not achieved.

subcrop-edge (where applicable) and combining it with a zero-edge, which were defined for coal zones based on the distribution of input filtered data representing stratigraphic picks for a discrete coal zone top or base. These zero-edges were constructed to ensure each input filtered data point was encompassed within the polygon defining the extent for each coal zone. In some cases an AGS geologist would also determine where a coal zone could no longer be correlated and these picks were considered ‘not deposited or eroded’ and the zero-edge was constructed to exclude these areas. Previously published literature (e.g., Beaton et al., 2002; Beaton, 2003; Pana 2007a; Prior et al., 2013) was also often used as a guide for the zero-edge construction to provide a conceptual understanding of where coal zones occur regionally.

Published maps were also used (Map 600, Prior et al., 2013) to limit coal zones to the areal extent of the bedrock formation it was interpreted to be reside within. And finally, the deformation edge (Figure 1) was included as a zero edge on the western extent of coal zones that continue into the Alberta Foothills to ensure the interpolated surface did not extend outside of the model domain.

The subcrop-edge and zero-edge were combined for each coal zone to create the geo-edge. Geo-edges were different for a coal zone top and base based on the location of subcrop-edge, as each interpolated surface had a unique intersection line with the bedrock topography. For the 3D coal model the top and base of a coal zone were intentionally modelled to span the same areal extent regardless of the differences in the location of the subcrop-edge. This manipulation was necessary to create coal zones that could be completely sealed during the construction of the 3D coal model (Section 6). To do this, the coal zone top interpolated surface was extended to the same areal extent as the coal zone base. Where the coal zone top was modelled to be truncated at the bedrock topography surface the interpolated surface was made equal to the bedrock topography surface until it met with the subcrop-edge of the coal zone base (Table 2).

The next manipulation ensured all interpolated surfaces had no surface crossovers. This was necessary as even though the conformal gridding algorithm was applied to coal zones where surface crossovers may be an issue (Section 5.3) the algorithm in some cases could not rectify the crossover problems (Table 2). To identify the remaining interpolated surface crossover issues an isopach grid was calculated between different coal zones that were in close proximity to one another or crossovers were visually examined. Where a surface crossover issue was identified further data were added to the input filtered data to reduce surface crossover problems or minimum thicknesses were applied.

The last manipulation to the interpolated surface applied a minimum thickness to coal zones where thicknesses of <1 m occurred. The crossovers between tops and bases occurred where input filtered points for coal zone top and base interpolated surfaces were extremely close together due to the large grid cell size (i.e., 500 m) used for the model. To eliminate this problem a 1 m minimum thickness was applied, only in areas where coal zones thicknesses were <1 m, by pushing the coal zone base interpolated surface down 1 m from where the coal zone top interpolated surface was rendered (Table 2). The 1 m thickness was determined to be a reasonable minimum thickness to apply and was validated by an AGS geologist (C. Pana) based on typical geophysical log signatures showing a coal zone.

5.5 Input Surface Uncertainty

Prior to combining all of the interpolated surfaces for use in the model construction stage (Figure 6) an effort was made to quantify the uncertainty of interpolated surfaces for each coal zone top and base (Part 4; Figure 4). Global and local uncertainties were evaluated, which provided a complementary analysis showing both the magnitude of estimation errors across an entire interpolated surface and the specific areas where the interpolated surface may be uncertain.

Global uncertainty was evaluated using RMSE values for each coal zone top and base. The RMSE was calculated by comparing the interpolated surface with the finalized input filtered data (published as model tabular data; see Section 7) with the goal of having the RMSE as low as possible (shown in Table 3). All RMSE values for the coal zone top and base interpolated surfaces (Figure 6) were quite low with the average RMSE equal to 1.82 m and a standard deviation of 0.31 m. The RMSE for individual interpolated surfaces did increase slightly with the addition of more lithological surface data (e.g., Ardley and Wayne /

Rockyford Standard), which were highly clustered along the eastern subcrop extent of a coal zone. These surface data points were considered variable quality data and were given a lower weight for surface interpolation in Petrel (see Appendix 1), which may have caused the slight increases in the RMSE. However, it was determined that the total number of data points from any source (i.e., subsurface, surface, or near-surface) did not significantly affect the RMSE values for these relatively simple interpolated surfaces. Data distribution also had a relatively low impact on RMSE values. In some cases the data were quite sparse (e.g., the Carbon-Thompson data distribution; Appendix 1) and the RMSE did not significantly deviate from the rest of the calculated RMSE values. The sparse datasets contained sufficient information to still capture the regional trend of the coal zone without significant errors in the RMSE, as RMSE is a global evaluation of uncertainty. However, the surfaces interpolated from these sparse datasets were problematic, and were better quantified by the local uncertainty.

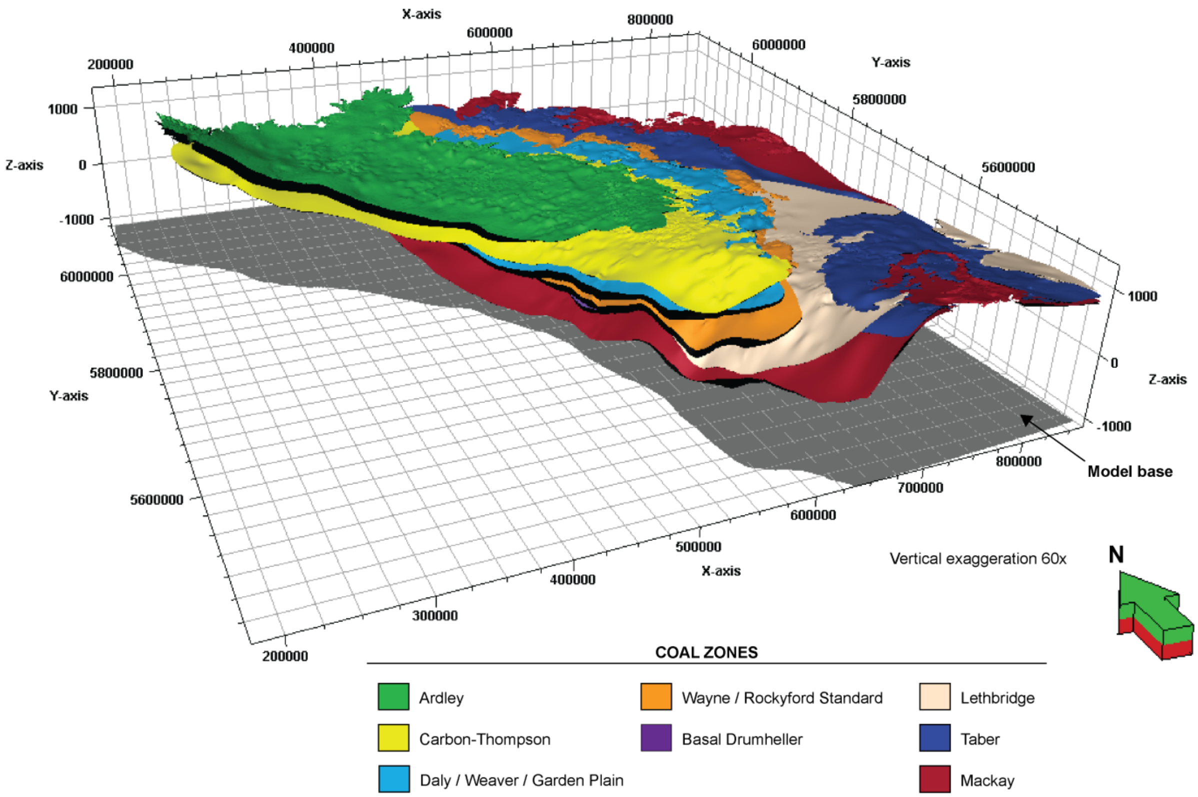

Figure 6. Discrete interpolated surfaces used in the model construction phase. For ease of visualization all black interpolated surfaces represent the base of a coal zone. Uncertainty analysis was produced for each of these discrete surfaces. The Basal Drumheller coal zone is not visible from this orientation.

Much of the uncertainty associated with the interpolated surfaces (Figure 6) was attributed to variations in data distribution. The local uncertainty for the interpolated surfaces is shown in a series of standard deviation maps in Appendix 2. These maps were created by randomly selecting 80% of the finalized input filtered data for each coal zone top and base in ten separate realizations. These ten data subsets were each used to generate new interpolated surfaces using the same algorithm method (convergent interpolator) in Petrel (Babakhani, 2016). Each interpolated surface was created with the same grid increment and the grid nodes of the interpolated surfaces were converted to points. The standard deviation was calculated at each grid node point location for all subset realizations of a coal zone top or base. The standard deviation between the grid nodes of subset realizations was interpolated as local uncertainty maps. Areas on the uncertainty map with higher standard deviation values represent locations of increased uncertainty.

Table 3. RMSE for each interpolated surface.

Interpolated Surface	Total Number of Filtered Input Data Points	RMSE (m)
Ardley top	6092	2.3
Ardley base	6135	1.9
Carbon-Thompson top	4194	1.5
Carbon-Thompson base	2851	1.2
Daly / Weaver / Garden Plain top	4195	2.2
Daly / Weaver / Garden Plain base	4121	1.6
Wayne / Rockyford Standard top	9413	2.0
Wayne / Rockyford Standard base	6976	1.4
Basal Drumheller top	5868	1.5
Basal Drumheller base	6907	1.9
Lethbridge top	6951	1.6
Lethbridge base	6888	1.8
Taber top	3640	2.2
Taber base	3265	2.1
Mackay top	5424	2.0
Mackay base	5409	1.9

Most of the maps in Appendix 2 show standard deviation values with approximately 5 m of uncertainty, which is a relatively low standard deviation value and is attributed to the flat-lying attitude and relatively simple geological complexity of the coal zones characterized at a regional scale. Where data are sparse (e.g., in the northern portions of the study area) as shown by the data density maps (Appendix 1) the local uncertainty maps show higher uncertainty in these regions. The local uncertainty maps typically also show considerable uncertainty at the boundaries of the model, specifically along the deformation edge, the Canada-USA border and the Alberta-Saskatchewan border (Figure 1) where data is more limited. Obtaining additional data points in these areas would help reduce the local uncertainty. However, the addition of more data would need to be done systematically as adding too many data points in areas of increased complexity may cause an over-prediction of the natural variability of the interpolated surface (MacCormack et al., 2013) and potentially cause the RMSE to increase.

The combination of the global and local uncertainty provides a good spatial understanding of where the most uncertain areas are located for each coal zone top and base. These uncertainty results were evaluated by the authors and the interpolated surfaces for each coal zone top and base (Figure 6) were deemed realistic and the best rendering of the coal zone geology from available data and of sufficient quality to be used as inputs in the model construction phase.

6 Model Construction

The 3D coal model was built by combining and importing the interpolated surfaces into a 3D simple grid in Petrel, an unfaulted structural framework model (Part 5; Figure 4) to achieve a gridded volume between each coal zone. Several decisions were made to create the geological model in Petrel including: model parameters (i.e., geometry and grid increment), the grid discretization based on the ordering and definition of interpolated surfaces (e.g., conformable, erosional), and the layering that was imposed to create the final model zones for each coal zone. The outcome of these decisions created a volumetrically sealed geological model that honoured the stratigraphic and geospatial relationships of coal zones.

6.1 Model Parameters

The 'Make simple grid' tool in Petrel was used to define model parameters needed to initialize the creation of the 3D coal model. Model parameters defined in this tool included the geospatial extent and geometry of the model domain as well as input data (i.e., the interpolated surfaces) used to discretize the simple grid.

The geospatial extent of the 3D coal model was made to encompass the entire model domain outlined in Figure 1 (i.e., 308 000 km^2). The geospatial extent was user defined with the geospatial coordinates and grid increments outlined in Figure 7. The grid increment used for the 3D coal model was selected to ensure the complexity of the coal zones was captured at a regional scale (i.e., approximately 1:500 000) based on the density and quality of input data. The interpolated surfaces discussed in Section 5.3 were then combined in stratigraphic order to discretize and build the 3D simple grid.

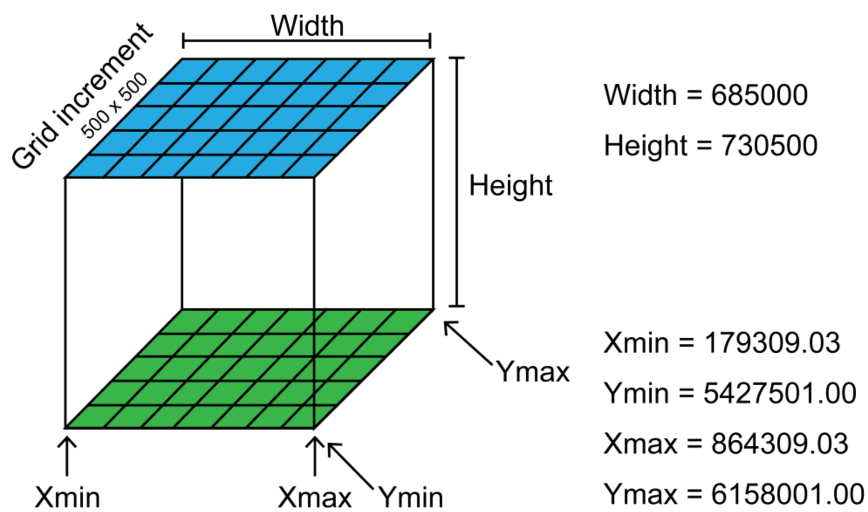

Figure 7. User-defined grid size (in metres) and position for the 3D simple grid construction (in NAD 1983 10TM AEP Forest).

6.1.1 Grid Discretization

The interpolated surfaces used to discretize the 3D simple grid were manipulated from the original discrete interpolated surfaces (Figure 6) to be continuous surfaces (Figure 8), which were used to create a volumetrically sealed 3D model (Section 3) with 8 discrete coal zones and 9 undifferentiated zones (see Generalized Model Column; Figure 2). Because the coal zones were intentionally modelled to not intersect each other, based on the conceptualization by the geomodeller and the geologist's geological understanding of coal zones (Figure 2), the undifferentiated zones needed to fill the intervening space between the coal zones (Figure 9). To ensure this space was properly filled, 18 continuous surfaces were rendered at a 500 m grid cell size to span the entire model domain (Figure 8). To maintain a reasonable geometry where coal zones pinch out at surface, the continuous surfaces were created using a trend surface of the input filtered data to extend across the model domain (Figure 8). Where the coal zone top or base should not exist, as defined by the geo-edge for a discrete coal zone, the trend portion of the continuous surfaces was set to 0 m thickness between a coal zone top and base surface. Following this technique, a series of continuous surfaces were created and used to discretize the 3D simple grid.

For each of the continuous surfaces the geological relationship was defined based on the relationship to overlying and underlying units to be used as input to discretize the 3D simple grid. Most of the units were set to conformable because the coal zone tops and bases were intentionally modelled to not crossover with each other with the exception of the bedrock topography surface, which was set to erosional and the model base was set as the base of the 3D simple grid.

The above parameters were used to initialize the 3D simple grid, which produced a skeleton framework with a top, middle, and base grid. These skeleton grids were linked by vertical pillars connecting each corner point of a grid cell with the corresponding grid cell of the other skeleton grids. The layering of the 3D simple grid was built along the vertical pillars and the horizontal layering of the 3D simple grid was defined by continuous surfaces with, no further discretization within each geological unit. The final 3D coal model contains 34 026 690 grid cells with 18 internal layers and 17 model zones (Figures 9 and 10).

7 Model Outputs

The main model outputs are continuous and discrete model horizons (Section 3) that were exported from the 3D coal model (Figures 9 and 10). Continuous model horizons were exported from the 3D simple grid and maintained in their original format spanning the entire model domain (Figure 1), as these surfaces are needed to rebuild the sealed 3D coal model with the intervening undifferentiated zones. Discrete model horizons (Figure 3) were generated by clipping all 0 m thickness areas that existed between the continuous model zones (Figure 8) to show only where the coal zone top or base was present (all discrete model horizons are shown in Appendix 3). From these discrete model horizons, model extents were generated, which define the perimeter or boundary of the model horizon for each coal zone top and base. The continuous and discrete model horizons, model extents, and finalized input filtered data (now considered model tabular data; see model definitions, Section 3) make up the digital data published on the AGS website.

7.1 Digital Data

Each of the model outputs from the 3D coal model (Figure 10) were deconstructed for dissemination (Part 6; Figure 4). There are four types of deconstructed digital data that are published on the AGS website:

- Model tabular point data: finalized input filtered data database for all coal zones in tab-delimited format
- Model extents: zone model extents published as GIS data polygon features
- Model horizons (discrete): discrete model horizons published as gridded data in ASCII format
- Model horizons (continuous): continuous model horizons published as gridded data in ASCII format
- for use with iMOD 3D visualization (Section 7.2)

Each of these digital datasets is available in standard formats, which can be used by numerous softwares. Proprietary Petrel formats are not published by the AGS, but the models are internally housed and maintained in Petrel to perform any necessary modifications or future updates to the 3D coal model.

7.2 iMOD 3D Visualization

Model tabular data, extents, and horizons can also be downloaded and visualized in 2D and 3D using iMOD, an easy-to-use graphical interface (Deltares, n.d.). This software allows users to rotate, slice, explode, and toggle coal zones on and off in 3D space. Cross-sections can also be cut in iMOD to view the 3D coal model in section along with the model tabular data. The 2D viewer shows the input data, model extents, and areal extent of the coal zones. Both the 2D and 3D viewer in iMOD allow users to import their own data in any area of the model domain and zoom in and out to view the interrelationships and areal extent of different coal zones in relation to their own data. However, users may find that the model may not correlate to their data in all areas as this model is a rendering from available data from numerous sources of variable quality at a 500 m grid cell size and meant to show coal occurrences at a regional scale (1:500 000).

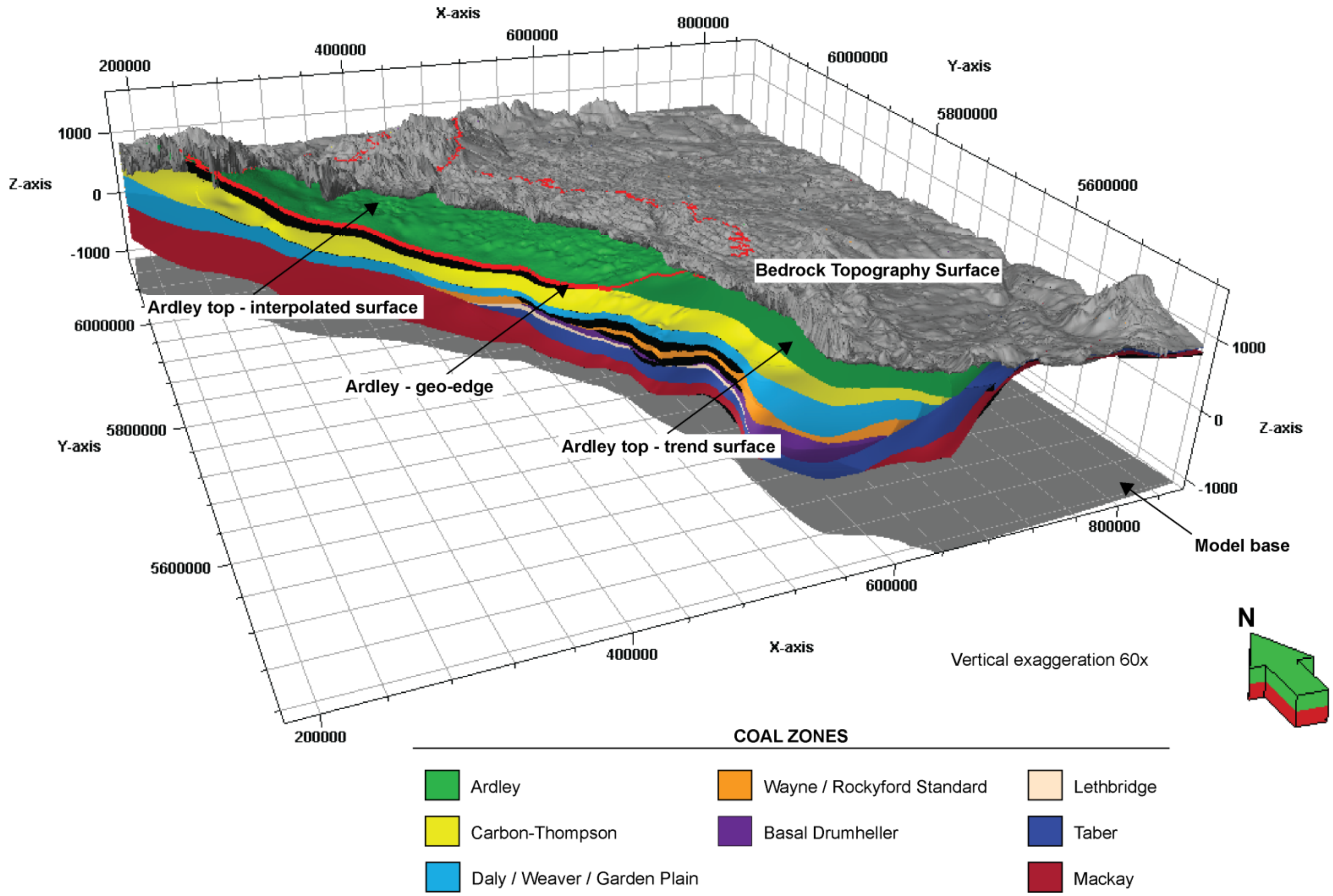

Figure 8. View of the continuous surfaces used to discretize the 3D simple grid. The continuous grids were created by combining the interpolated surface of a coal zone with a trend surface outside the coal zone geo-edge and truncating the combined surface at the bedrock topography surface (if applicable). For ease of visualization all black continuous surfaces represent the base of a coal zone. The bedrock topography surface and model base are shown in grey and these surfaces represent the upper and lower limits of the 3D simple grid.

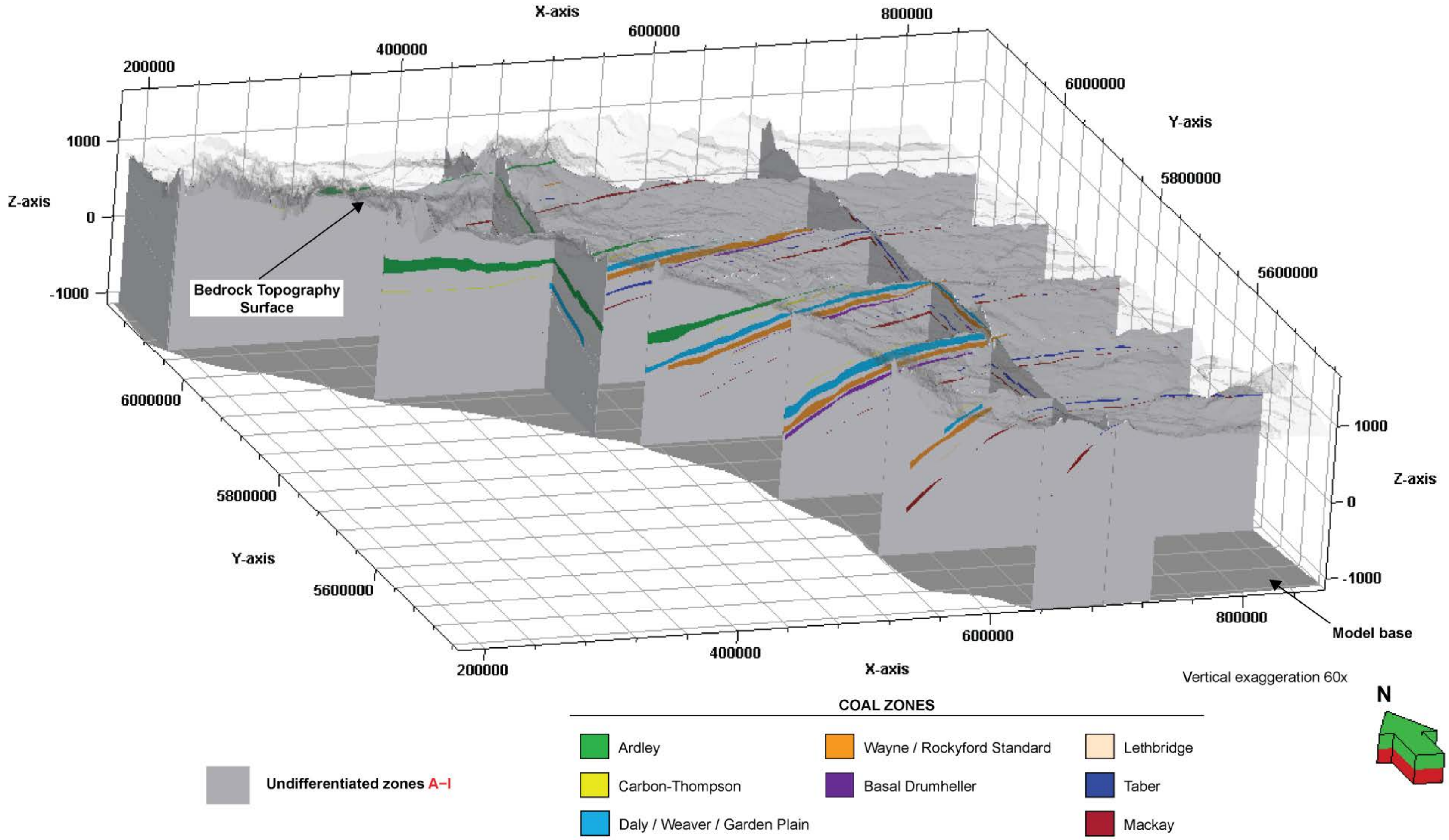

Figure 9. Fence diagram showing coal zones and the intervening undifferentiated zones A-I modelled to fill the volume between the detached coal zones.

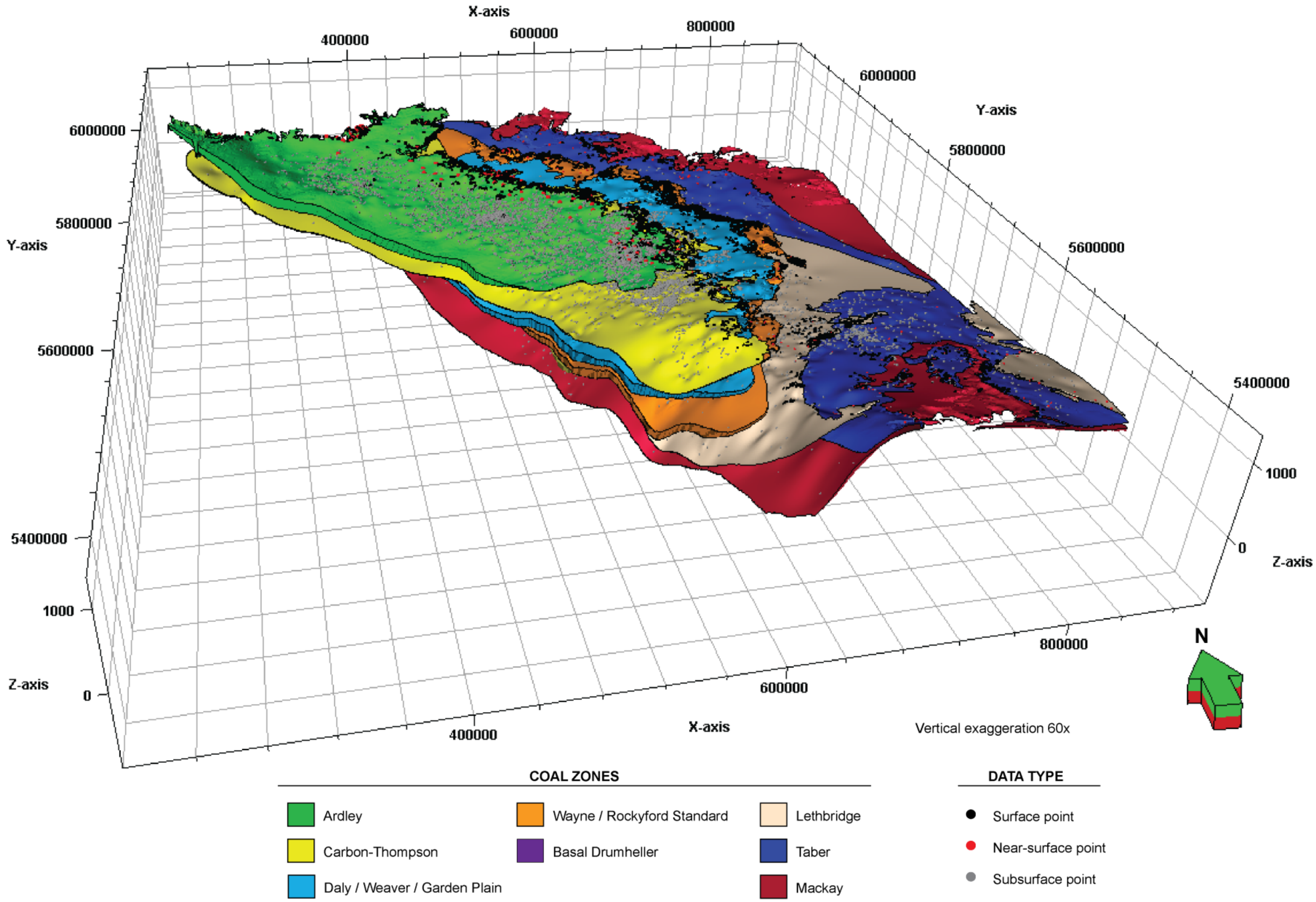

Figure 10. Oblique-view of the 3D coal model as well as data used to define the top and base of a coal zone. Undifferentiated model zones are not included in this view. The Basal Drumheller coal zone is not visible from this orientation.

8 Model Quality

The 3D coal model represents a visualization of the current understanding of coal as rendered from available data sources. As a result, the authors recognize that model quality varies across the domain as well as between coal zones. Although uncertainty in the input interpolated surfaces has already been outlined above (Section 5.5), a discussion of model quality is warranted to ensure that end users of the 3D coal model will have a qualitative understanding of model quality, as communicated by the AGS geomodeller. Communicating the overall model quality is important to maintain a record of the current state of the model and to initiate additional model updates or versions in areas of seemingly low model quality, especially if new data or interpretations become available.

Model quality is evaluated in this report through a qualitative assessment of data quality, data quantity, and trueness to geological concept, as model quality is not solely reliant on the interpolation algorithms used to generate the model. Table 4 outlines these categories for each coal zone top and base. The qualitative assessment in Table 4 has been generated by the geomodeller and seeks to provide a confidence level ranging from low-to-high for each modelled coal zone. The assessment of model quality excludes the undifferentiated zones, which were simply components of the model used to fill the 3D volume between discrete coal zones.

Table 4 shows that all modelled coal zones have a medium confidence level or higher, with the most confident level of high allocated to the Ardley model zone. This coal zone is considered the highest quality in the coal model, as it has been the subject of recent investigations at the AGS, and the majority of the data used to model this zone has been generated or validated by AGS geologists. The Wayne / Rockyford Standard model zone is the model component with the second highest confidence based on the abundance of data for this coal zone with good coverage and few outliers. The rest of the model zones are considered medium quality for a variety of different reasons. Coal zones such as the Basal Drumheller were rated medium because it may not quite capture the true geological concept, as only subsurface data were used to support the modelled distribution of the coal zone. Additional data could help provide a better conceptual model for this zone. The other medium quality confidence level was assigned to coal zones based on the sparse data distributions, especially on the boundaries of the model zones. These contrasts in data density are better captured by quantitative local uncertainty assessments discussed in Section 5.5 and shown in Appendix 2.

The contrasts in model quality highlight the limitations of the 3D coal model. All of the categories outlined in Table 4 can vary significantly between each model zone, and spatially across the model domain. End users should note that this model does vary in quality and uncertainty as it was created from available data from numerous sources of varying quality and rendered at a regional scale (1:500 000). This model is not intended to be used for local-scale or site-specific investigations and users should consider the level of model confidence provided in Table 4 along with the discussion of global and local uncertainty (Section 5.5 and Appendix 2) prior to using the 3D coal model.

Although the contrasts in model quality and model limitations are apparent, the entire 3D coal model is considered high quality (Figure 11). There is good correspondence between the subcrop-edge of many of the coal zones (shown in Figure 11 where surface data points from mining operations are located) and the known coal fields and deposits mapped in the Alberta Plains (Figure 11). The 3D coal model and the known coal fields and deposits were generated separately and the similarity between the two renderings of coal occurrences increases our confidence in the 3D coal model.

Table 4. Confidence level of model zones.

Model Zone	Data Quality	Data Quantity	Trueness to Geological Concept	Model Zone Confidence Level		Comments
Ardley top	3	3	3	9	high	Large portion of the subsurface data was picked and verified by AGS geologists.
Ardley base	3	3	3	9	high	
Carbon-Thompson top	3	2	2	7	medium	Sparse data distribution to the north.
Carbon-Thompson base	3	2	2	7	medium	
Daly / Weaver / Garden Plain top	2	2	2	6	medium	Data from three coal zones were grouped, as Daly data were confined to small geographic area and data for each zone were located in close proximity. Further subdivisions of these coal zones could be implemented in future modelling.
Daly / Weaver / Garden Plain base	2	2	2	6	medium	
Wayne / Rockyford Standard top	2	3	3	8	high	Abundant data with good coverage; numerous surface and near-surface data source delineating the subcrop edge.
Wayne / Rockyford Standard base	2	2	3	7	medium	
Basal Drumheller top	2	2	2	6	medium	Good subsurface data coverage; poor surface and near-surface coverage. Areal extent may be modified with additional data.
Basal Drumheller base	2	2	2	6	medium	
Lethbridge top	2	2	2	6	medium	Sparse data distribution to the east; additional data would better define the areal extent and subcrop edge.
Lethbridge base	2	2	2	6	medium	
Taber top	2	2	2	6	medium	Sparse data distribution at model boundaries. Additional data would better define these areas.
Taber base	2	2	2	6	medium	
Mackay top	2	2	2	6	medium	Sparse data distribution at model boundaries. Additional data would better define these areas.
Mackay base	2	2	2	6	medium	

*All categories are scored between 1 and 3 (1 being poor, 2 being average, and 3 being good). For each model zone the categories values are summed for each coal zone (minimum of 3 and maximum of 9). The Model Zone Confidence Level is based on this total summed value, with low being 3-4; medium being 5-7; and high being 8-9.

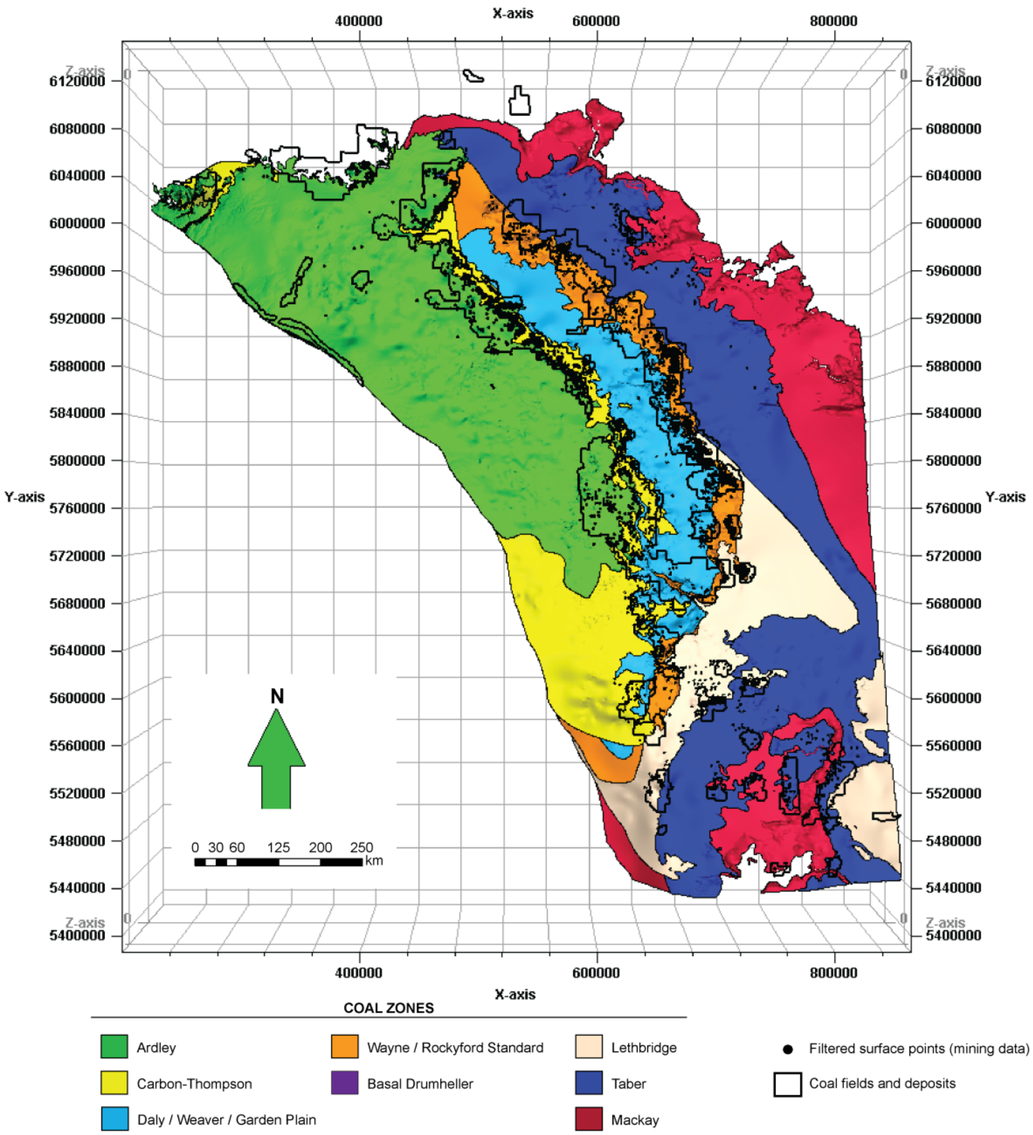

Figure 11. 2D view of the top of the 3D coal model overlain by surface points, coal fields, and deposits (coal fields and deposits from Smith et al., 2008). The Basal Drumheller coal zone is not visible from this orientation.

9 Summary

A 3D coal model has been built for the Upper Cretaceous−Paleogene succession in central and southern Alberta. The model provides an updated view of coal zones in Alberta and contributes to the 3D Provincial Geological Framework Model. The 3D coal model covers approximately 308 000 km^2 of the Alberta Plains and includes geological units from the bedrock topography surface down to the coal zones occurring at the base of the Belly River Group. This report documents the methodology used to create the 3D coal model and the workflow used, which has broad applicability to a number of different stratigraphic units in the Alberta Plains. The report also includes specific information about model parameters needed to reproduce the 3D coal model.

The 3D coal model was created using available data from subsurface (stratigraphic information from geophysical logs), surface (mining and outcrop information), and near-surface (water wells and legacy ARC borehole records) sources of varying quality and spatial coverage. Several iterations of geostatistical filtering were applied to these datasets to achieve a dataset that was suitable to represent the top or base of each coal zone. These data were then imported into Petrel resulting in the interpolation of 16 discrete surfaces representing coal zone tops and bases. These interpolated surfaces were then manipulated to honour the geological relationships of each coal zone in 3D space.

The 16 interpolated surfaces were continuously extended over the model domain and combined with 2 surfaces representing the bedrock topography and model base to discretize a 3D simple grid in Petrel. The resulting 3D coal model contains 34 026 690 grid cells with 17 model zones. The modelled coal zones and their correlative equivalents include: 1) Ardley; 2) Carbon-Thompson; 3) Daly / Weaver / Garden Plain; 4) Wayne / Rockyford Standard; 5) Basal Drumheller; 6) Lethbridge; 7) Taber; and 8) Mackay. The remaining modelled zones are undifferentiated strata of the Scollard, Wapiti, Horseshoe Canyon, and St. Mary River formations as well as the Belly River Group. These 17 model zones from the 3D coal model have been deconstructed for dissemination of model products, which are published on the AGS website.

This 3D coal model was built using an iterative approach with an AGS geologist to create a model that honours both the data and conceptual geological understanding of coal in the Alberta Plains. However, as this model is limited by the available data and has been rendered for regional-scale applications, it should not be used in place of site-specific investigations. Instead this model is meant to provide a 3D overview of coal occurrences in the province and act as a tool for end users to visualize the distribution, spatial continuity, elevation, and thickness of coal zones at a regional scale.

10 References

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Appendix 1 − Model Weighting and Data Distribution

Table 5. Data weighting applied for each coal zone in Petrel.

Coal Zone	Data Type	Data Source	Interpolated Surface Weighting
Ardley	Subsurface	Recent AGS data (picked and verified by an AGS geologist)	1.0
		Legacy AGS data (some data verified by an AGS geologist)	0.8
		CBM datasets from AER corporate database	0.6
	Surface and near-surface datasets	Lithological logs from ARC coal investigations and water-well records	0.6
Carbon-Thompson	Subsurface	CBM datasets from AER corporate database	1.0
		Legacy AGS data	0.8
	Surface and near-surface datasets	Lithological logs from ARC coal investigations and water-well records	0.6
Daly / Weaver / Garden-Plain	Subsurface	CBM datasets from AER corporate database	1.0
	Surface and near-surface datasets	Lithological logs from ARC coal investigations and water-well records	0.6
Wayne / Rockyford Standard	Subsurface	CBM datasets from AER corporate database	1.0
	Surface and near-surface datasets	Lithological logs from ARC coal investigations and water-well records	0.6
Basal Drumheller	Subsurface	CBM datasets from AER corporate database	1.0
	Surface and near-surface datasets	Lithological logs from ARC coal investigations and water-well records	0.6
Lethbridge	Subsurface	CBM datasets from AER corporate database	1.0
		Legacy AGS data	0.8
	Surface and near-surface datasets	Lithological logs from ARC coal investigations and water-well records	0.6
Taber	Subsurface	CBM datasets from AER corporate database	1.0
		Legacy AGS data	0.8
	Surface and near-surface datasets	Lithological logs from ARC coal investigations and water-well records	0.6
Mackay	Subsurface	CBM datasets from AER corporate database	1.0
		Legacy AGS data	0.8
	Surface and near-surface datasets	Lithological logs from ARC coal investigations and water-well records	0.6

* Data weighting is applied in Petrel based on the data source. Higher quality data are the most heavily weighted in the surface interpolation. Weights from 0-1 are applied to data with the highest weight not exceeding 1.

† Data weighting was not modified for a coal zone top and base of the same coal zone.

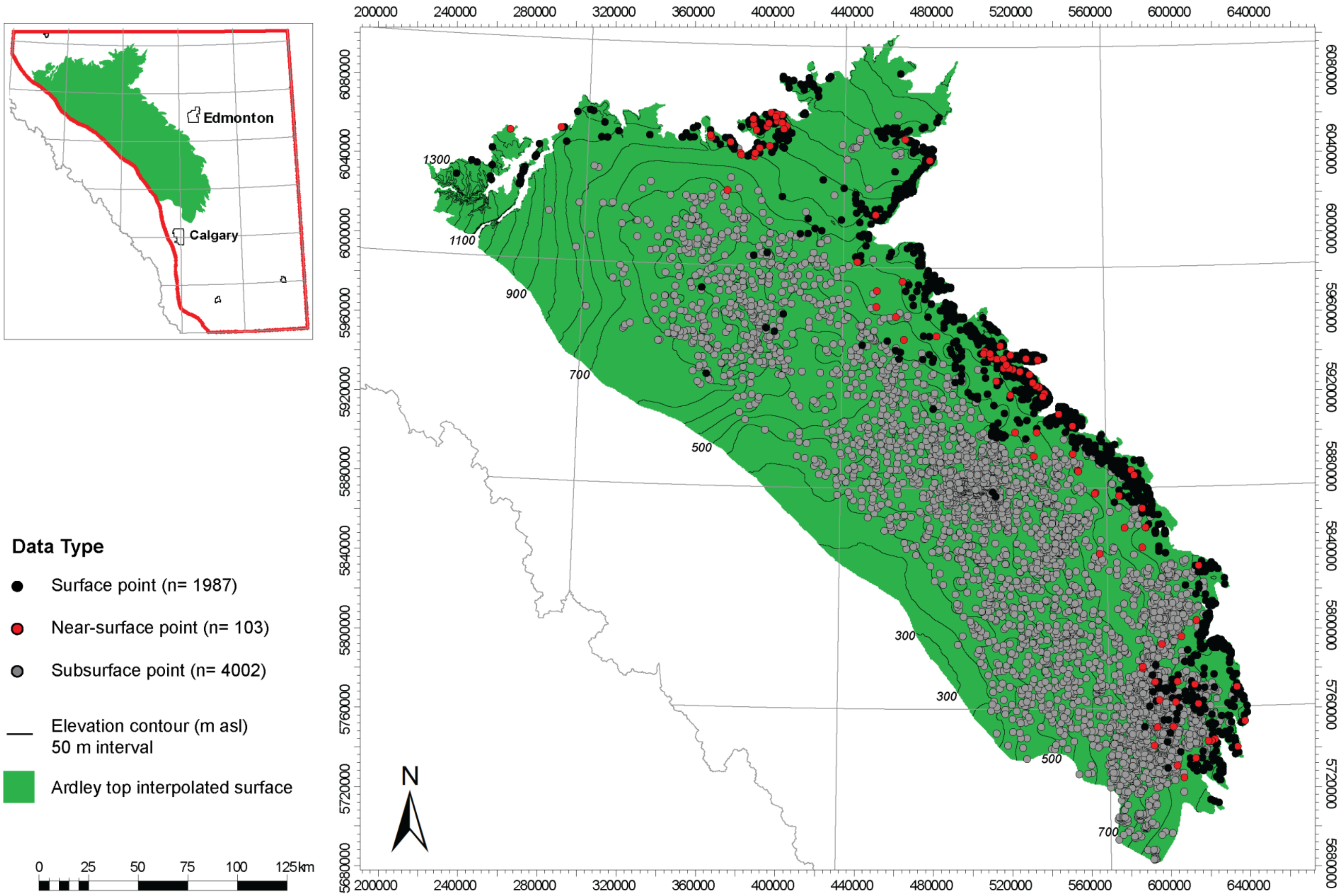

Figure 12. Data distribution for Ardley top interpolated surface.

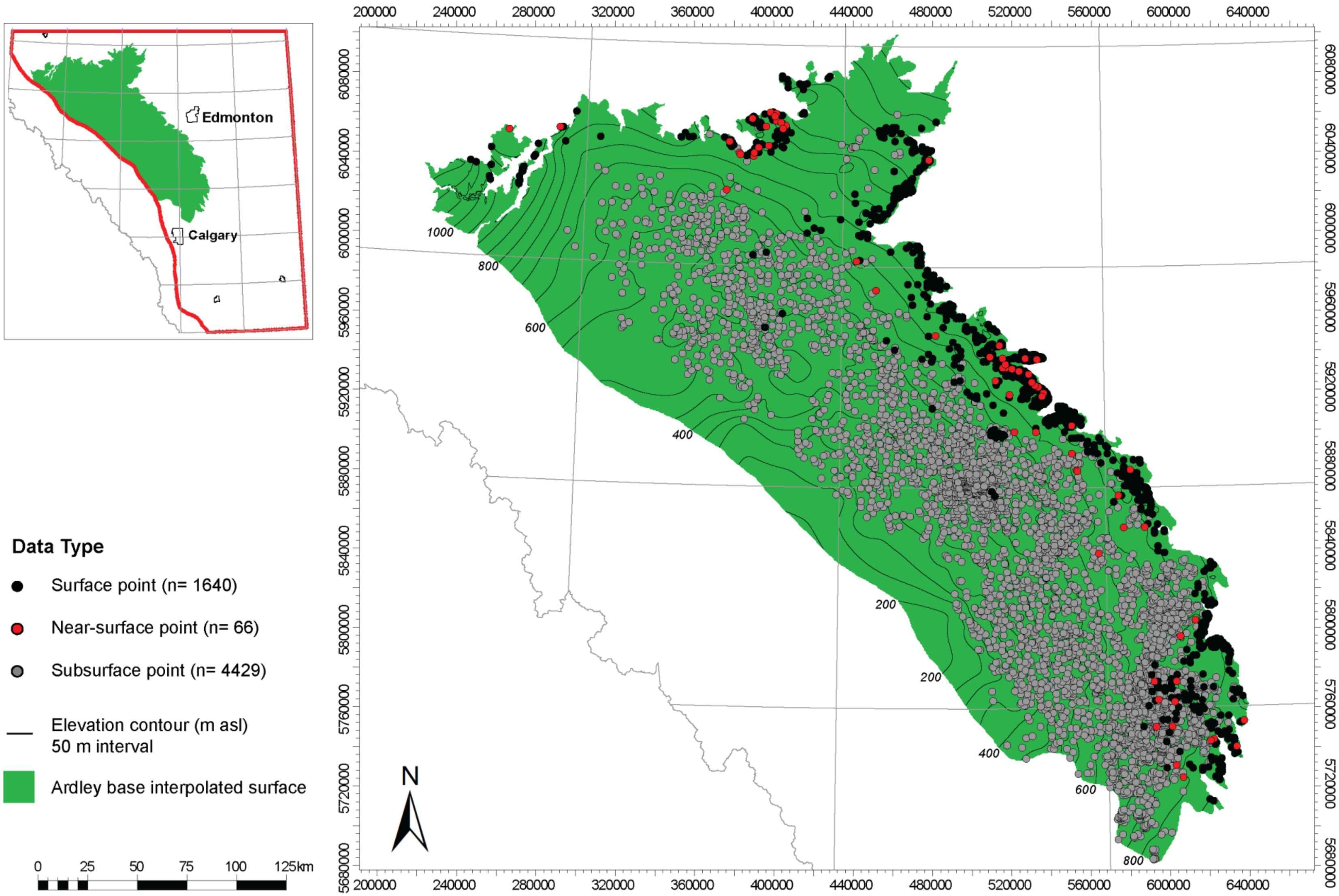

Figure 13. Data distribution for Ardley base interpolated surface.

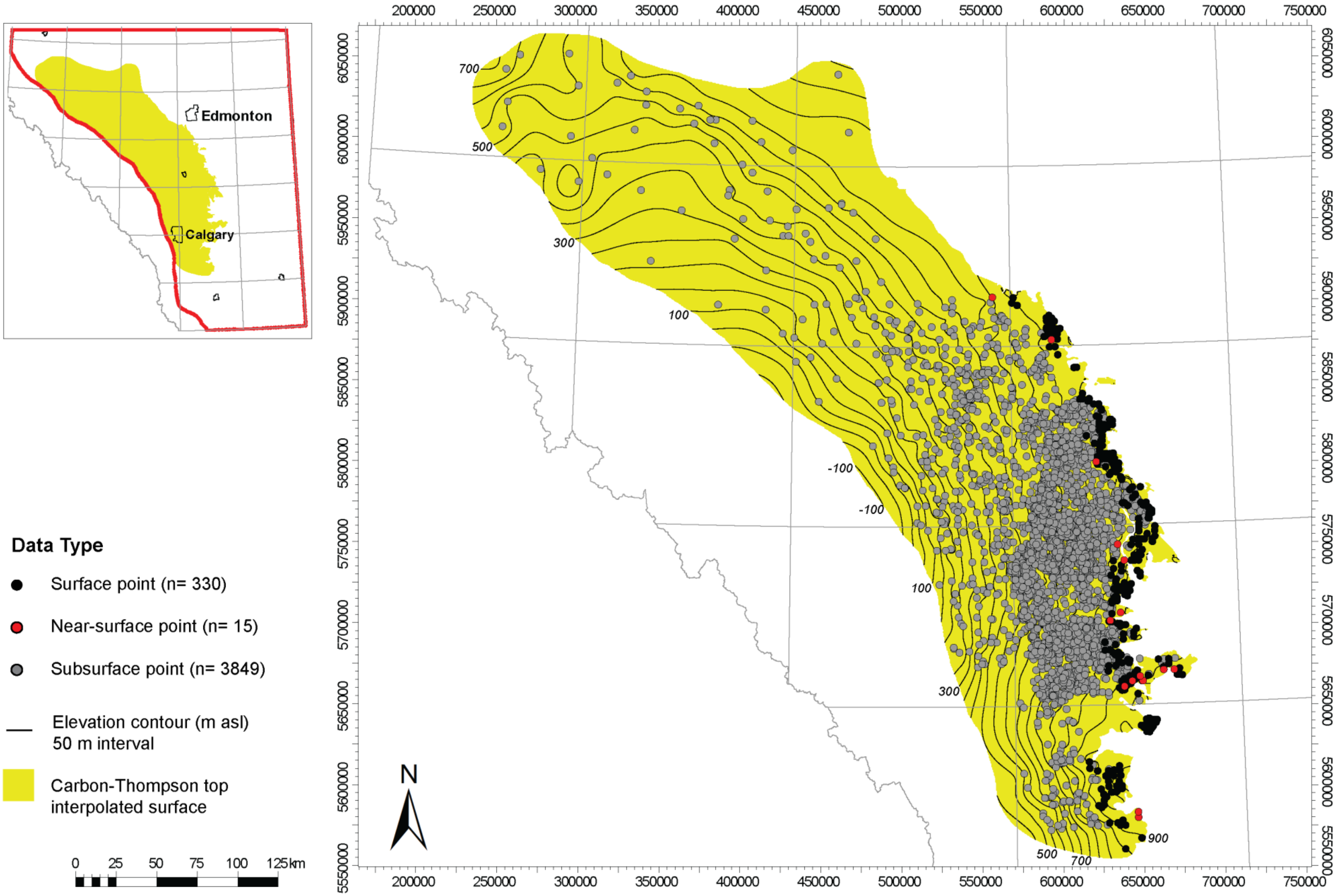

Figure 14. Data distribution for Carbon-Thompson top interpolated surface.

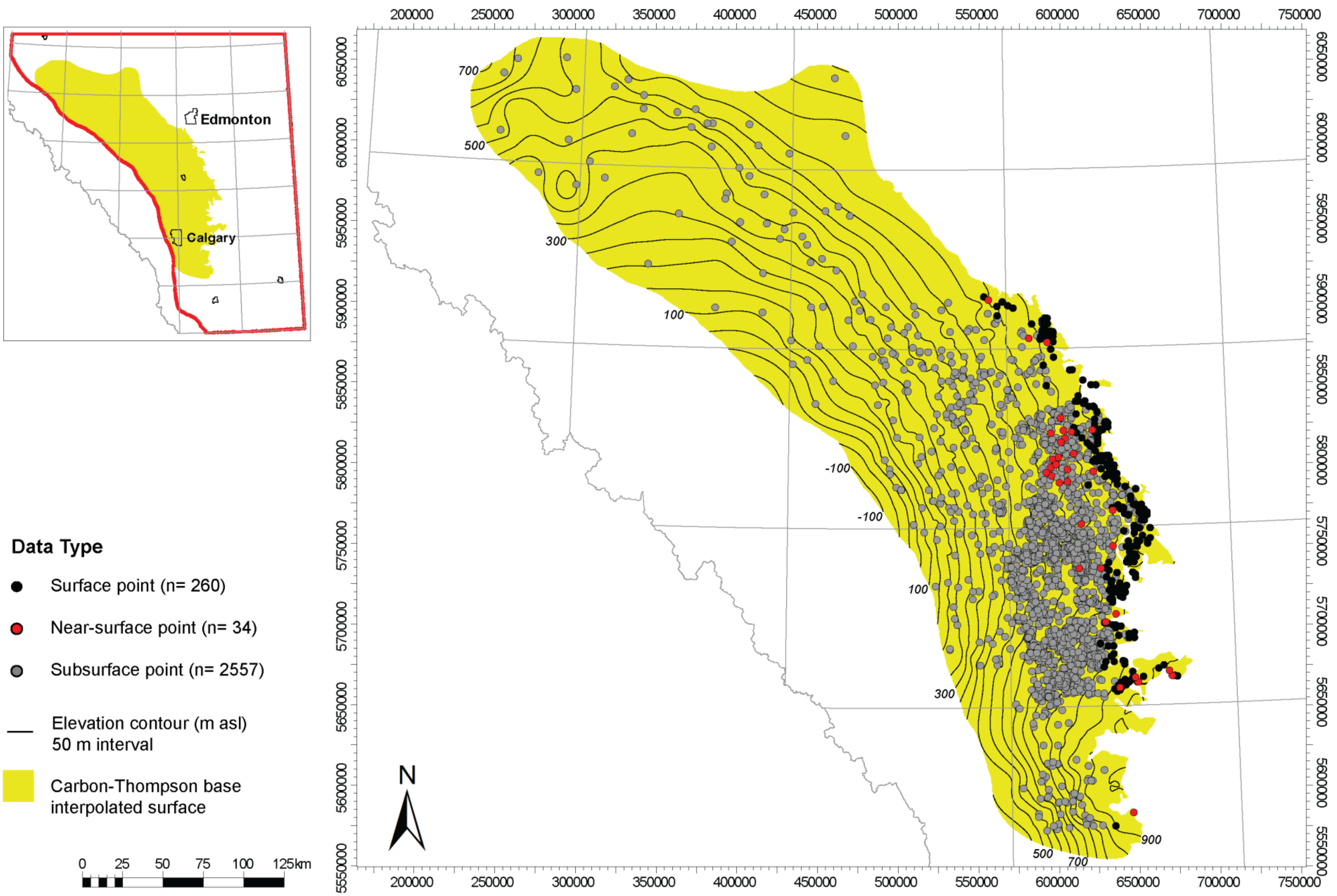

Figure 15. Data distribution for Carbon-Thompson base interpolated surface.

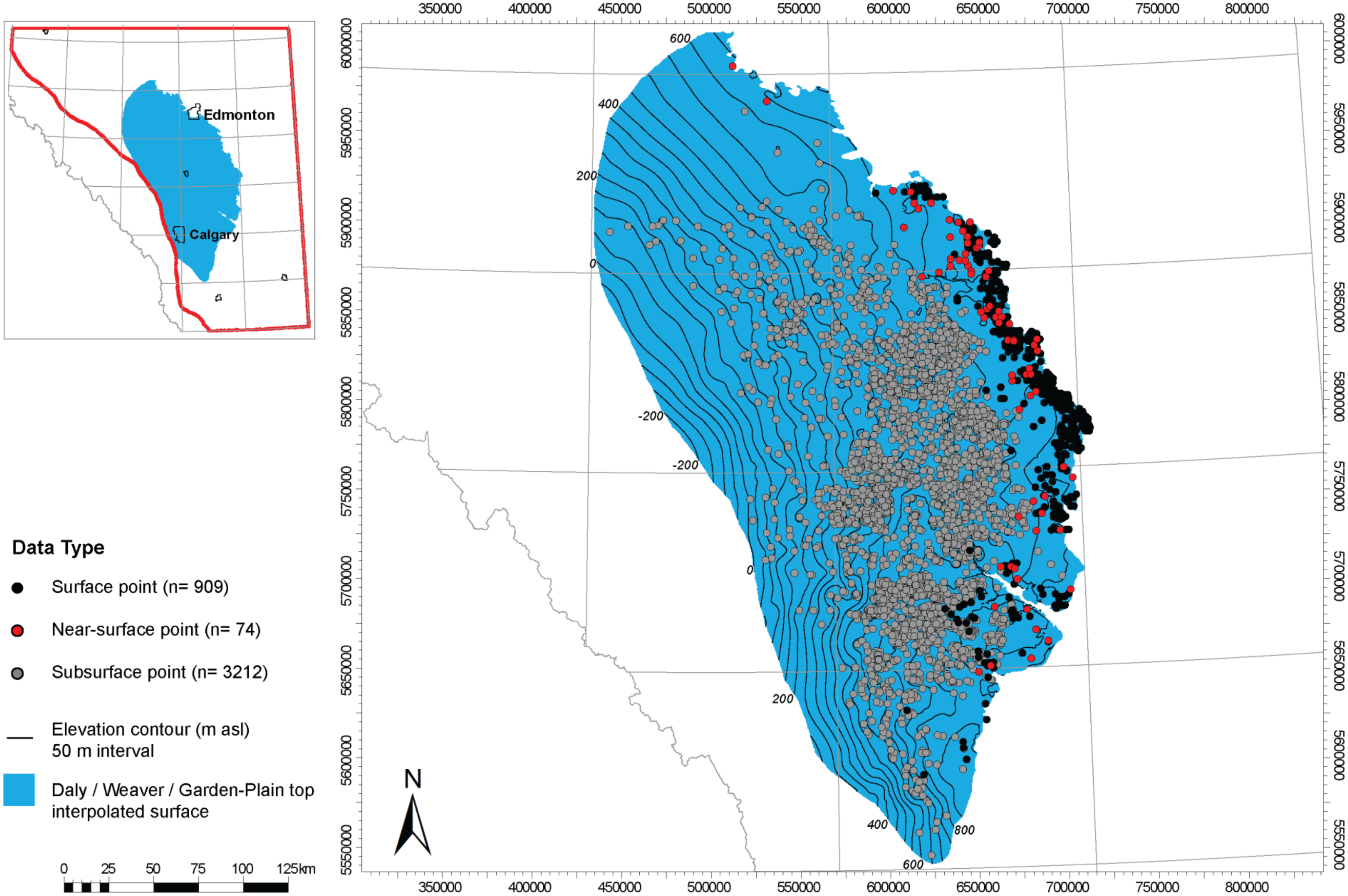

Figure 16. Data distribution for Daly / Weaver / Garden-Plain top interpolated surface.

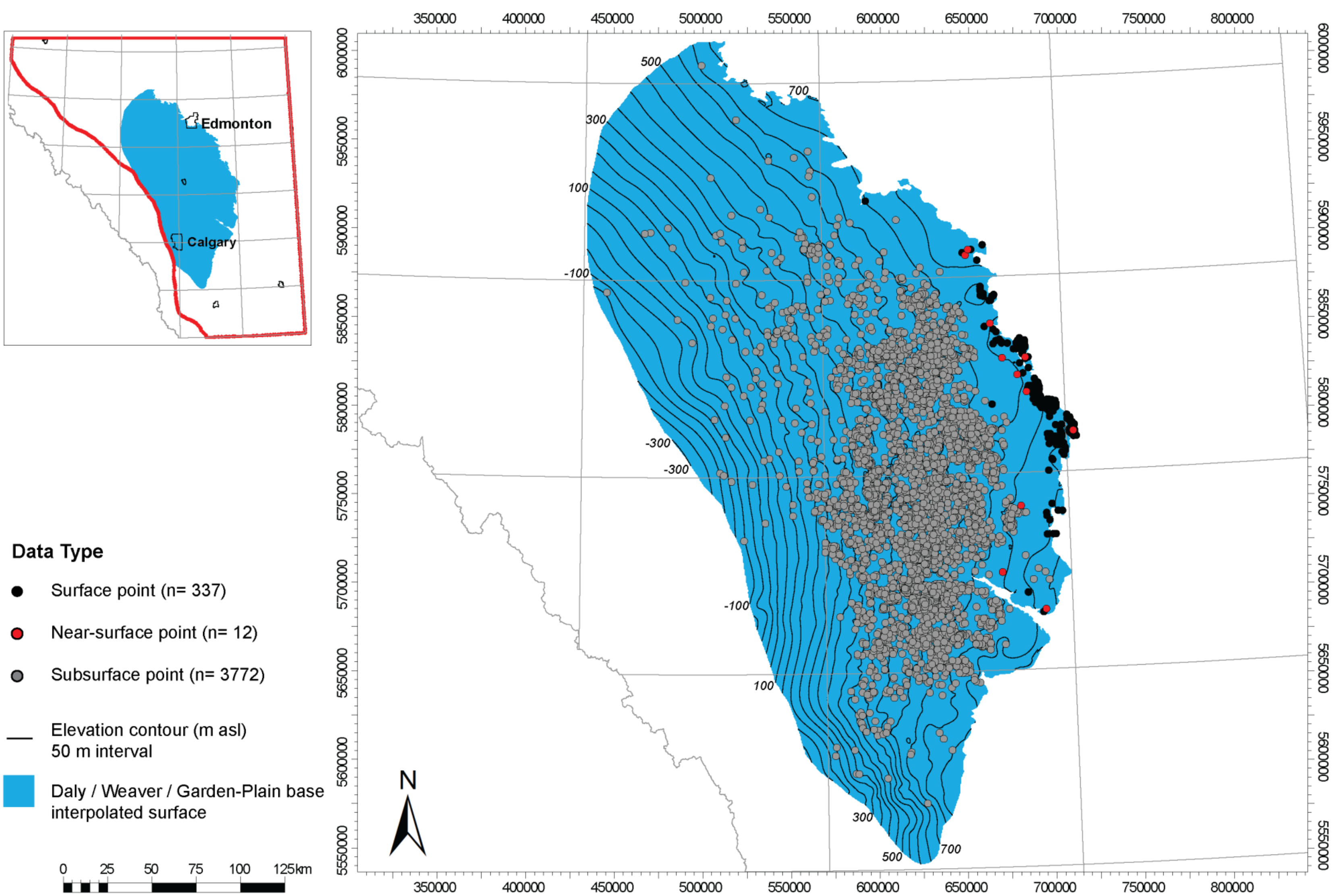

Figure 17. Data distribution for Daly / Weaver / Garden-Plain base interpolated surface.

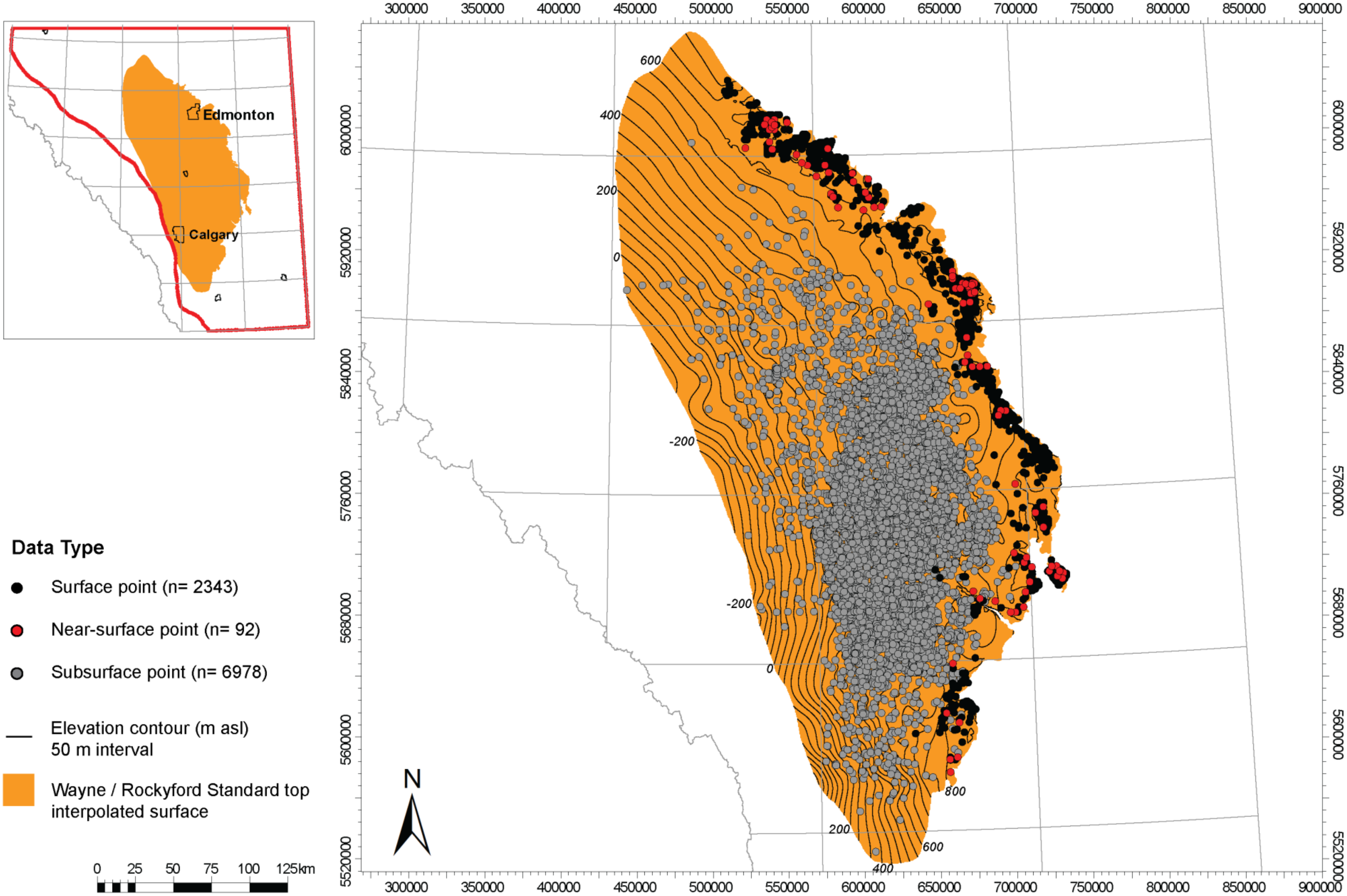

Figure 18. Data distribution for Wayne / Rockyford Standard top interpolated surface.

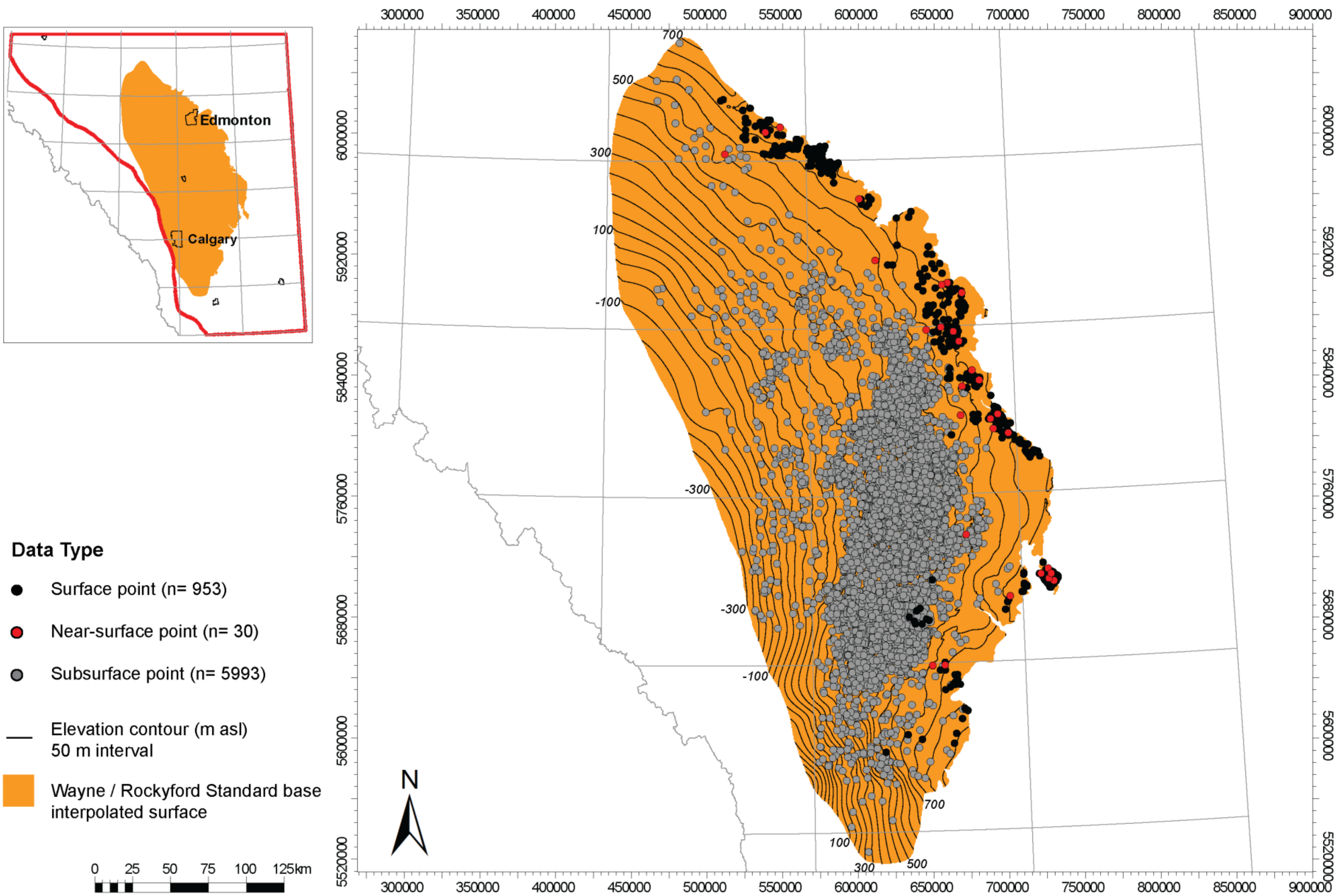

Figure 19. Data distribution for Wayne / Rockyford Standard base interpolated surface.

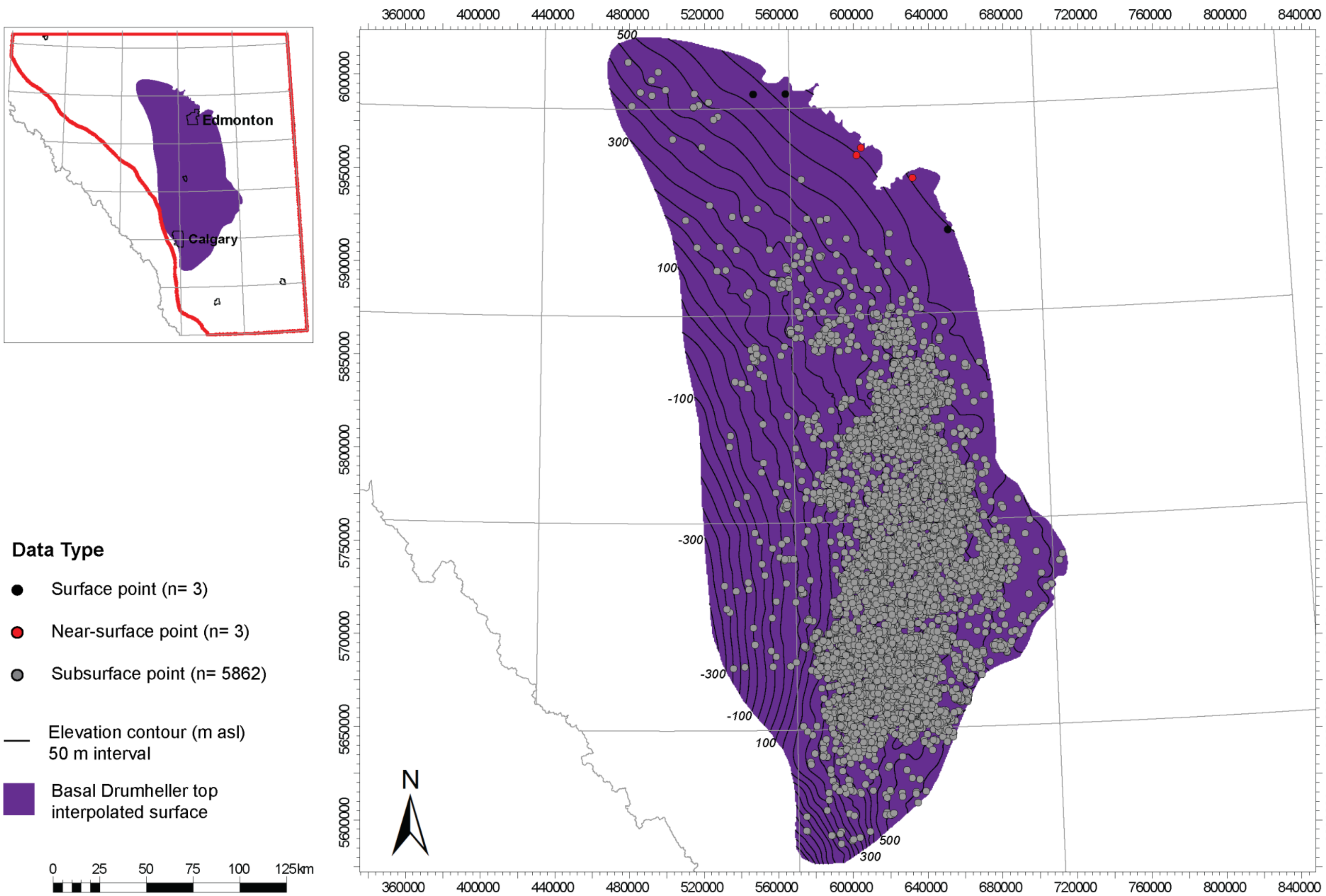

Figure 20. Data distribution for Basal Drumheller top interpolated surface.

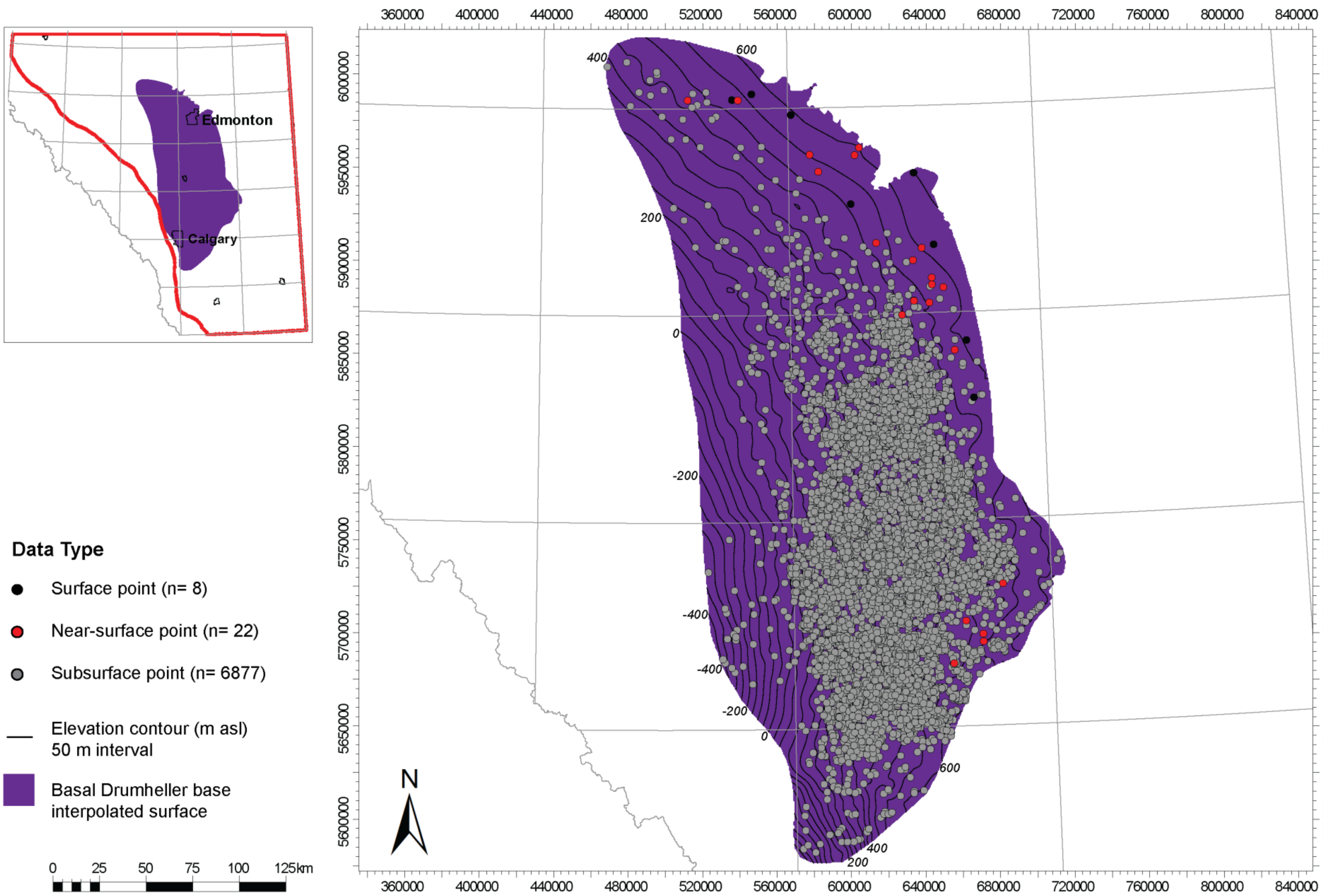

Figure 21. Data distribution for Basal Drumheller base interpolated surface.

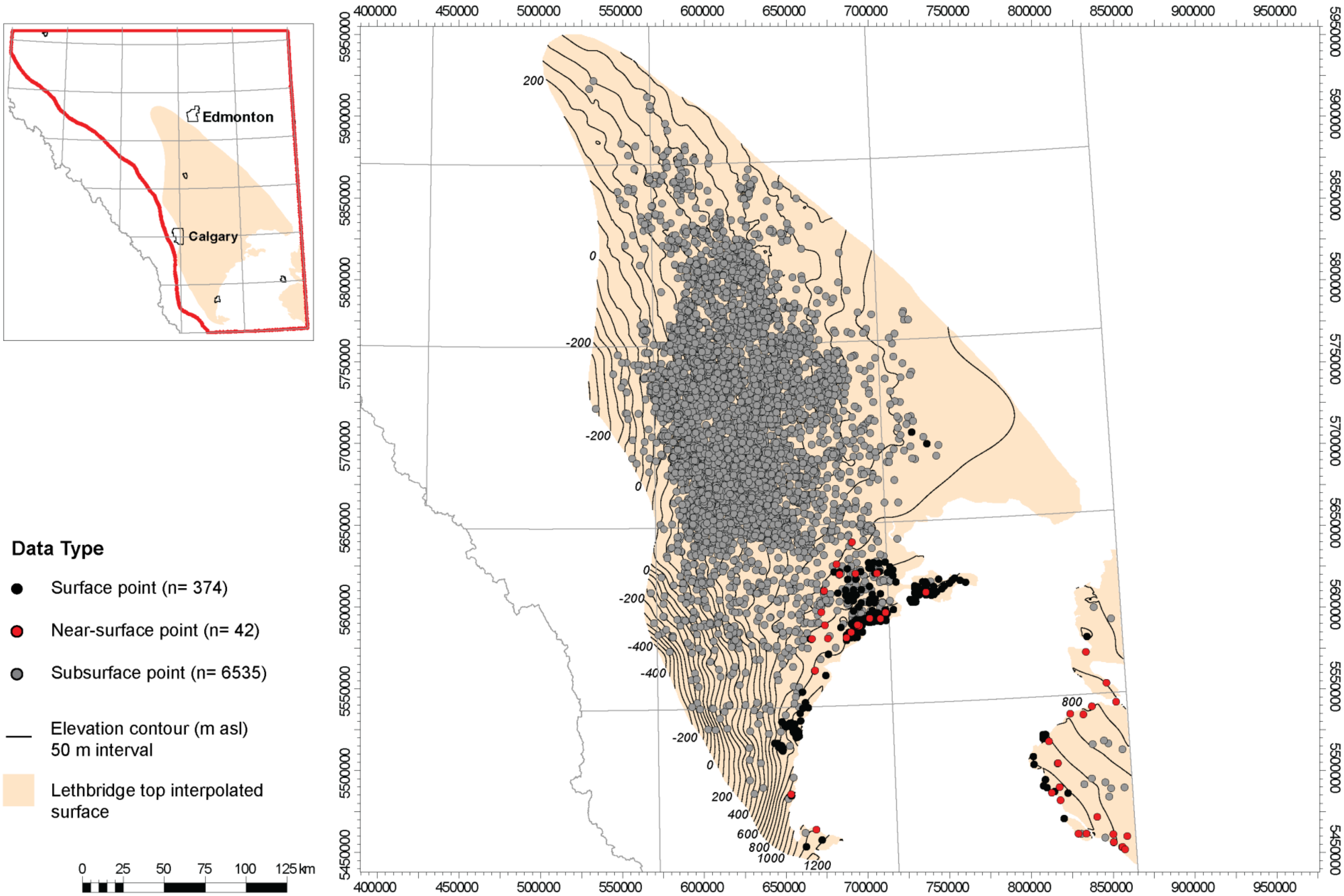

Figure 22. Data distribution for Lethbridge top interpolated surface.

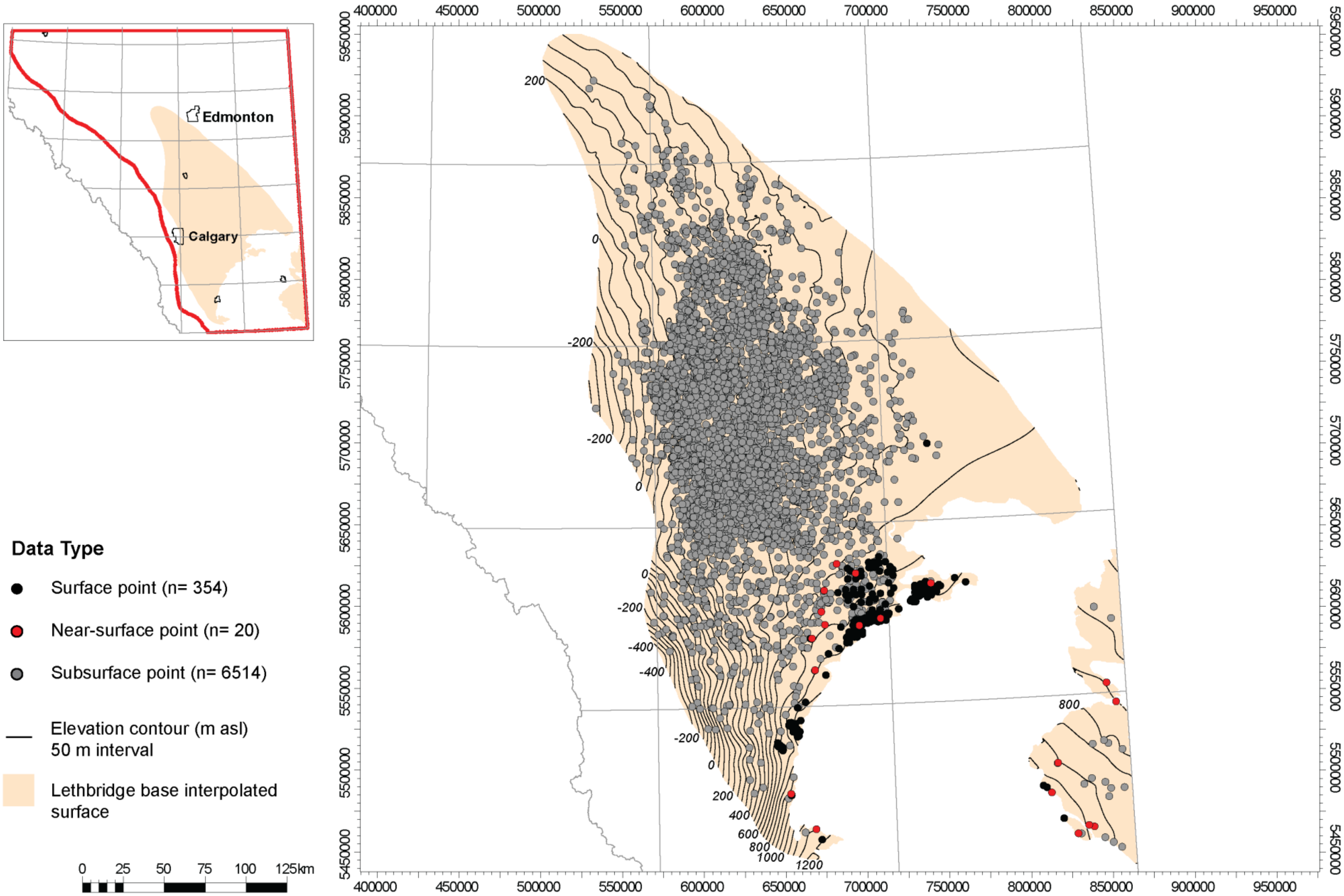

Figure 23. Data distribution for Lethbridge base interpolated surface.

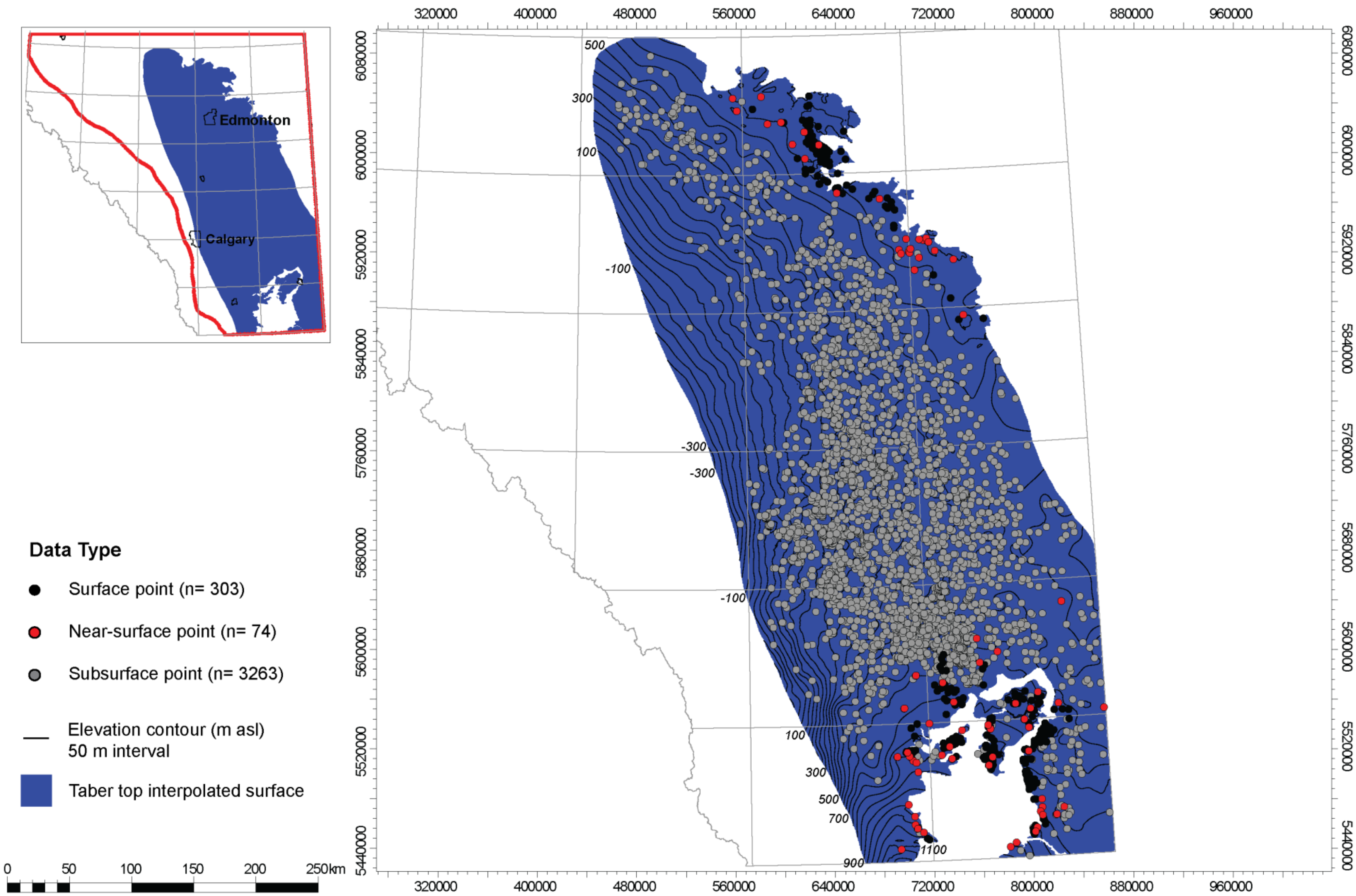

Figure 24. Data distribution for Taber top interpolated surface.

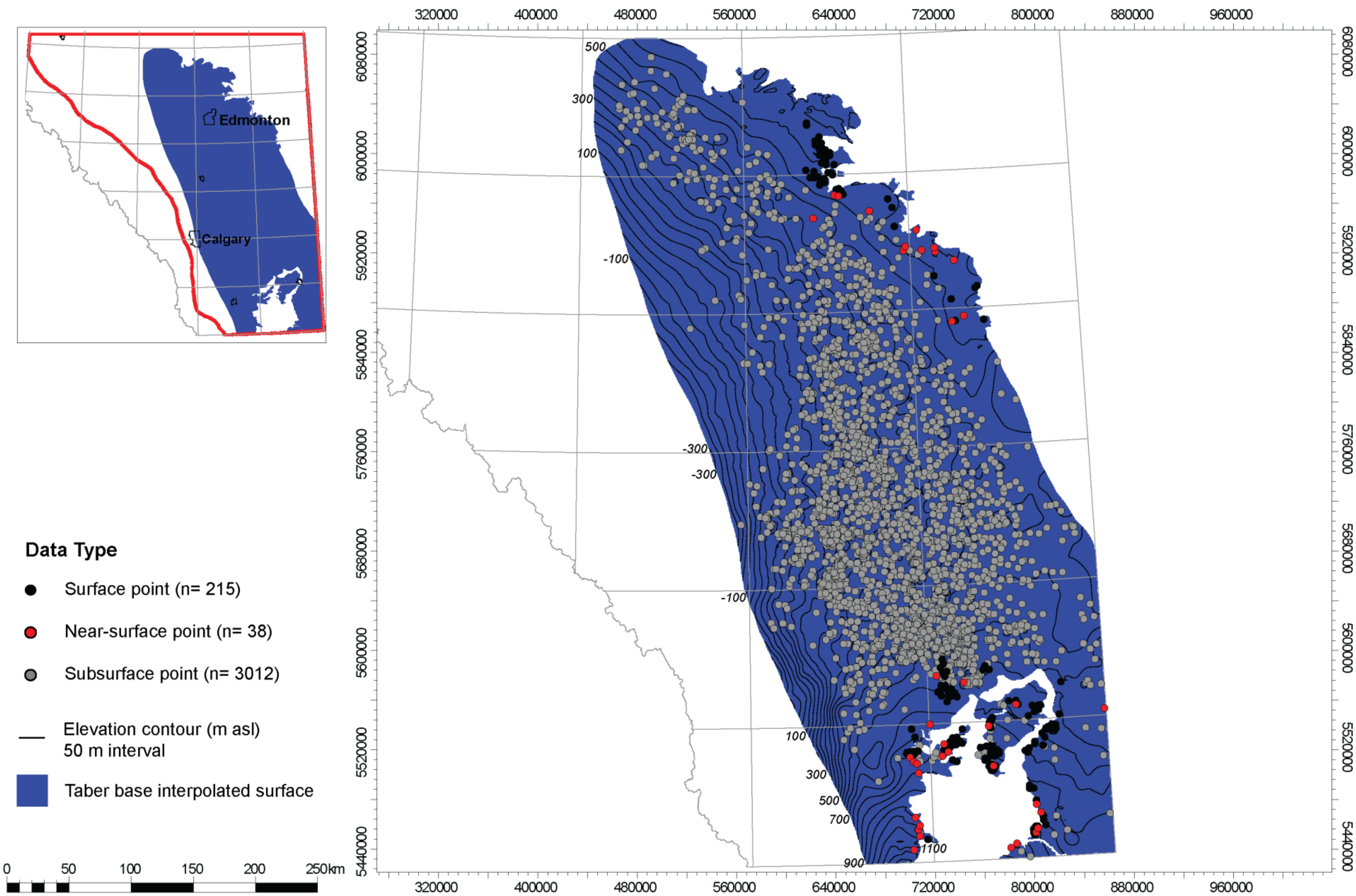

Figure 25. Data distribution for Taber base interpolated surface.

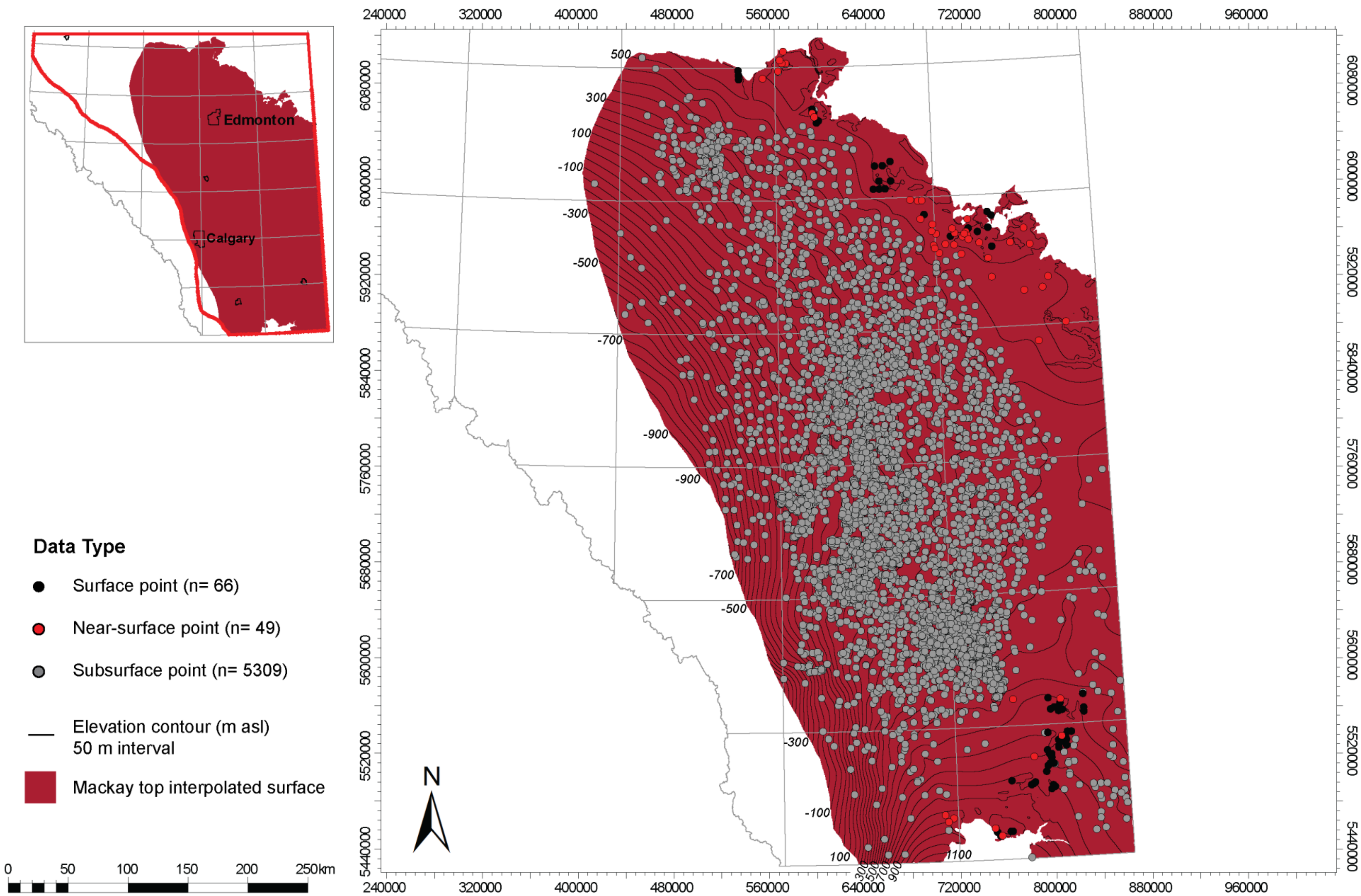

Figure 26. Data distribution for Mackay top interpolated surface.

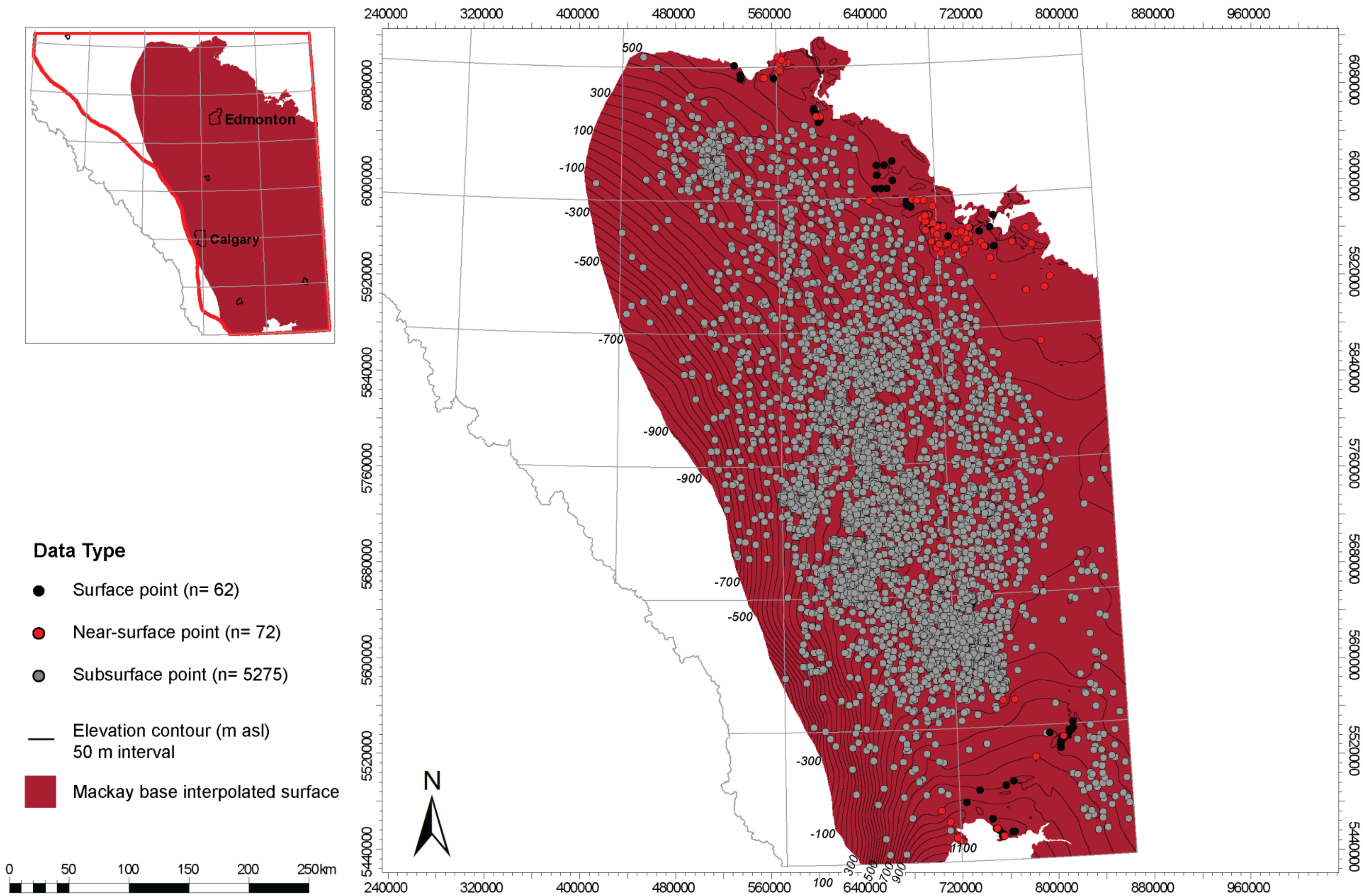

Figure 27. Data distribution for Mackay base interpolated surface.

Appendix 2 − Uncertainty Maps

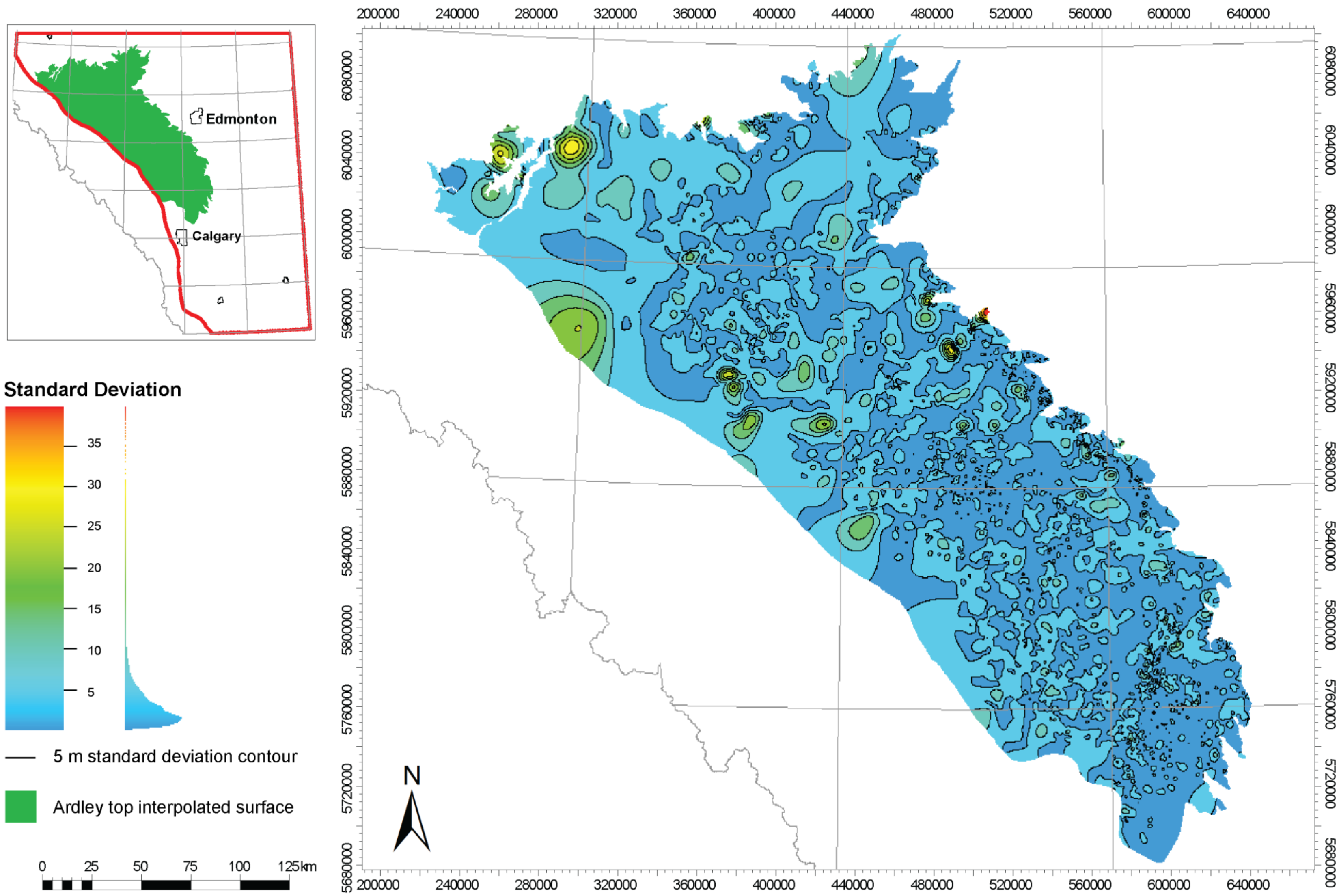

Figure 28. Uncertainty map for Ardley top interpolated surface.

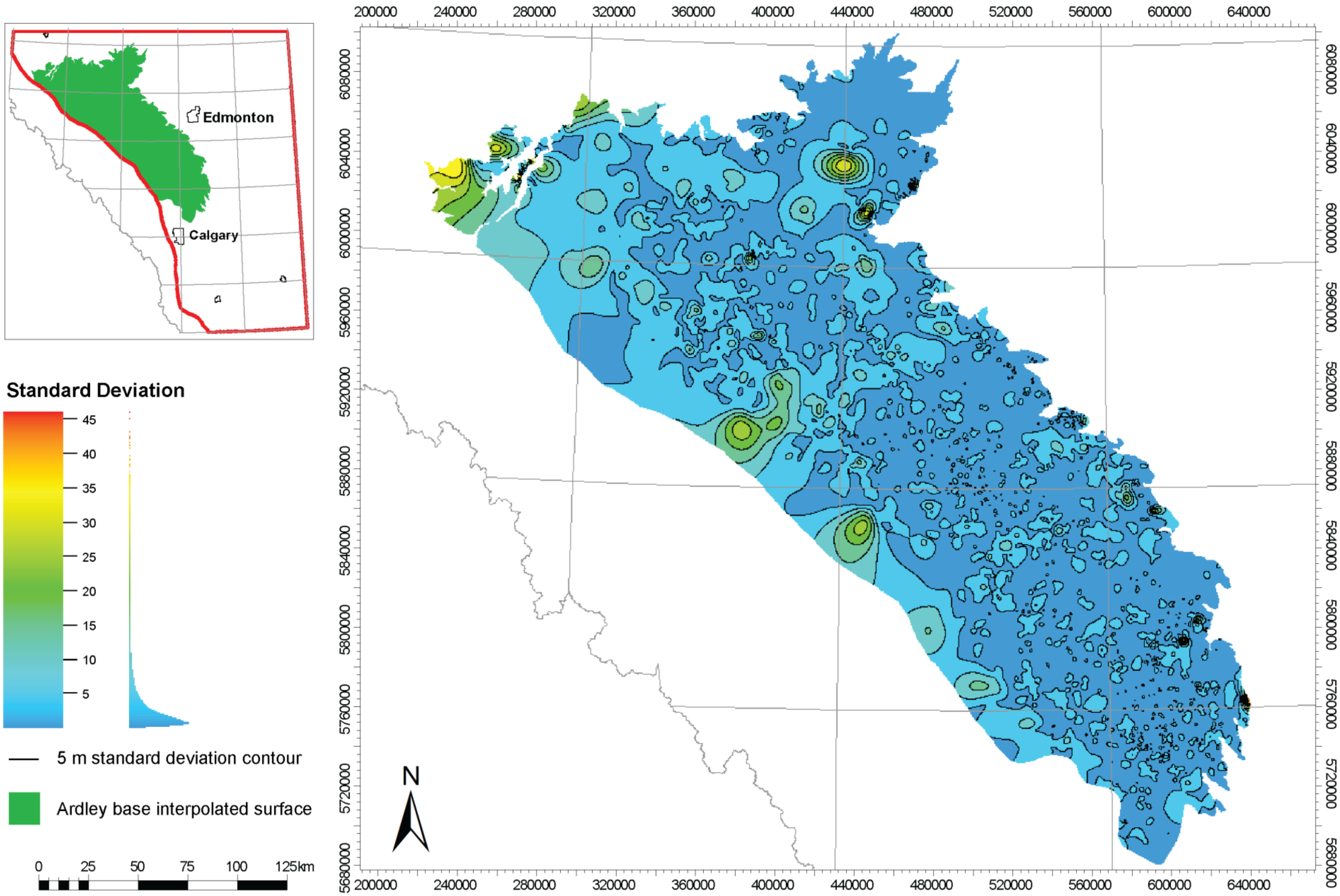

Figure 29. Uncertainty map for Ardley base interpolated surface.

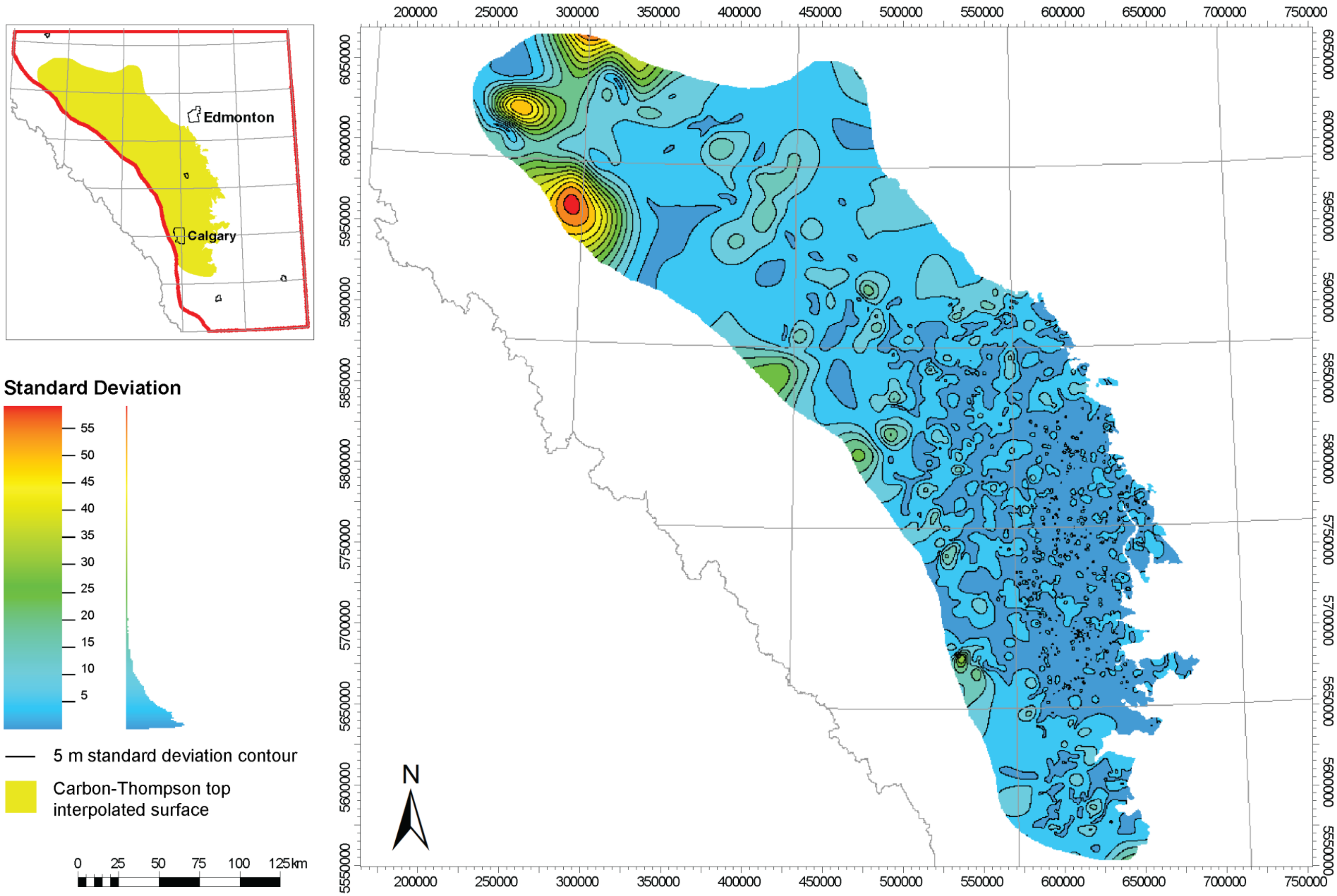

Figure 30. Uncertainty map for Carbon-Thompson top interpolated surface.

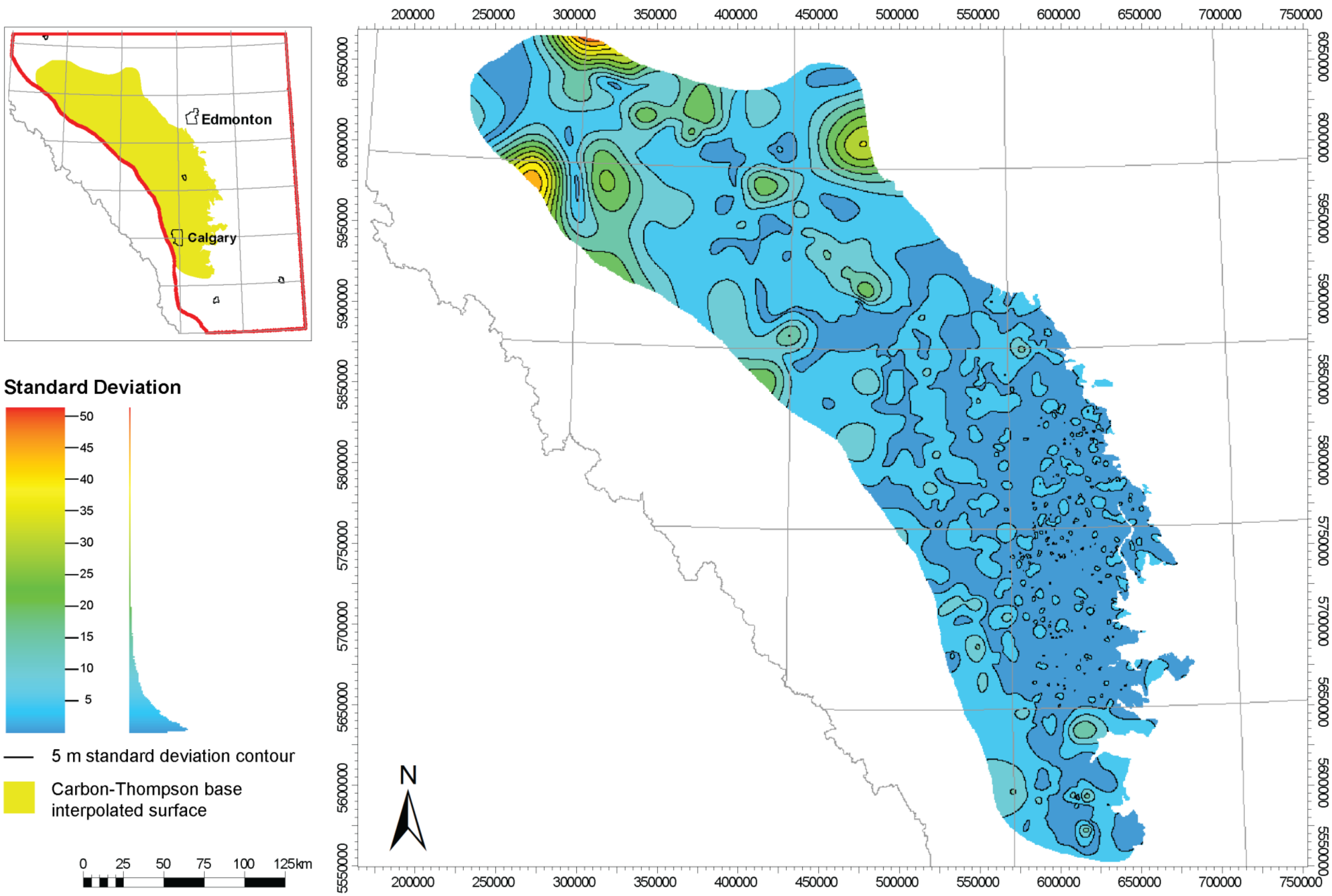

Figure 31. Uncertainty map for Carbon-Thompson base interpolated surface.

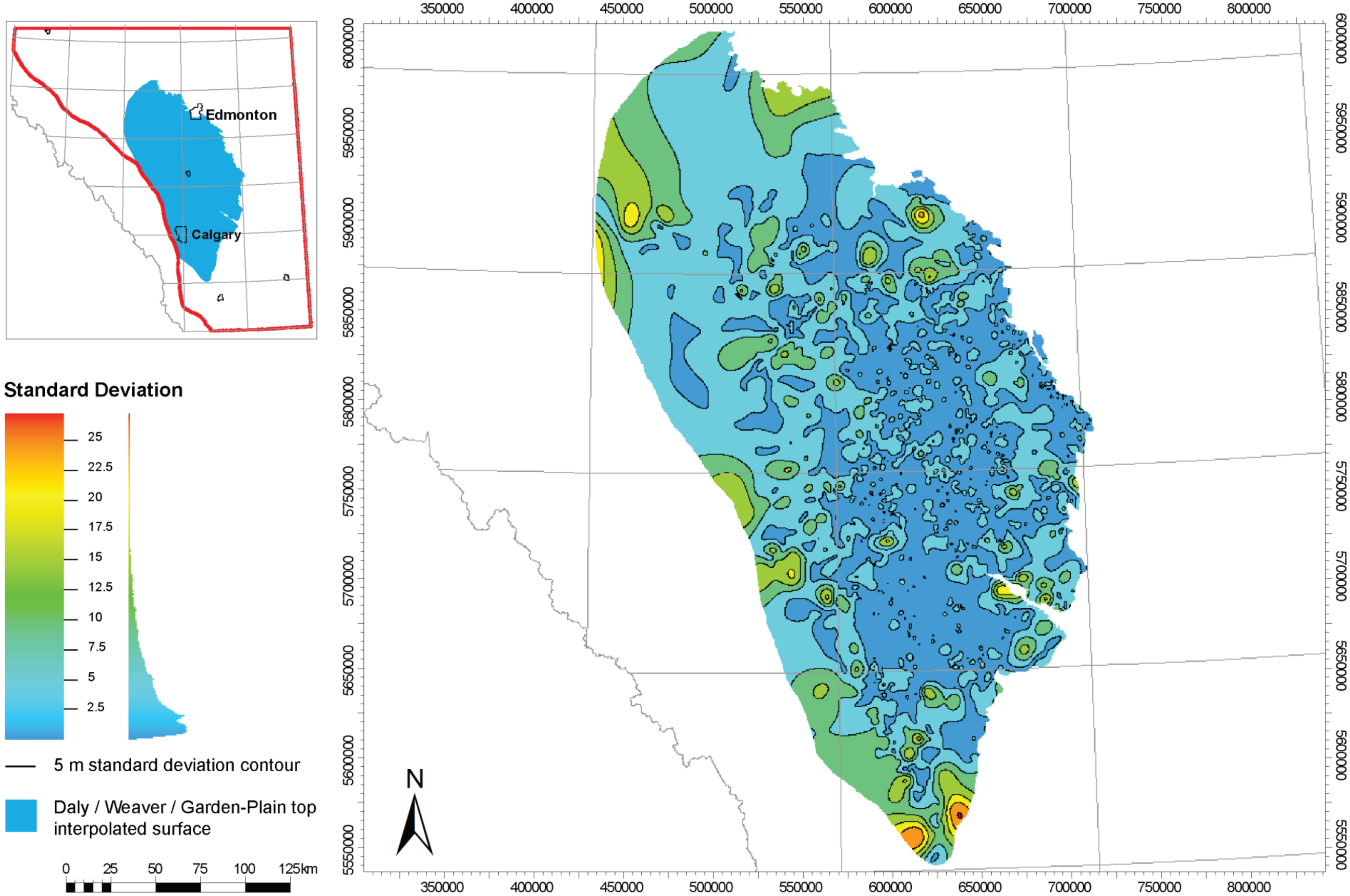

Figure 32. Uncertainty map for Daly / Weaver / Garden-Plain top interpolated surface.

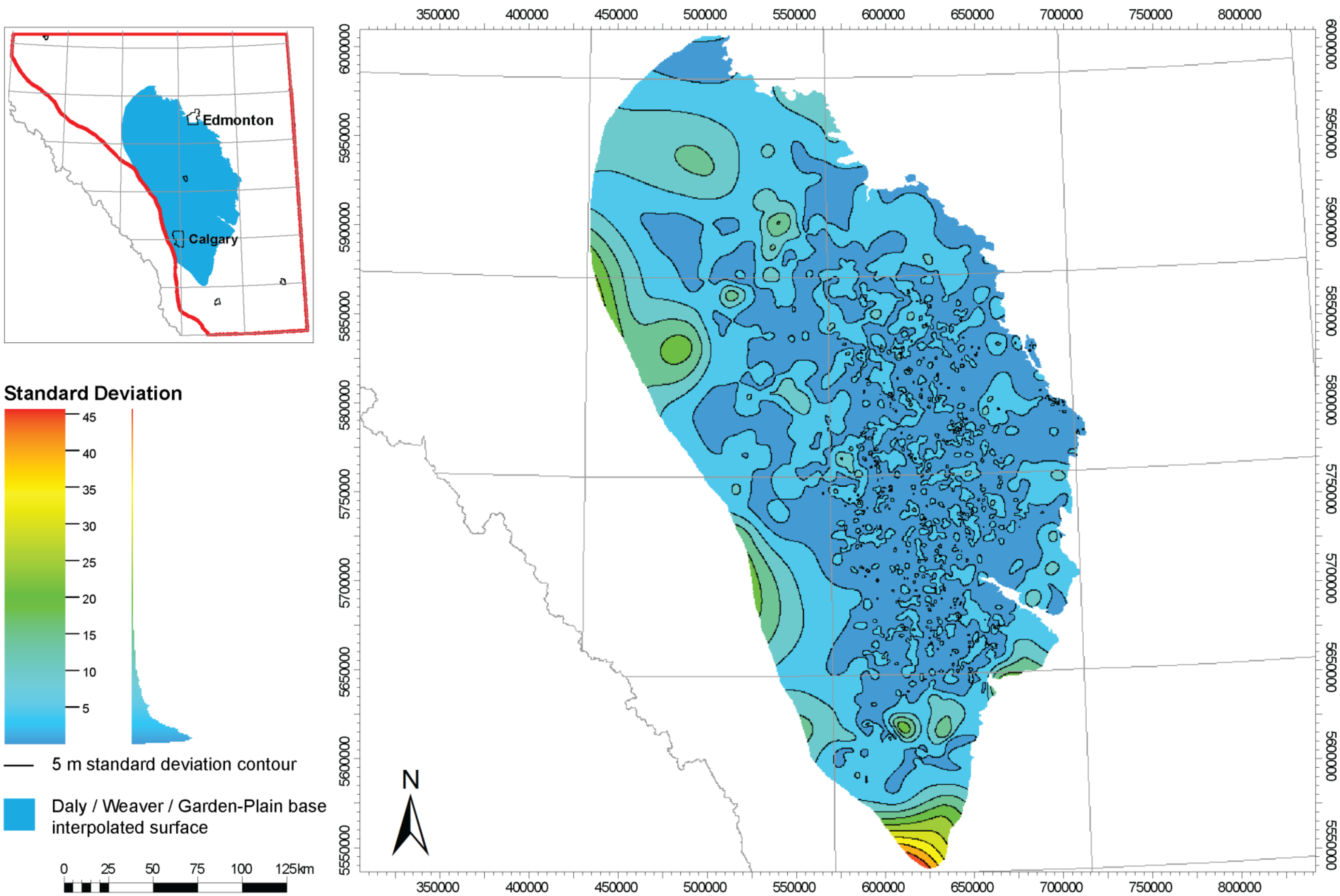

Figure 33. Uncertainty map for Daly / Weaver / Garden-Plain base interpolated surface.

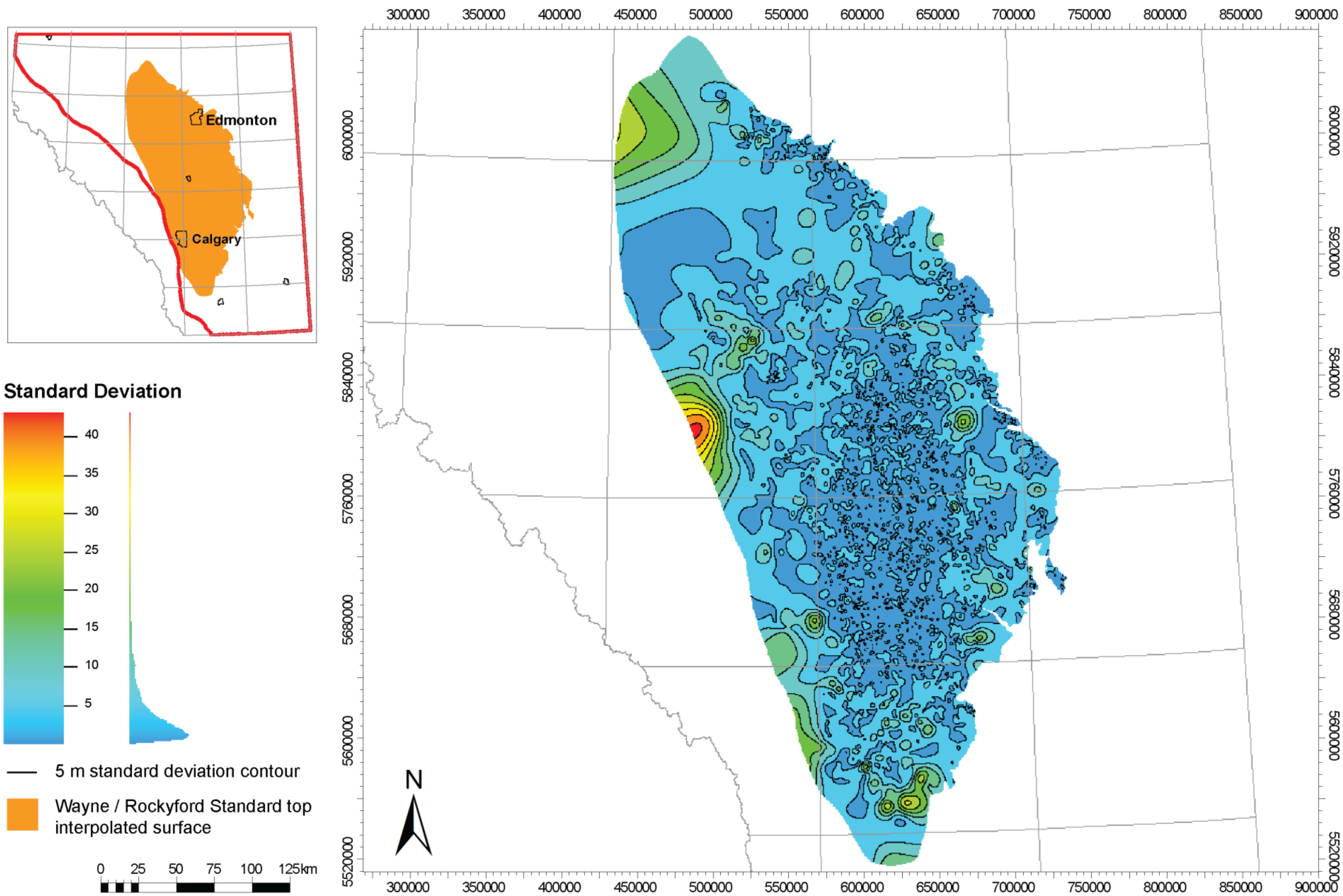

Figure 34. Uncertainty map for Wayne / Rockyford Standard top interpolated surface.

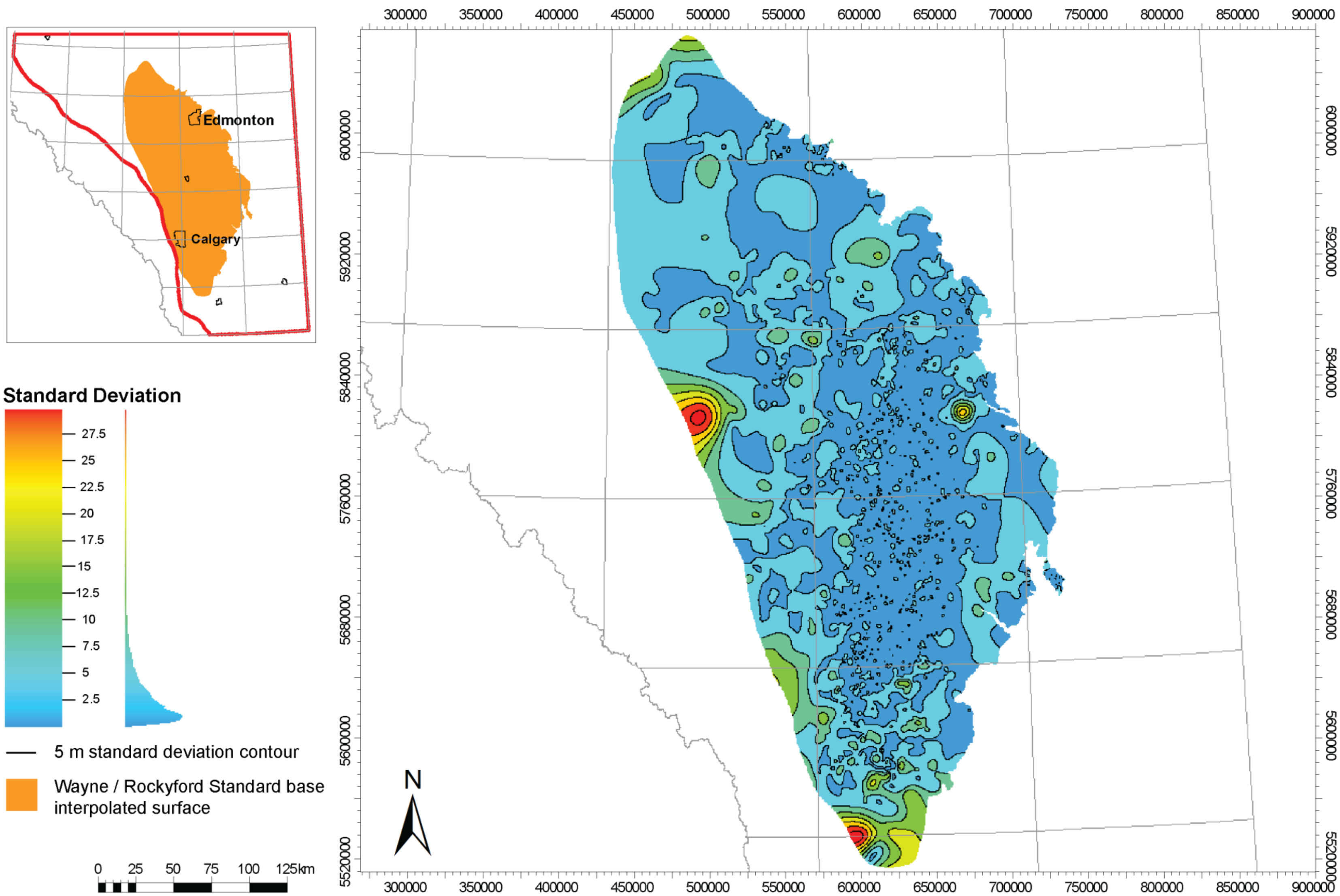

Figure 35. Uncertainty map for Wayne / Rockyford Standard base interpolated surface.

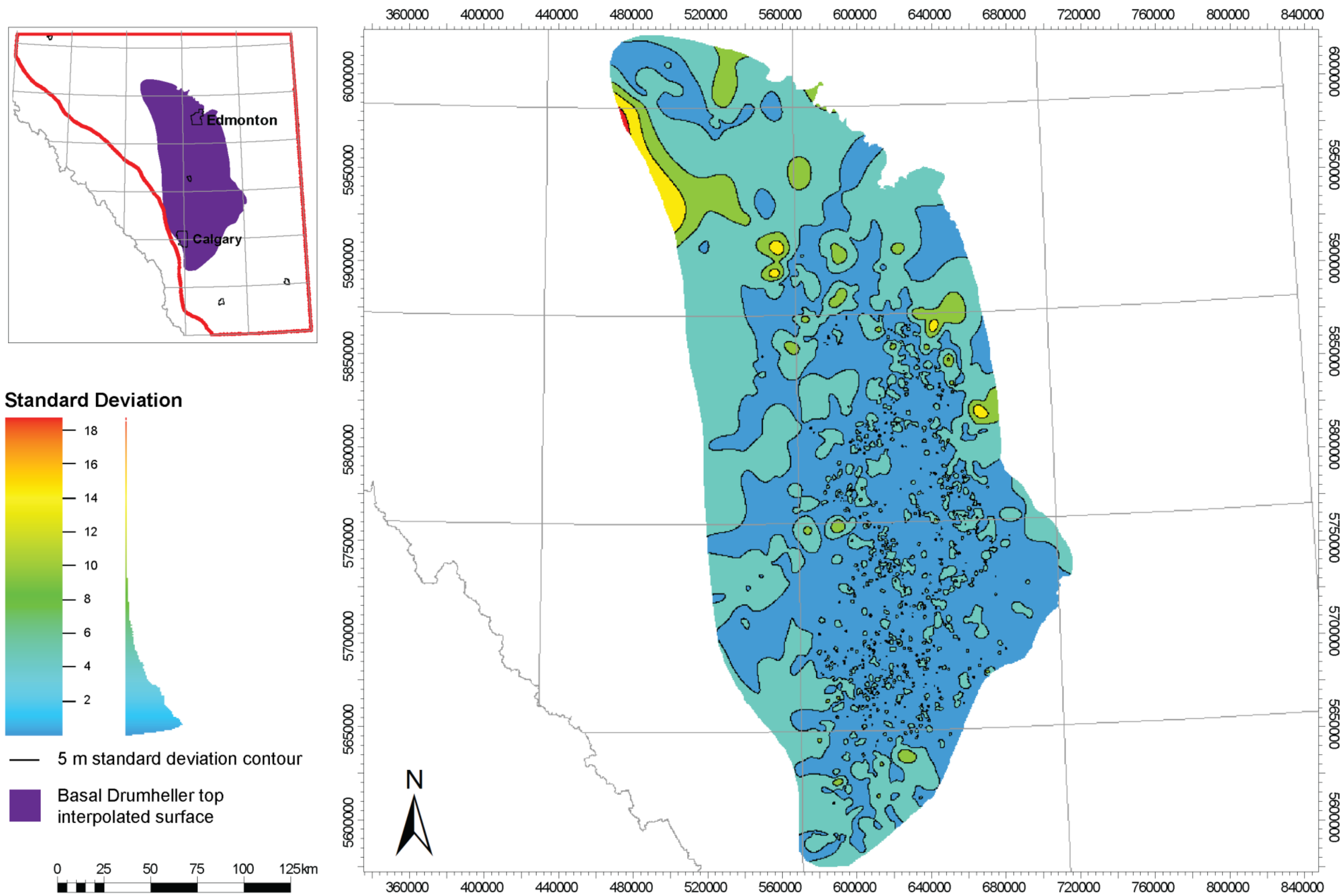

Figure 36. Uncertainty map for Basal Drumheller top interpolated surface.

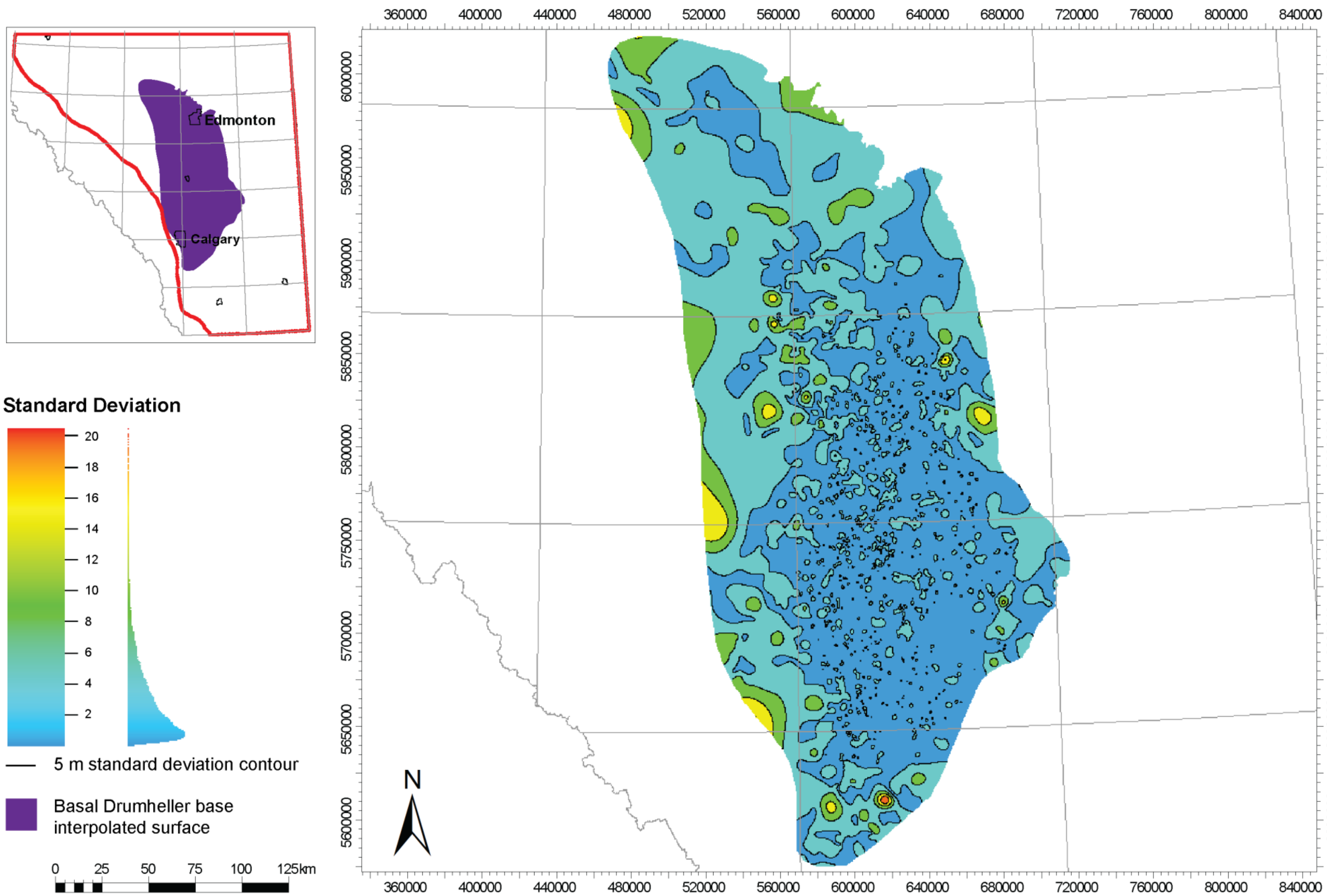

Figure 37. Uncertainty map for Basal Drumheller base interpolated surface.

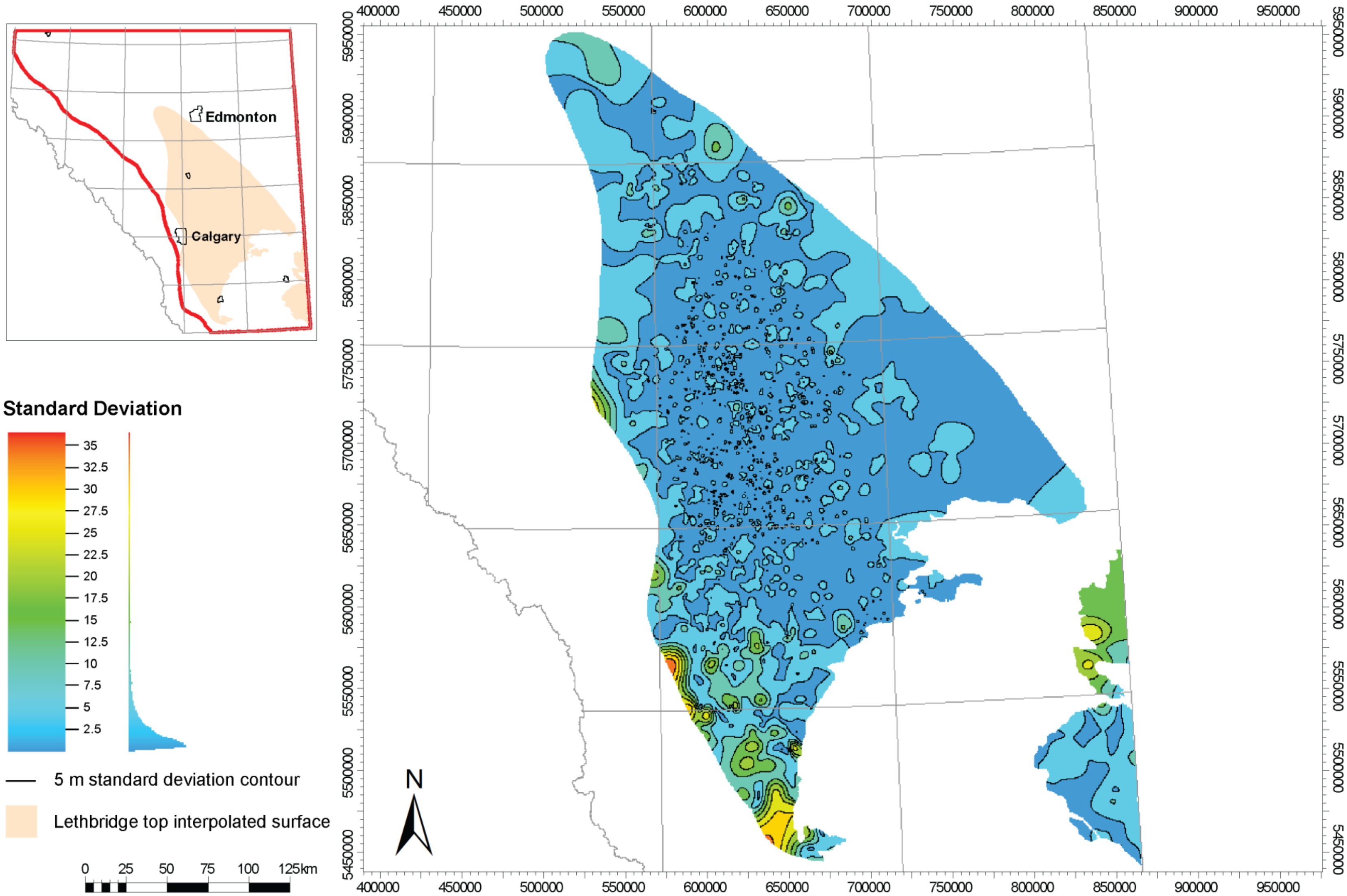

Figure 38. Uncertainty map for Lethbridge top interpolated surface.

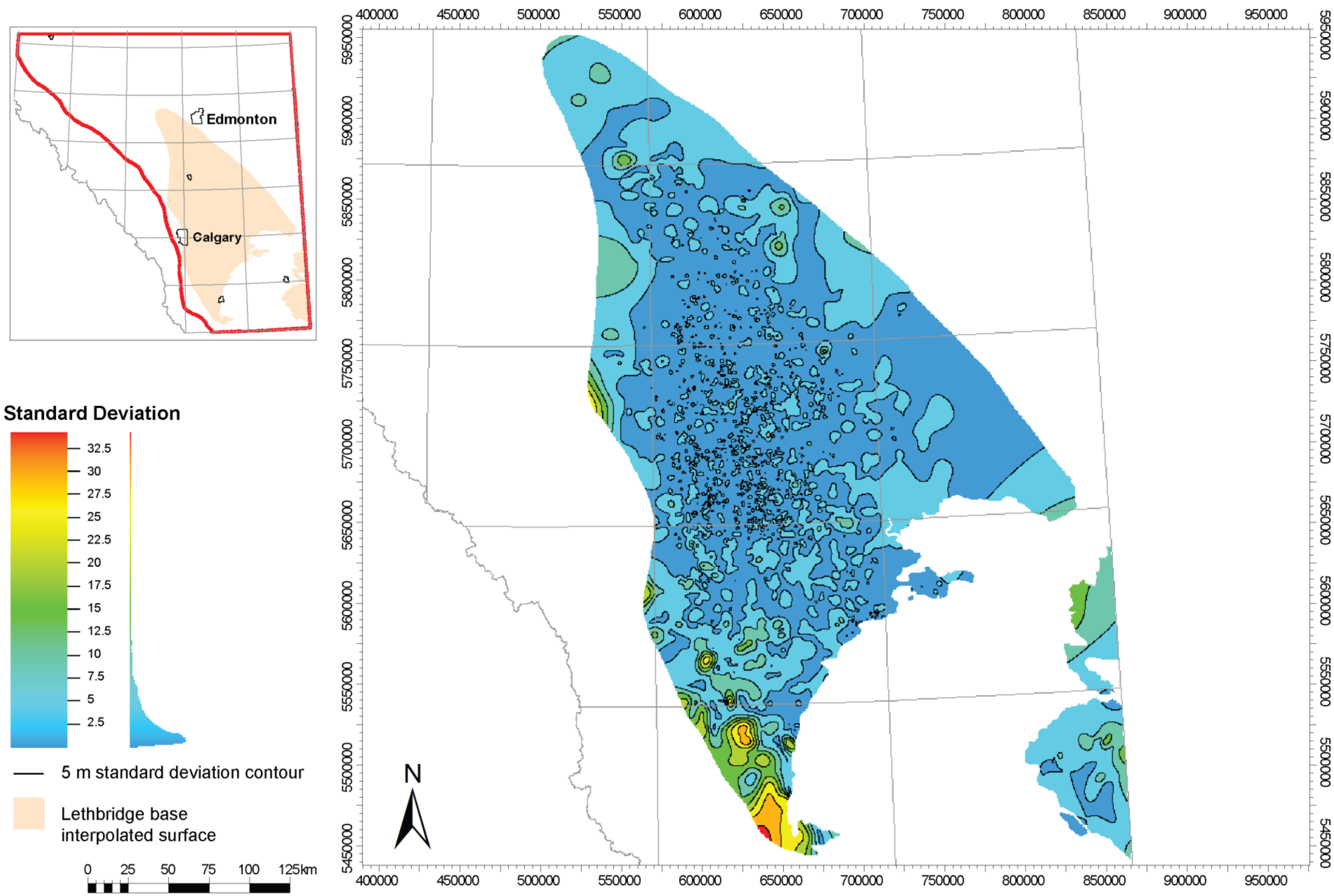

Figure 39. Uncertainty map for Lethbridge base interpolated surface.

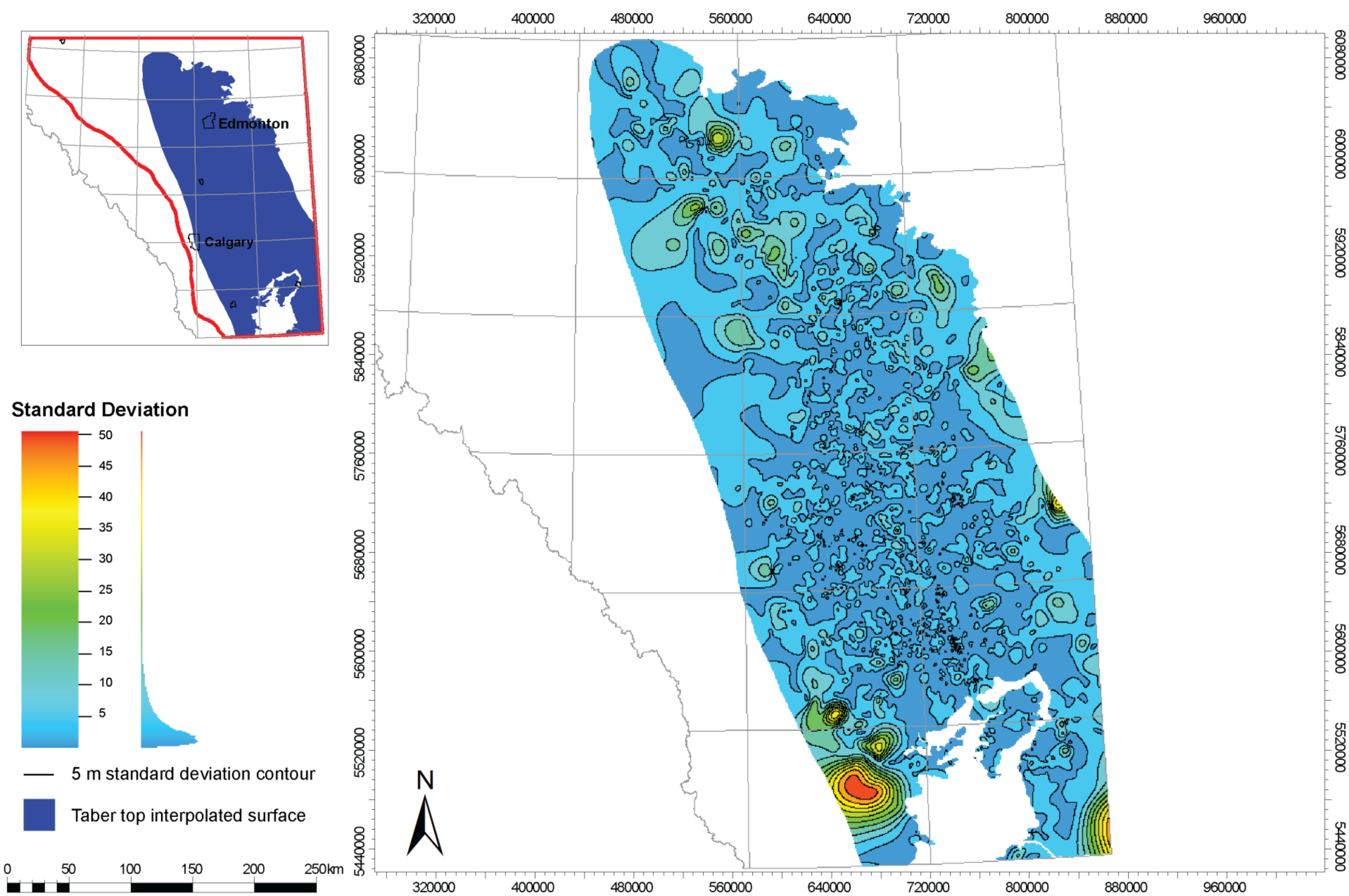

Figure 40. Uncertainty map for Taber top interpolated surface.

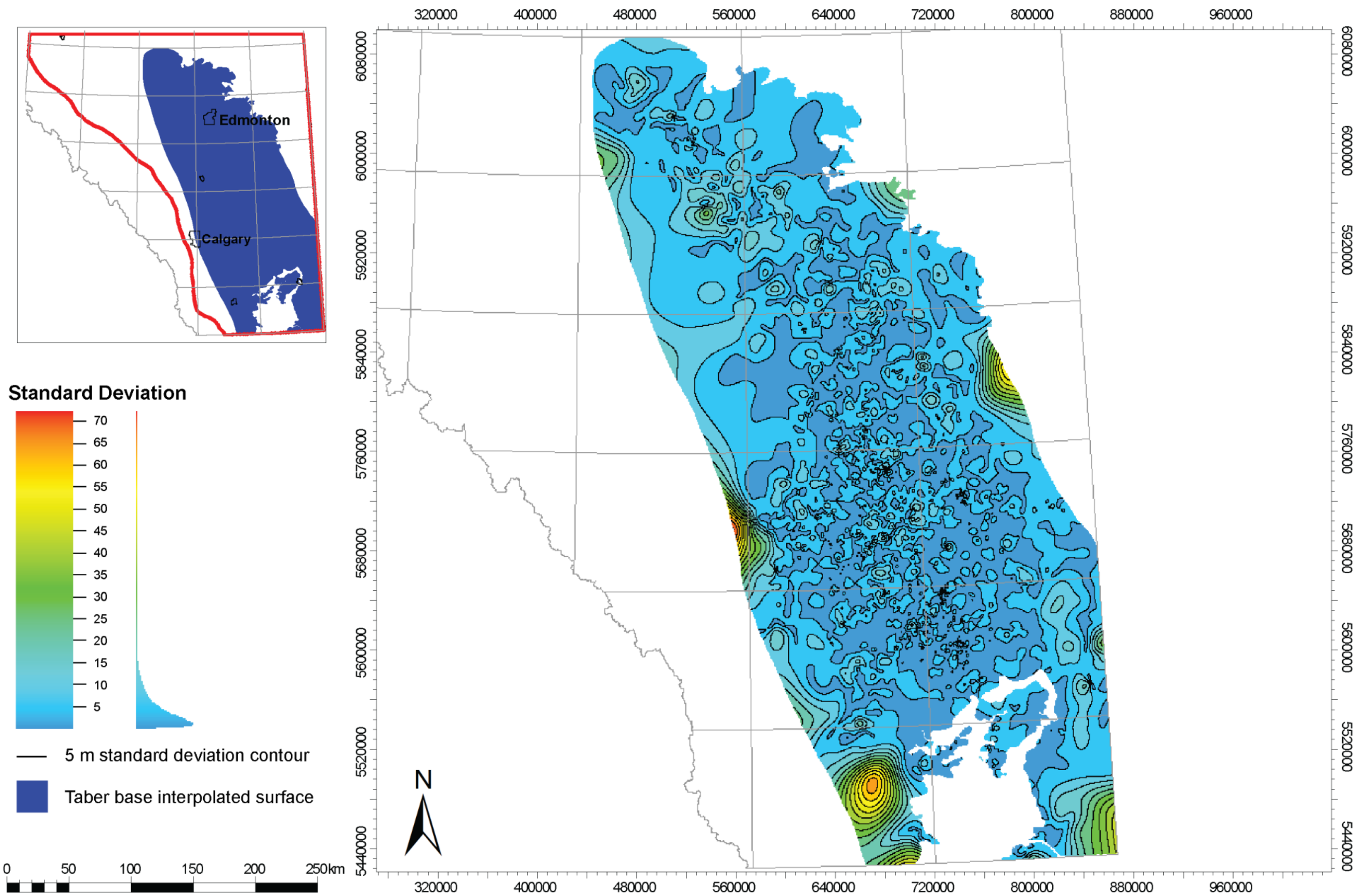

Figure 41. Uncertainty map for Taber base interpolated surface.

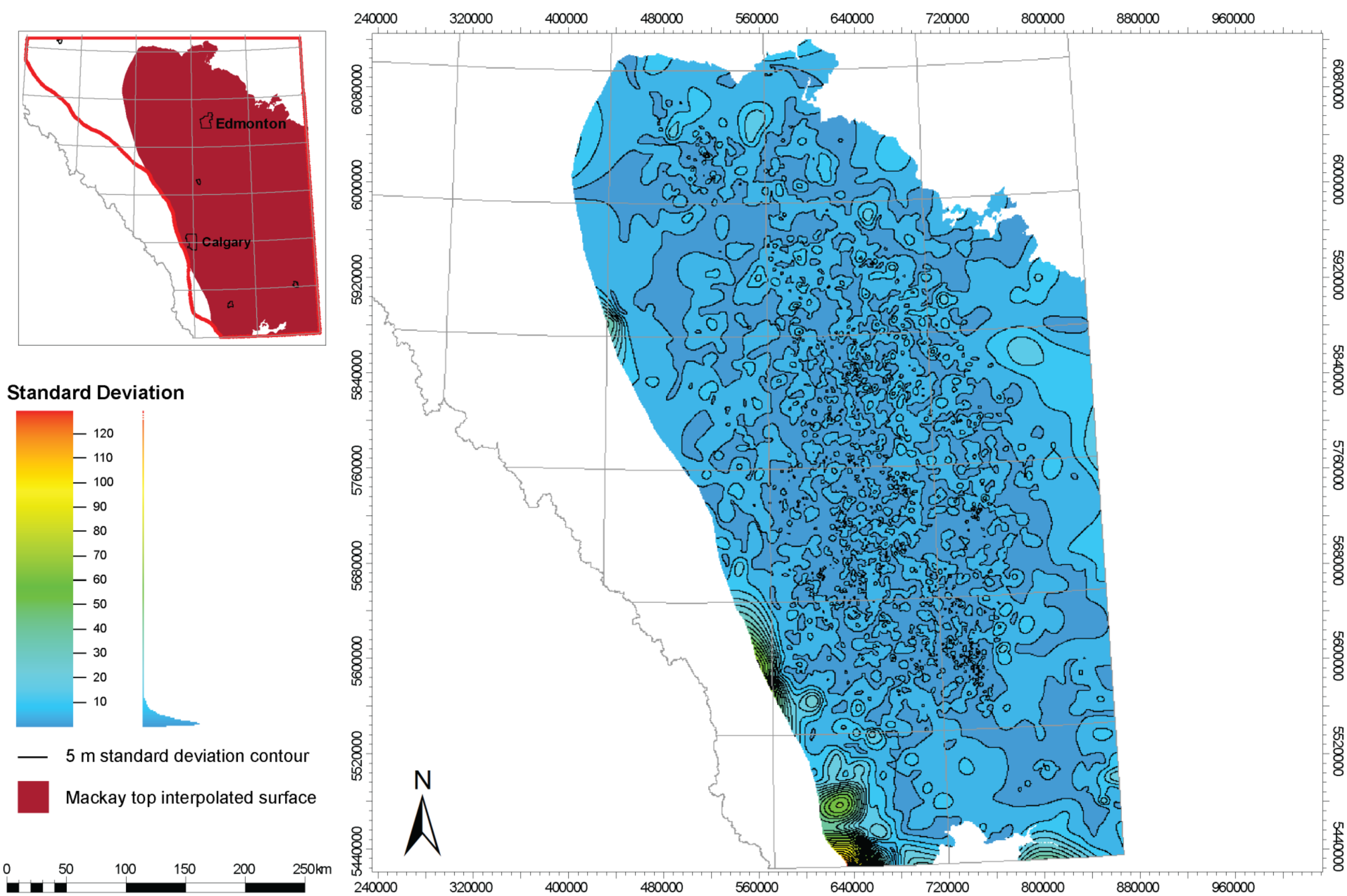

Figure 42. Uncertainty map for Mackay top interpolated surface.

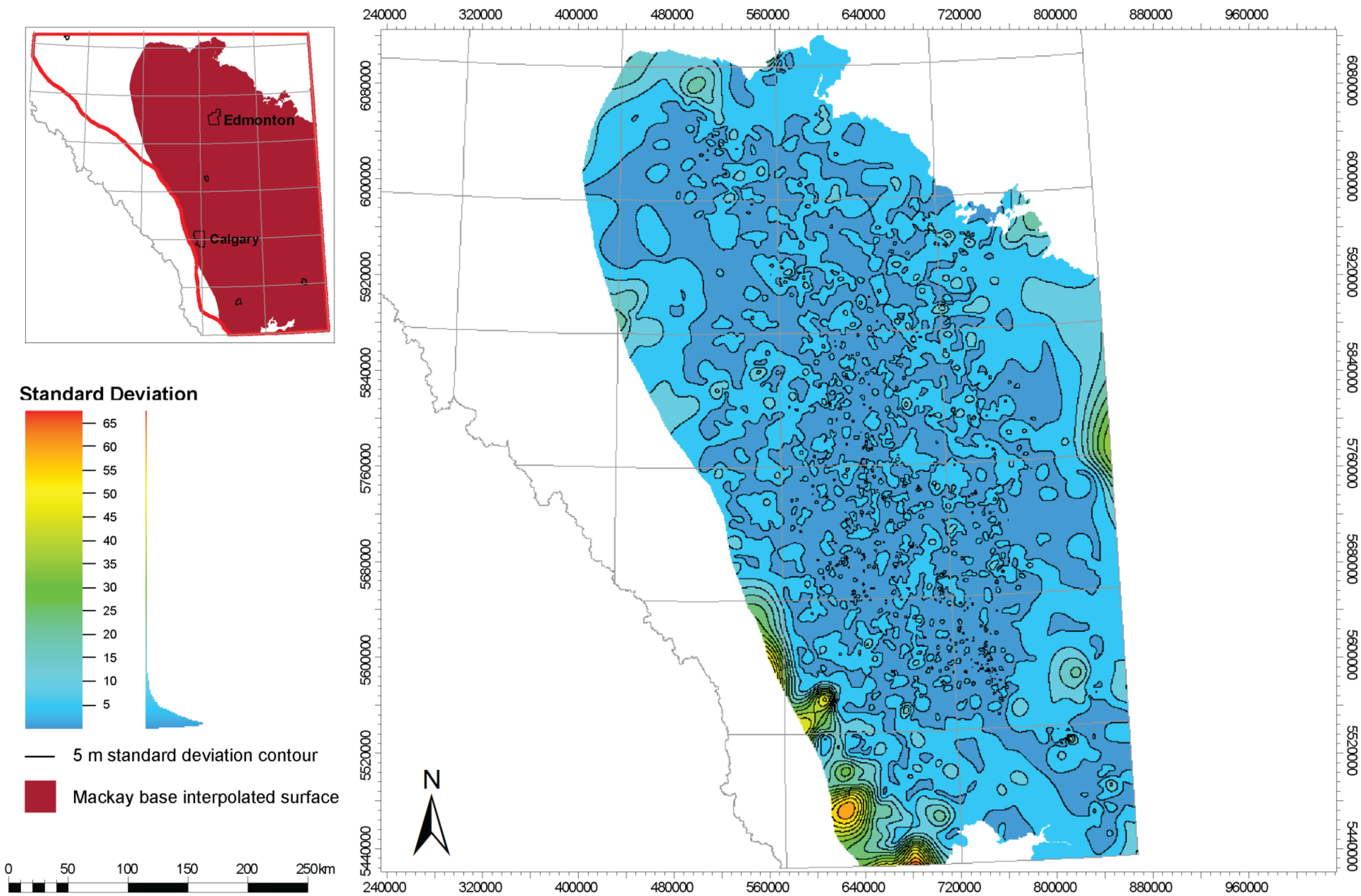

Figure 43. Uncertainty map for Mackay base interpolated surface.

Appendix 3 − Oblique Views of Model Zones

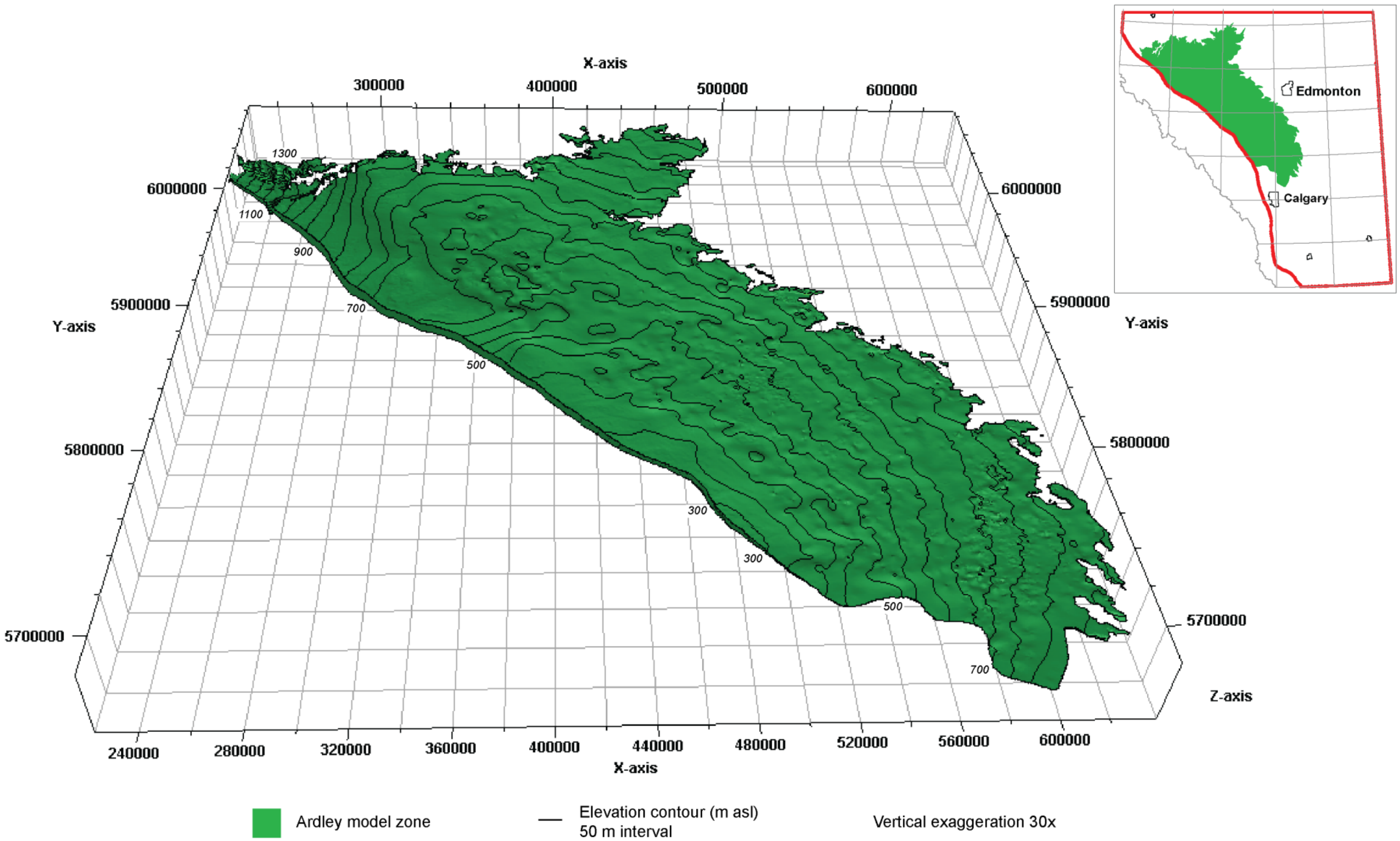

Figure 44. Oblique view of the Ardley model zone.

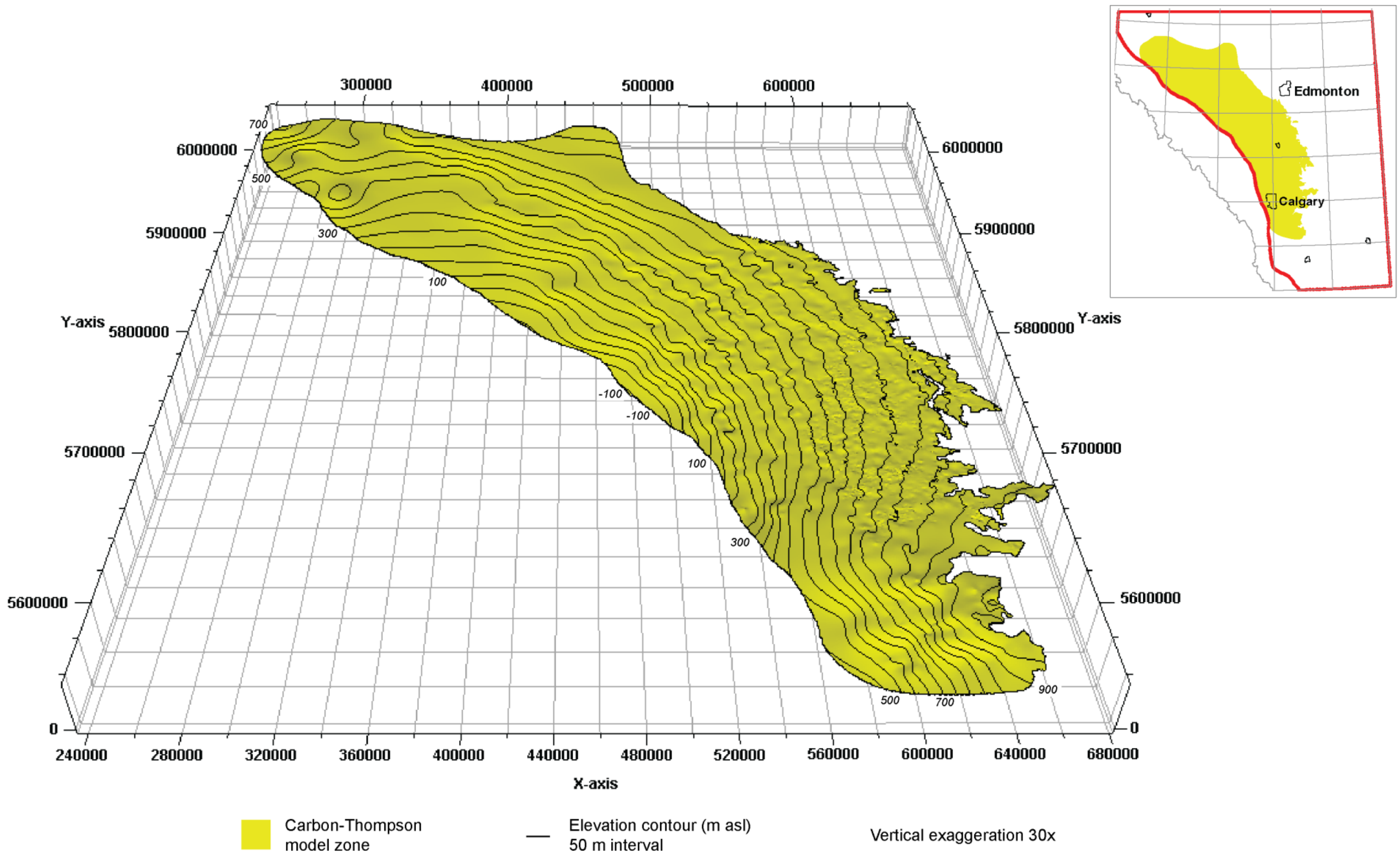

Figure 45. Oblique view of the Carbon-Thompson model zone.

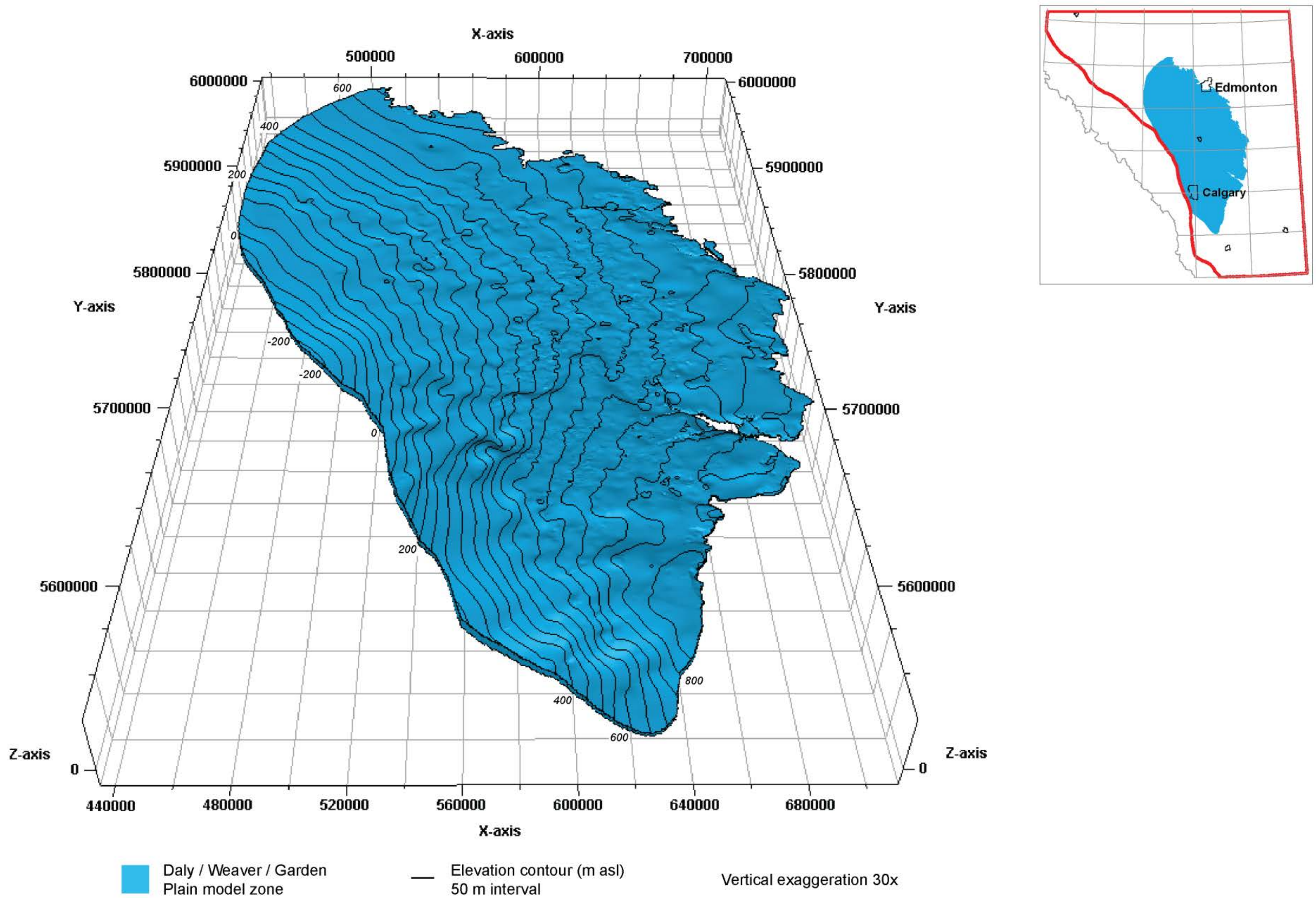

Figure 46. Oblique view of the Daly / Weaver / Garden Plain model zone.

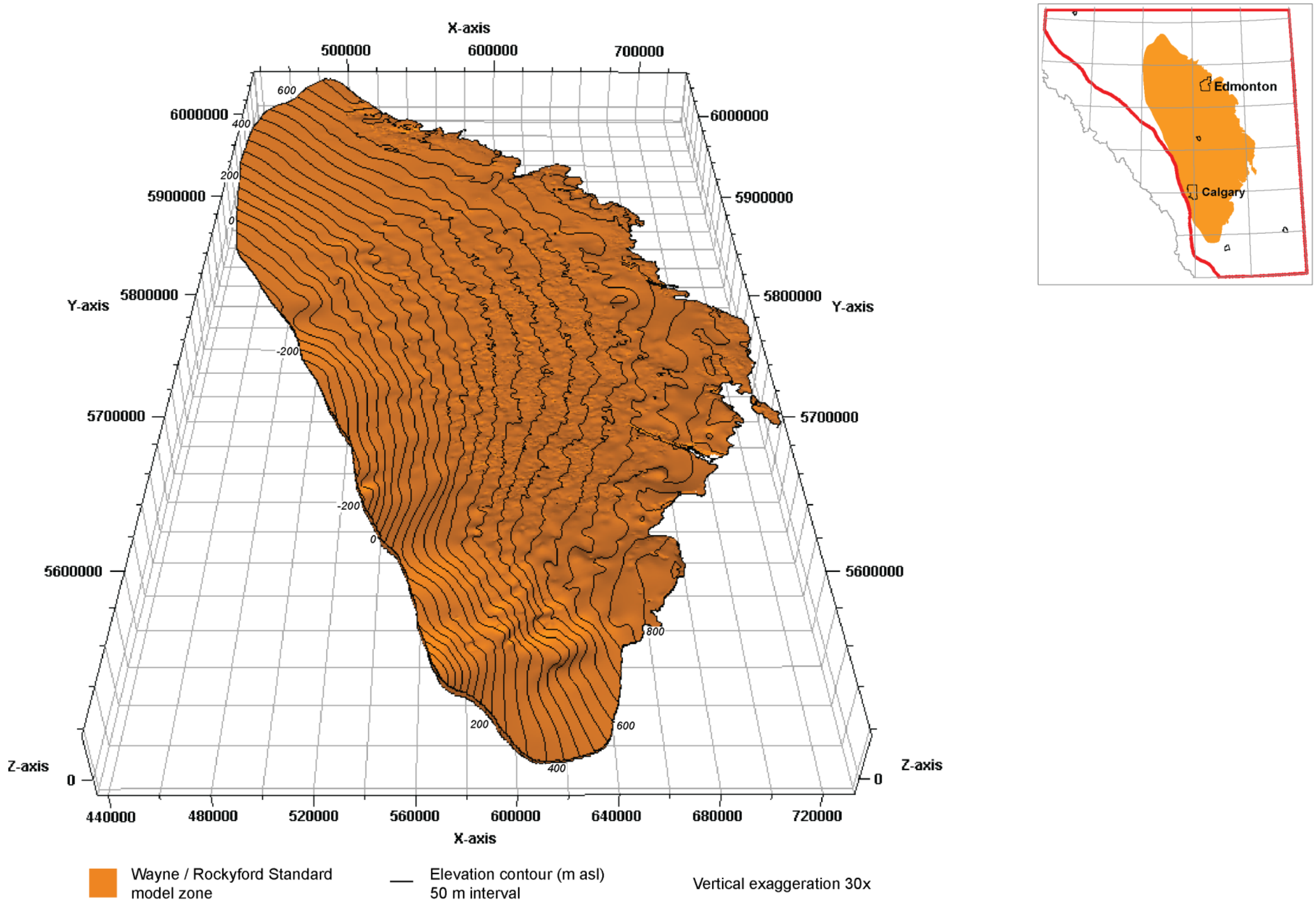

Figure 47. Oblique view of the Wayne / Rockyford Standard model zone.

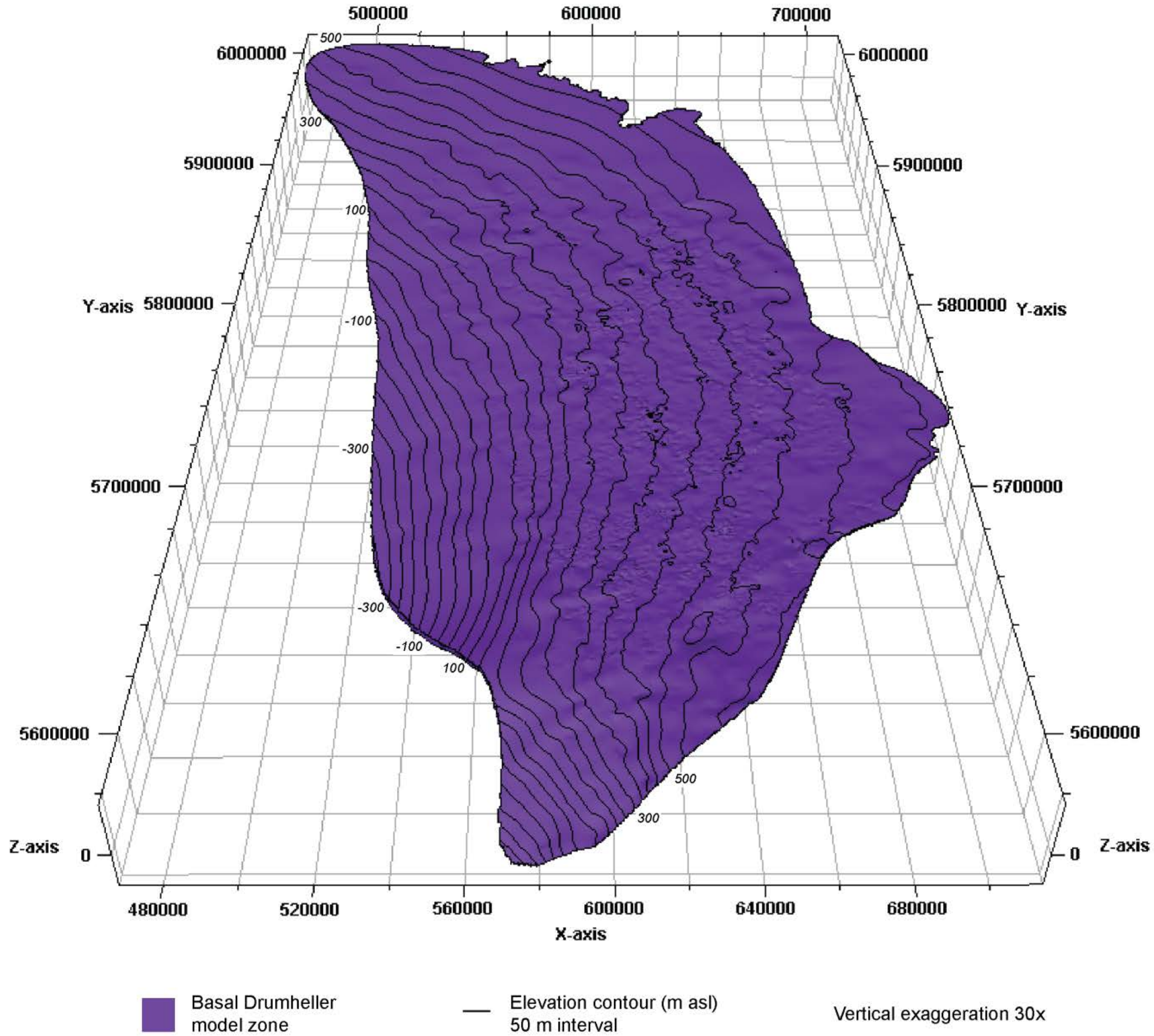

Figure 48. Oblique view of the Basal Drumheller model zone.

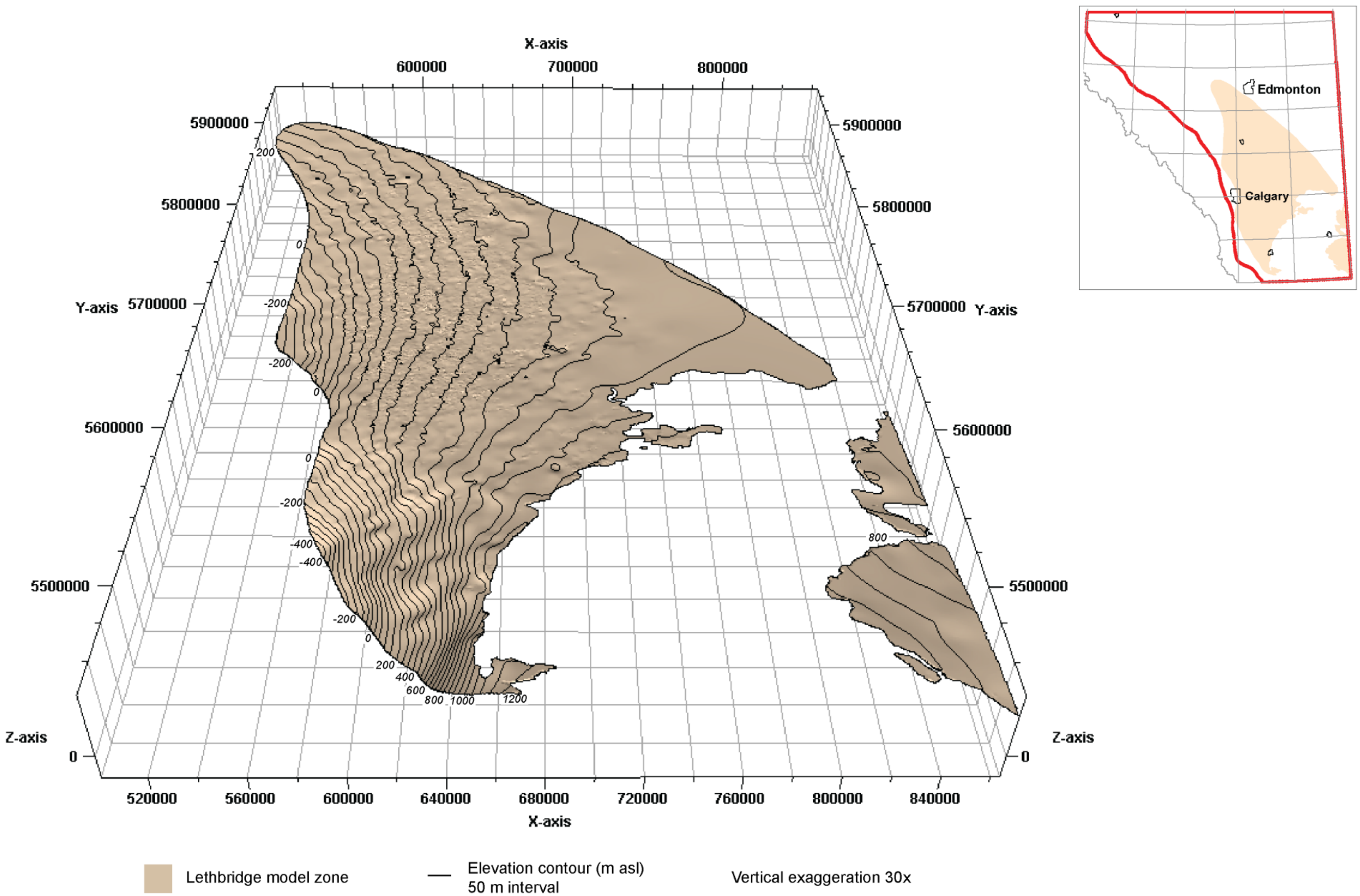

Figure 49. Oblique view of the Lethbridge model zone.

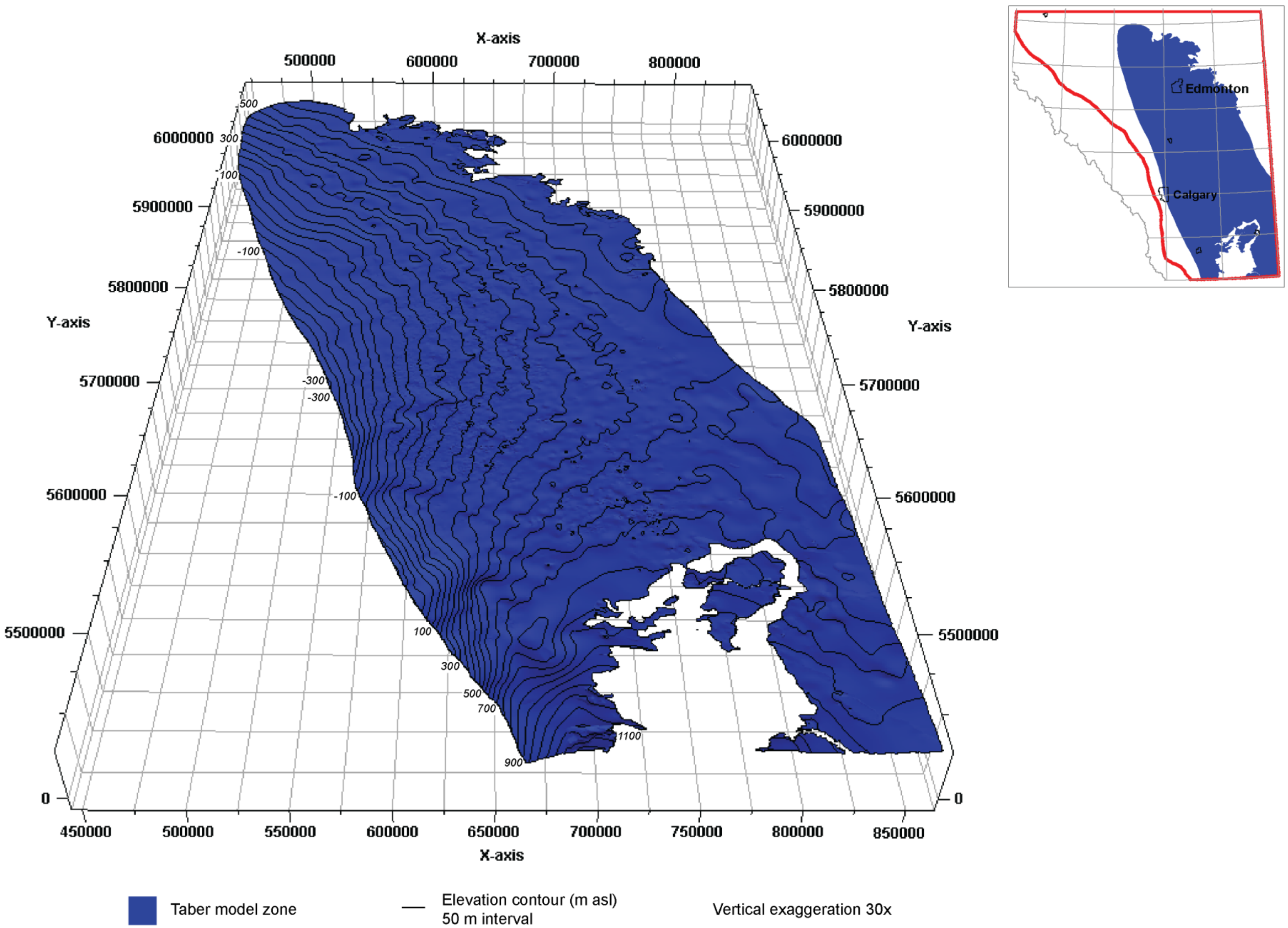

Figure 50. Oblique view of the Taber model zone.

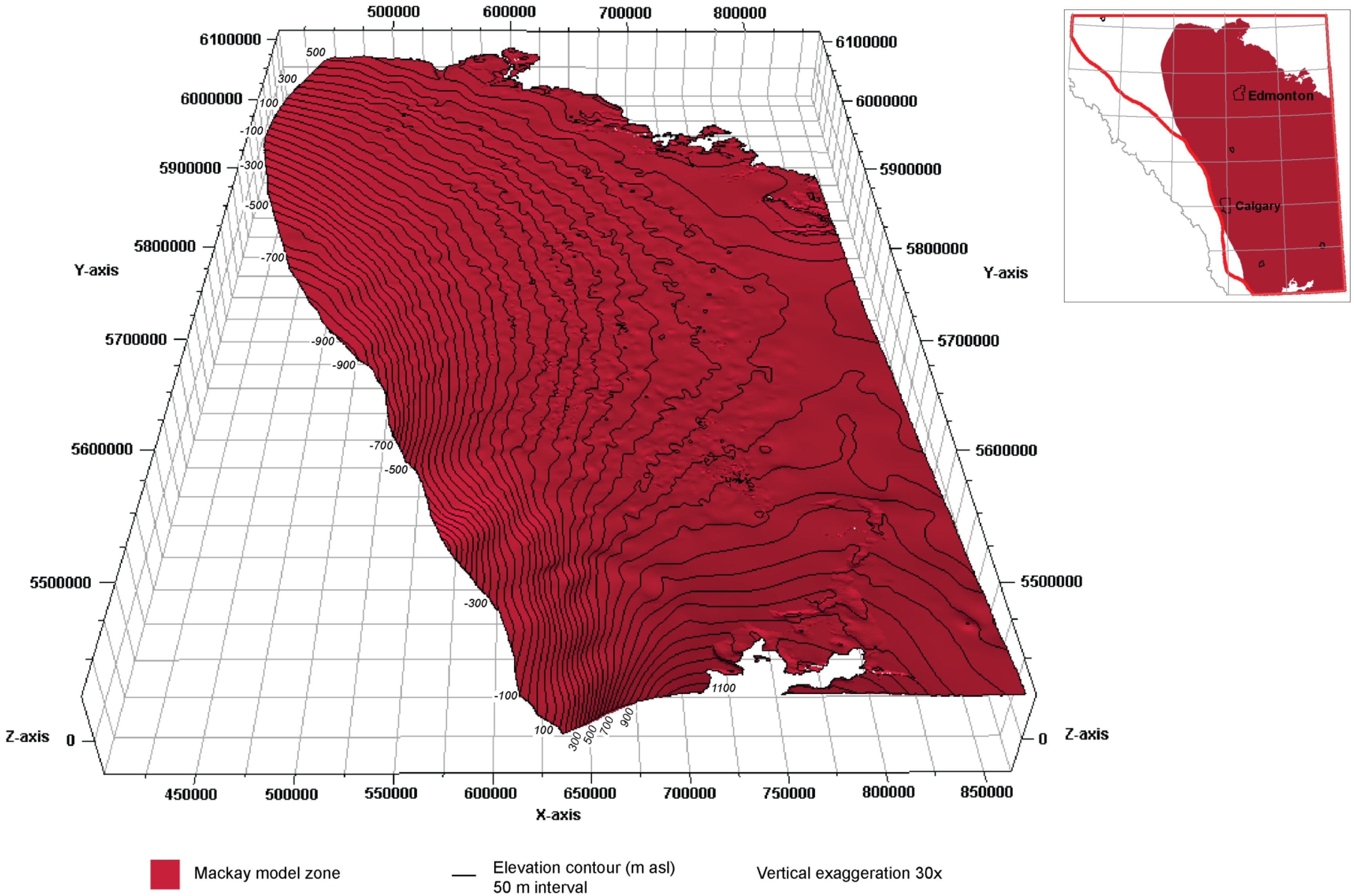

Figure 51. Oblique view of the Mackay model zone.