Alberta Energy Regulator | AGS Alberta Geological Survey

Alberta Geological Survey Map 602

Bedrock Topography of Alberta

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www.ags.gov.ab.ca

Published 2015 ISBN 978-1-4601-0121-6

Alberta Geological Survey Map 602 Explanatory Notes

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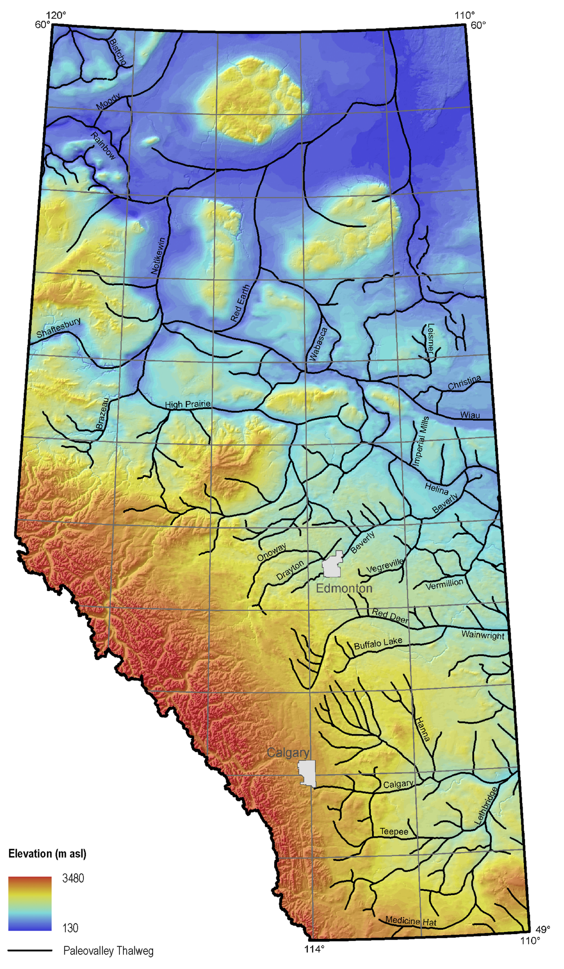

Figure 1. Bedrock paleovalley systems and thalwegs across the Alberta Plains.

Introduction

This map represents a geostatistical model of the bedrock topography of Alberta and updates AGS Map 550 (Atkinson and Lyster, 2010). The bedrock topography of Alberta is the surface between the top of Upper Cretaceous and Paleogene bedrock and the modern land surface, and reveals geomorphic features created by Paleogene to Recent river systems as well as the advance and retreat of the Laurentide and Cordilleran ice sheets during Quaternary glaciation. The bedrock surface in Alberta is covered by a variable thickness of sediment ranging from less than 1 m, where bedrock occurs at the modern land surface, to greater than 350 m along the axes of infilled paleovalleys (Figure 1). Establishing depth to bedrock is important for drilling operations and for delineating infilled paleovalleys, which often contain sand and gravel deposits that have aquifer or aggregate resources potential. The province of Alberta occupies approximately 662 000 km^2 within the Interior Plains of western Canada, with small components of the Canadian Shield and Western Cordillera in the northeast and southwest respectively. Alberta is bounded to the south by the state of Montana along the 49th parallel, and to the north by the Northwest Territories along the 60th parallel. To the east, Alberta borders Saskatchewan along the 110th meridian, and to the west, its border with British Columbia follows the 120th meridian until the Continental Divide, which extends south into Montana. The surface topography of Alberta is characterized by five major physiographic regions: lowlands (275–750 metres above sea level [m asl]), plains (450–1100 m asl), uplands (350–1650 m asl), foothills (1200–2000 m asl) and mountains (1200–3400 m asl; Pettapiece, 1986; Figure 1).

Interpretation

Atkinson and Lyster (2010) classified the major bedrock terrain elements within Alberta as: lowlands, plains, uplands, and paleovalley systems. This map provides a new and refined provincial-scale interpretation that improves our understanding of the distribution and topography of these bedrock terrain elements.

Bedrock Lowlands

The bedrock lowlands terrain element spans northern Alberta and is characterized by a gently undulating, low-relief bedrock surface ranging from 165 to 850 m asl. The physiography of the modern Alberta landscape across the Fort Nelson (E1), Vermilion (E2), McMurray (E3), Peace River (E4), and western Wabasca (E5) lowlands, and the Harrison River, Great Slave, and Delta plains (B1, C1, and C2, respectively) is largely dictated by the topography of these bedrock lowlands (Figure 2). Exceptions to the spatial relationship between bedrock topography and the physiography of the Northern Alberta Lowlands occur in areas underlain by dissected bedrock plain, such as the central Wabasca Lowland (E5) or along the axes of prominent paleovalley systems which cross the Fort Nelson and Vermilion lowlands (E1 and E2, respectively). Recent valleys that extend into Cretaceous units, notably along the Peace, Smoky, Athabasca, and Clearwater rivers, represent an additional topographic feature across these bedrock lowlands.

Bedrock Plains

The bedrock plains terrain element occurs in parts of southern, central, and northeastern Alberta. In southern and central Alberta, the bedrock plains comprise a gently undulating slope that rises westward from 400 m asl to the transition with the bedrock uplands terrain element at 700 m asl. The physiography of the modern land surface in the eastern and western parts of the Alberta Plains is primarily influenced by the topography of these bedrock plains (Pettapiece, 1986; Figure 2). In northeast Alberta, the bedrock plains comprise a low-lying, gently sloping surface that rises from 165 m asl in the east to 350 m asl in the west. The northern Alberta bedrock plains are incised by a regional system of paleovalleys that span the width of the province between northeast British Columbia and west-central Saskatchewan (Figure 1). There is little physiographic expression of these paleovalleys in the modern landscape of the Peace River (E4) and Wabasca (E5) lowlands and the Lac La Biche (F2) and Tawatinaw (F5) plains. This lack of expression is particularly evident in the Mostoos Hills Upland (F10) which exhibits a topographic reversal within which prominent physiographic features occur above the deepest parts of the buried Wiau paleovalley (Figure 1).

Bedrock Uplands

Bedrock uplands mainly occur in western and northern Alberta, with small components in central and southern parts of the province. In western Alberta, bedrock uplands comprise moderately sloping, dissected surfaces which descend eastward from 1500 to 500 m asl. In northern Alberta, bedrock uplands form isolated plateaus which rise from the surrounding bedrock lowlands (500 m asl), to summits that range from 800 to 900 m asl. These plateaus include the Cameron Hills (H1), Clear Hills (H3), Birch Mountains (H5), Utikuma (H6), and Stony Mountain uplands (H7; Figure 2). Isolated bedrock plateaus in central and southern Alberta include the Saddle Hills (J2), Swan Hills (J3), and Cypress Hills (J11) uplands, which rise from the adjacent bedrock plains at 700 m asl to summits that reach 1430 m asl (Figures 1 and 2). The spatial relationship between the topography of bedrock uplands and the physiography of the Northern Alberta and Southern Alberta uplands indicates that large parts of the modern landscape reflect the topography of the underlying bedrock.

Bedrock Highlands

Bedrock highlands occur in southwestern Alberta and are characterized by steep slopes and variable relief that reflect the physiography of the Alberta Rocky Mountains and Foothills. This relationship between the topography of the bedrock highlands and the physiography of the land surface demonstrates that the landscape of southwestern Alberta is controlled by the topography of the underlying bedrock, except along the axes of large valleys, which contain a succession of Quaternary sediments.

Paleovalley Systems

Paleovalley systems are common across bedrock plains and lowlands in central and northern Alberta. This distribution broadly corresponds to the physiographic boundary between the Northern Alberta and Southern Alberta uplands and the northern edge of the Eastern Alberta Plains (Figure 2), as well as the transition between Upper Cretaceous Waipti Formation sandstone and Middle Cretaceous Colorado Group shales (Prior et al., 2013). These paleovalleys form regionally integrated systems comprising two southeast-trending trunk paleovalleys (Wiau and High Prairie-Helina), with subsidiary paleovalleys extending to the north and south. The Wiau is the longest of these paleovalleys, which extends eastwards for at least 600 km, from the Buffalo Head Hills (H4) and Utikuma (H6) uplands to the Stony Mountain and Mostoos Hills uplands (H7) en route to the Alberta-Saskatchewan border. A subparallel system lies to the south and extends eastward beneath the Lac La Biche Plain (F2) into Saskatchewan. The High Prairie paleovalley parallels the Wiau paleovalley and extends eastwards beneath the Peace River Lowlands and Lesser Slave Lake to the Tawatinaw Plain (F5), where it possibly converges with the Helina paleovalley (Figures 1 and 2).

The bedrock plains of southern Alberta contain two major dendritic paleovalley systems separated by a northwest-trending divide. The southern paleovalley system occupies a basin-shaped catchment containing six sub-basins that comprise subsidiary paleovalleys (Hanna, Red Deer River, Calgary, Teepee, Lethbridge, and Medicine Hat; Figure 1) that converge beneath the town of Empress to form an eastward-trending trunk paleovalley that is eroded to 520 m asl, approximately 160 m below the adjacent bedrock surface. The northern paleovalley system occupies a linear, eastward-trending basin that comprises the Red Deer and Buffalo Lake paleovalleys (Figure 1), which converge to form the Wainwright trunk paleovalley. This paleovalley is eroded to 520 m asl, up to 130 m below the adjacent bedrock surface and extends eastward beneath Wainwright, en route to the Alberta-Saskatchewan border.

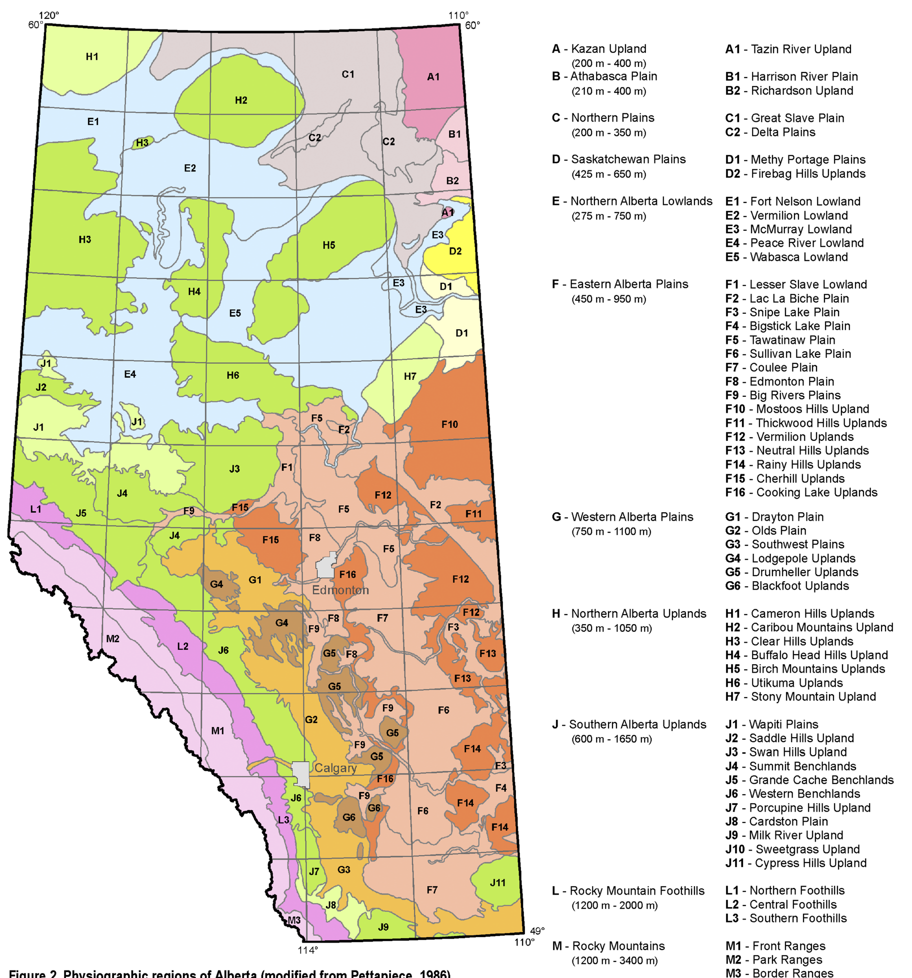

Figure 2. Physiographic regions of Alberta (modified from Pettapiece, 1986).

Data Quality and Quantity for the Alberta Plains

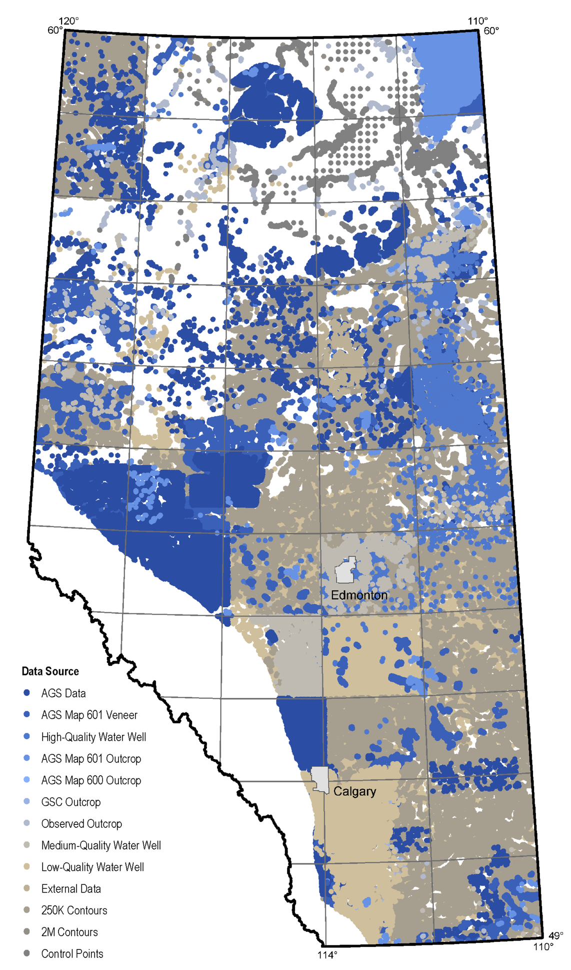

Figure 3. Distribution of bedrock elevation data for the Alberta Plains, coded by source.

Quality Filter Approach

Datasets with information on the top of bedrock were collected from all available sources and categorized based on quality (Figure 3 and Table 1). Data from all high quality sources (Table 1) were combined to form the high-quality dataset that contain 72 131 data points (Figure 4). Data from all medium quality sources (Table 1) were merged into a single file and then filtered to remove any points that are within 1000 m (equivalent to two grid cells) of any high-quality data points (Figure 4). This reduced the number of medium-quality points used for interpolation from 119 005 to 32 720. The remaining medium-quality data points were merged with the high-quality data points, and then used to filter the low-quality dataset to remove any data points that were within 2500 m of any high- or medium-quality data points (Figure 4). This reduced the number of low-quality data points used for interpolation from 253 824 to 67 989. The filtered low-quality data points were then combined with the high- and medium-quality data (Figure 4). The final quality filter was applied to the 2M dataset, which consisted of contour data points from Map 226 (Pawlowicz and Fenton, 1995) for which much of the map area represents a collection of geologists' conceptual ideas of the bedrock surface. Although the 2M data points are not hard data, they do represent expert geological knowledge through the rendering of concepts. Therefore, in the absence of any other bedrock data, these points were included to help constrain the bedrock surface. The 2M points were filtered to remove any data points that were within 10 km of any high-, medium-, or low-quality data point (Figure 4). This reduced the number of 2M data points from 48 086 to 15. This quality filtering approach ensures that the model is based primarily on high-quality data, and uses the lower-quality data only in areas where there is no high-quality data. The data composition for the final model consisted of 41.7% data from high-quality sources, 18.9% from medium-quality sources, 39.3% from low-quality sources, and 0.1% from the 2M dataset.

Table 1. Data sources used to model the bedrock topography of the Alberta Plains.

Source	Count	Description	
AGS Data	7695	Picks produced by geologists' at the Alberta Geological Survey (AGS) identified as either 'base of drift' or 'top of bedrock.'	High-Quality
AGS Map 601 Veneer	46 968	AGS Map 601 polygons indicating a thin layer (less than 1 m) of sediment overlying bedrock, converted to point data.	High-Quality
Water Well	13 718	Picks from water well boreholes drilled to bedrock that were identified by an AGS geologist to be reliable and from high-quality sources.	High-Quality
AGS Map 601 Outcrop	3746	Polygons from AGS Map 601 delineating areas of bedrock outcrop identified by AGS geologists and converted to point data.	High-Quality
AGS Map 600 Outcrop	4	Polygons from AGS Map 600 delineating areas of bedrock outcrop identified by AGS geologists and converted to point data.	High-Quality
GSC Outcrop	434	Bedrock outcrop data pulled from thirteen GSC plains maps. The majority of this data is along river valleys in southern Alberta.	Medium-Quality
Observed Outcrop	24 310	Locations where bedrock outcrop was observed (not all verified for elevation or location accuracy).	Medium-Quality
Water Well	7976	Picks from water well boreholes drilled to bedrock that were identified by an AGS geologist to be from somewhat reliable sources.	Medium-Quality
Water Well	43 166	Picks from water well boreholes drilled to bedrock from all sources that were not identified as being reliable. This dataset may include reliable picks; however, without knowing the reliability or source, they were categorized as being low-quality.	Low-Quality
External Data	85	Points from external studies determined to be lower quality because the geologists were unsure of the data's location accuracy.	Low-Quality
250K Contours	24 738	Bedrock elevation data generated from the 1:250 000 topographic contour maps.	Low-Quality
2M Contours	15	Bedrock elevation data digitized from the 1:2 000 000 scale bedrock topography map (AGS Map 226).	Control Points
Control Points	5611	Point data that were used only in areas of very sparse data coverage to help constrain the bedrock surface.	Control Points

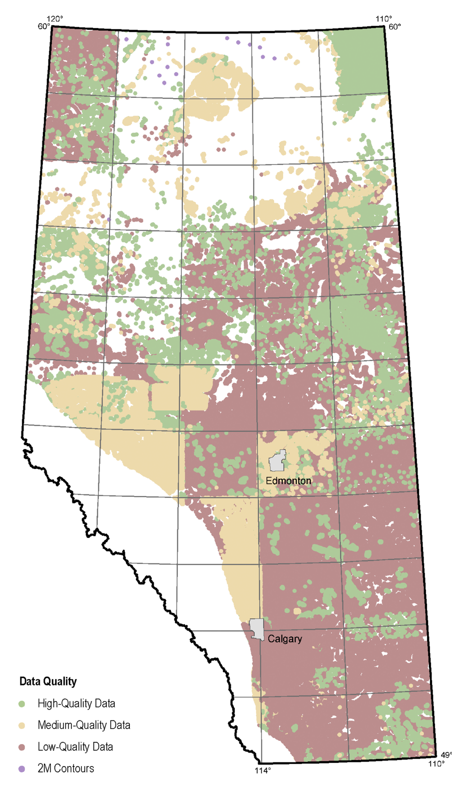

Figure 4. Distribution of high-quality, medium-quality, low-quality, and control point bedrock elevation data.

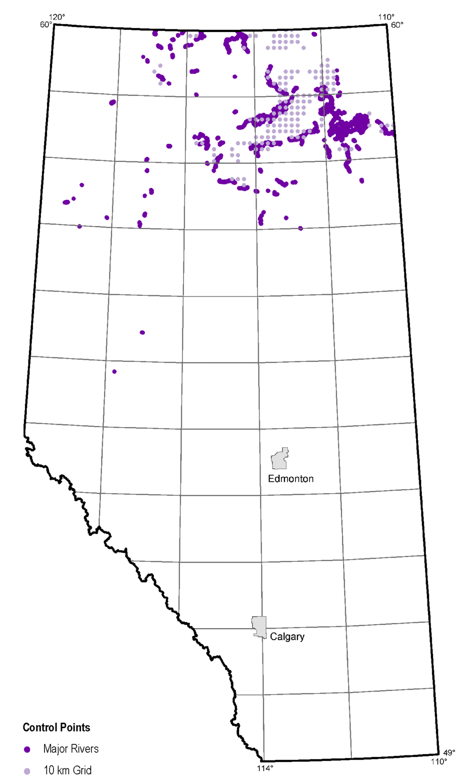

Figure 5. Locations of control points along major rivers and in areas of sparse data coverage using a geologists' best estimates.

Control Points

Control points were used in strategic locations to help constrain the model where data was very sparse or unavailable to help constrain the bedrock topography surface. This was accomplished by using control points along major rivers and in areas with very sparse data coverage (Figure 5).

Major River Valleys

These points were created using a 5 km spacing and applied only in areas where the geologists felt that there could be bedrock at surface. From the remaining points, only those that were greater than 5 km from any other data point were used, leaving 5468 points for interpolation (Figure 5).

Control Points in Areas of Sparse Data Coverage

In areas where the data is sparse or nonexistent, control points were created at a 10 km spacing to constrain the bedrock surface in areas where there were no data points within a 10 km radius, leaving a total of 143 control points (Figure 5). Each control point was examined by a geologist and an informed decision was made on the likely depth to bedrock at each location. This was accomplished by: using available LiDAR tiles to help determine areas where bedrock was close to surface or likely covered by thick sediment depending on the landforms or features observed at the surface; through discussions with geologists that had done work in the areas surrounding the control point locations; and through information that was collected from various reports and could be applied using reasonable assumptions to the control point locations. Although every attempt was made to include reliable information, these points were not considered as actual data points. It is important that these areas be considered as areas of high uncertainty regardless of how the values were obtained, as we do not have any known/actual data at these locations.

Modelling the Alberta Rocky Mountains and Foothills

Data from the Alberta Rocky Mountains and Foothills region was interpolated separately from the Alberta Plains region due to the drastic contrast in data variability and topography (Figure 6). There was very little information on the depth to bedrock within the Alberta Rocky Mountains and Foothills region because bedrock is assumed to be at surface throughout much of this region. A significant amount of work had been done for AGS Map 601 (Surficial Geology of Alberta; Fenton et al., 2013) to identify areas of bedrock outcrop or thin sediment throughout the Alberta Rocky Mountains and Foothills. In order to capture this information, a grid of 500 m spaced points was created across the Alberta Rocky Mountains and Foothills region. If these points fell within the areas of bedrock outcrop identified on AGS Map 601, they were assigned an elevation equal to the DEM (Figure 7). If the points fell within a polygon listed as colluvium, moraine deposits, etc., they were assigned an elevation value of 1 m below the Alberta Sustainable Resource Development (SRD) DEM surface elevation. The points identifying bedrock outcrop were considered as actual data points, whereas the points located within the sediment polygons (AGS Map 601 veneer; Table 2) were considered control points as we had to make an assumption on the depth to bedrock. Although AGS Map 601 provided the bulk of the data for the Alberta Rocky Mountains and Foothills region, data identifying the top of bedrock were also included from other sources, such as project datasets, field observations, water well database, and geologists' well picks (Figure 7; Table 2).

Table 2. Data sources used to model the bedrock topography of the Alberta Rocky Mountains and Foothills.

Source	Count	Description
AGS Map 601 Outcrop	38 423	Polygons from AGS Map 601 delineating areas of bedrock outcrop identified by AGS geologists and converted to point data.
AGS Data	3003	Picks produced by geologists at the AGS identified as either 'base of drift' or 'top of bedrock'.
High-Quality Water Well	1	Picks from water well boreholes drilled to bedrock that were identified by an AGS geologist to be reliable and from high quality sources.
AGS Map 601 Veneer	68 231	AGS Map 601 polygons indicating a thin layer (less than 1 m) of sediment overlying bedrock converted to point data.

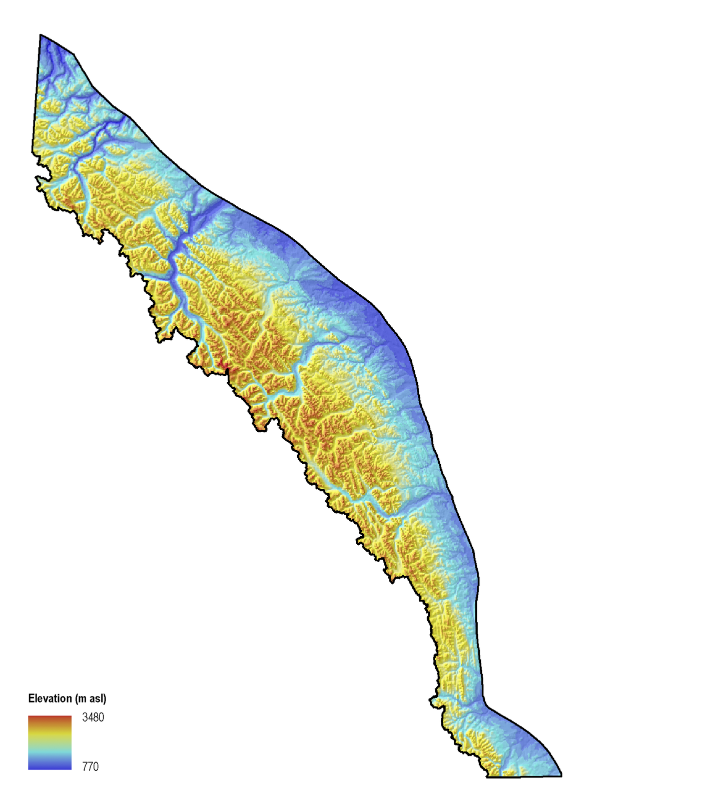

Figure 6. Bedrock topography of the Alberta Rocky Mountains and Foothills.

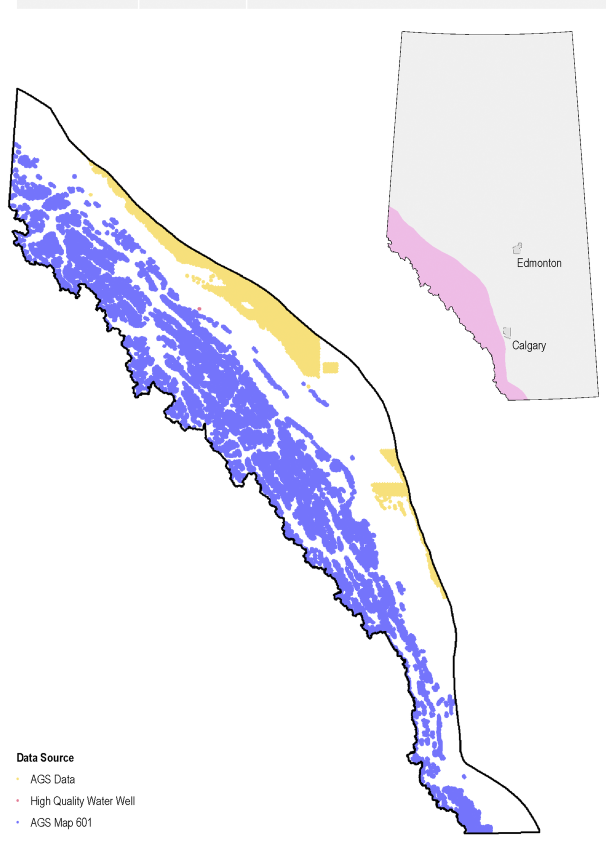

Figure 7. Distribution of bedrock elevation data for the Alberta Rocky Mountains and Foothills, coded by source.

Modelling Procedure and Results

Exploratory data analysis demonstrated that the variability of the data within the Alberta Rocky Mountains and Foothills needed to be interpolated separately from that within Alberta Plains to avoid transferring the topographical variability from one region to the other. This avoids propagating the extreme topographical variability and spatial structure of the Alberta Rocky Mountains and Foothills into the Alberta Plains, and conversely minimizing the variability in the Alberta Rocky Mountains and Foothills due to the overwhelming proportion of the model that is covered by the less topographically variable Alberta Plains.

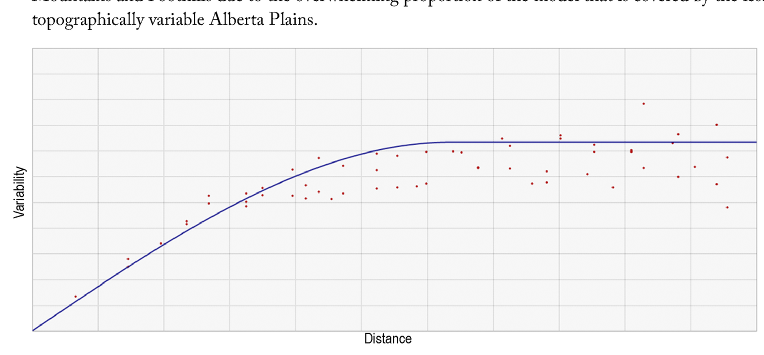

Figure 8. Example variogram used during kriging interpolation.

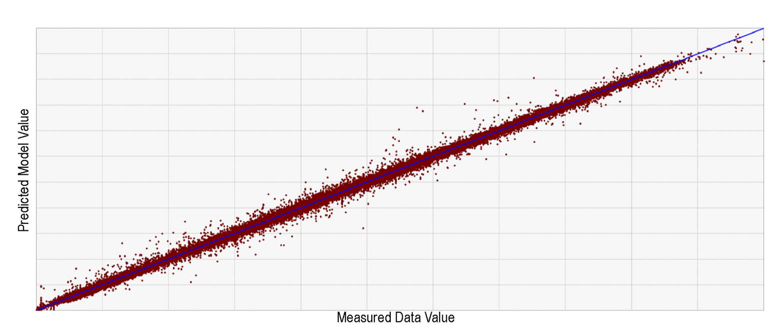

Figure 9. Example of cross-validation results used to assess the accuracy of the model results.

Modelling the Alberta Plains

The quality-filtered top of bedrock elevation data was detrended and geostatistically interpolated in ArcGIS 10.1 using the ordinary kriging algorithm. When geostatistically modelling data, it is important to remove any regional trends, because stationarity is an assumption of most algorithms (Chilès and Delfiner, 2012). The trend is then added back into the predictions after interpolation of the residuals. For the Alberta Plains, a first-order local trend was removed from the data, and the residual values were used to produce a variogram (Figure 8; Table 3). It is important to ensure that the variogram model is properly parameterized to make sure that the interpolated results are as accurate as possible (Gringarten and Deutsch, 2001). Variogram parameters used to create the first-pass model are provided in Table 3. The data were interpolated and the model cross-validation results were analyzed to provide an estimate of model accuracy and precision (Figure 9; Table 4). The cross-validation results were also used to identify potential outliers (data points greater than 20 m from the interpolated surface). Potential outliers were removed from the interpolation dataset, and the model was rerun using the parameters listed in Table 3. The model cross-validation results for the remaining model runs are provided in Table 4. Ideally, the root mean square error (RMSE) and average standard error (ASE) values should be as low as possible and similar to one another, and the RMSE standardized value should be close to 1.0 (Davis, 2002). If the RMSE standardized value is greater than 1.0, the predicted surface is likely underestimating the variability. If it is less than 1.0, the predicted results are likely overestimating the variability. The cross-validations results for the final AGS Map 602 surface were a RMSE of 7.4 m and a RMSE standardized error of 1.02, indicating that the model results are valid and accurately characterize the uncertainty.

Table 3. Variogram parameters for the Alberta Plains modelling runs.

Variogram	Range (m)	Sill (m^2)	Nugget (m^2)	Lag Size (m)
1	15 000	1322	84	1200
2	17 000	1302	21	1300
3	13 000	1035	3.5	1100
4	9500	634	0.8	900

Table 4. Cross-validation results from the Alberta Plains modelling runs.

Modelling Result	RMSE (m)	ASE (m)	RMSE Standardized
1	19.7	15.8	1.28
2	12.5	11.95	1.01
3	8.29	10.1	0.93
4	7.4	9.93	1.02

Modelling the Alberta Rocky Mountains and Foothills

The data for this region were much more difficult to model due to the extreme variations in the topography over relatively short distances. The data were interpolated using ordinary kriging with the variogram parameters listed in Table 5. The variogram range was much smaller than the values observed in the Alberta Plains, while the variogram nugget and sill values were very large in comparison. This is due to the considerable variations in topography within this region and the large scale that was used to create the provincial-scale model. The modelling results show that high RMSE and ASE values (Table 6), which while not ideal, are completely acceptable considering the variations in the data.

Table 5. Variogram parameters for the Rocky Mountains and Foothills modelling runs.

Variogram	Range (m)	Sill (m^2)	Nugget (m^2)	Lag Size (m)
1	4200	41 384	446	500

Table 6. Cross-validation results from the Rocky Mountain and Foothills modelling runs.

Modelling Result	RMSE (m)	ASE (m)	RMSE Standardized
1	88.9	139.2	0.68

Understanding Map Uncertainty and Variability

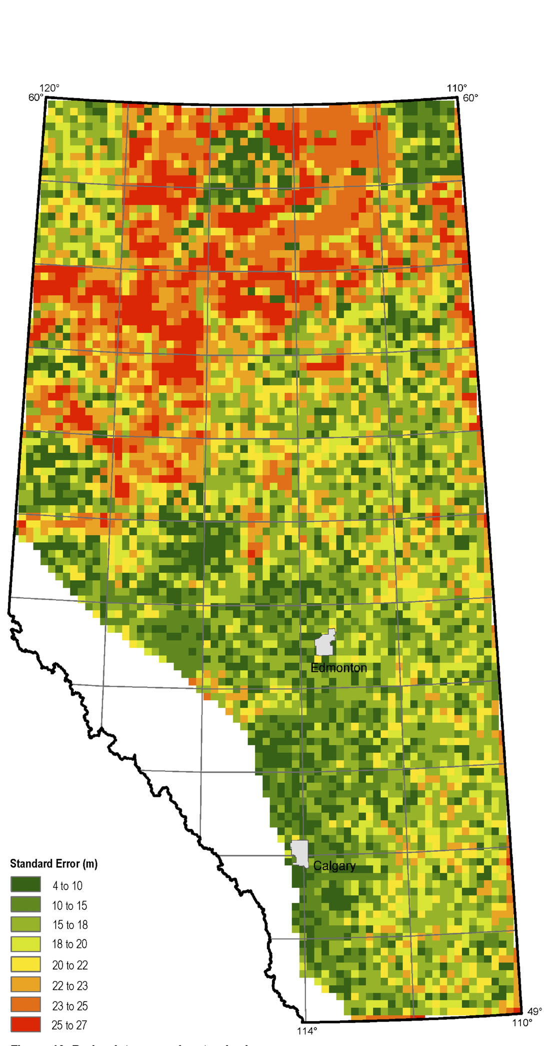

Figure 10. Bedrock topography standard errors.

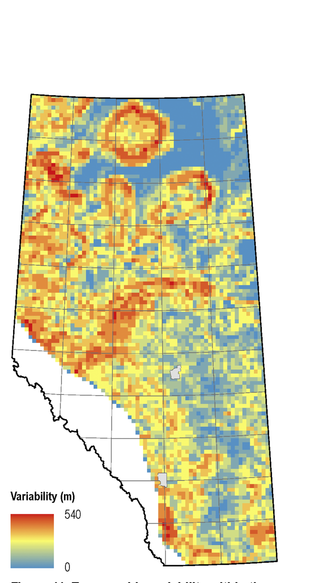

Figure 11. Topographic variability within the model grid cells for the Alberta Plains.

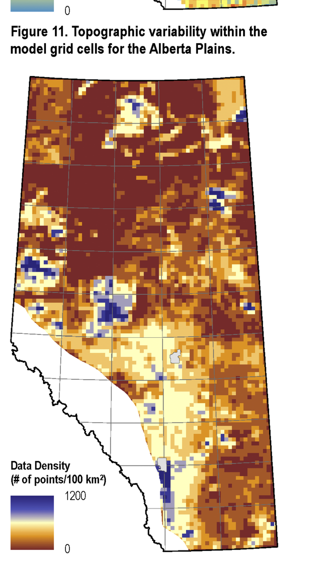

Figure 12. Bedrock elevation data density for the Alberta Plains.

Standard error maps are useful for quickly assessing those regions where the predicted surface has high uncertainty (Figure 10). Multiple factors can affect the uncertainty associated with a predicted surface. For the bedrock topography, the most likely causes are topographic variability and data availability (Figures 11 and 12). If the topography is highly variable in an area, then there is a greater likelihood that there will be greater uncertainty at that location (Figure 11). However, it is necessary to have sufficient data in order to determine if the topography of an area is highly variable (Figure 12). To evaluate these components of topographic uncertainty, maps displaying the local data variability and data density were compared to the standard error map.

Quantifying Topographical Variability

Figure 11 shows the variability in the top of bedrock data points within 10 km × 10 km grid cells in the Alberta Plains region. Areas with the lowest topographic variability are generally in the northeastern and southeastern portions of the province (Figure 11). Areas with the greatest variability in topography occur in isolated regions, typically in the western and central portions of the province.

Data Density

A kernel density tool was used to evaluate the concentration of bedrock elevation data points within a 10 km × 10 km grid cell (Figure 12). The kernel density map shows that the majority of data points (greater than 70 points per grid cell) are located in the south-central portions of the province, in the extreme northeast where bedrock is exposed, and in sporadic locations of geological exploration. Areas of lowest data coverage (less than ten points per grid cell) are primarily in the northern portions of the province where there is limited resource exploration and fewer residential communities. Data availability can have a significant impact on model uncertainty. Therefore, areas with sparse data (maroon areas) are more likely to have higher model uncertainty (Figure 10).

Model Comparison

Data density has the greatest impact on reducing standard error in the predictions. This is evidenced by the similarities between the map of standard error and the map of data density (Figure 12) versus the map showing the variation in range of data values (Figure 11). Areas of the kernel density map showing the higher data densities coincide with the regions showing the lower standard errors (Figure 10). Thus, the amount of data available for a given area had the greatest impact on the relative model uncertainty of the bedrock topography. However, for a more complete assessment of the model uncertainty it is important to also consider the local data variability.

Difference Between the Previous Bedrock Topography Map of Alberta (AGS Map 550) and the Current Version (AGS Map 602)

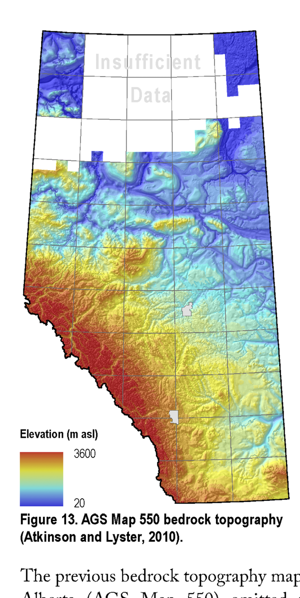

Figure 13. AGS Map 550 bedrock topography (Atkinson and Lyster, 2010).

The previous bedrock topography map of Alberta (AGS Map 550) omitted the northern portion of the province due to a lack of data and information (Figure 13).

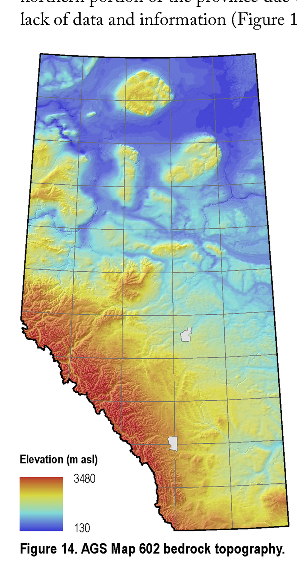

Figure 14. AGS Map 602 bedrock topography.

The new bedrock topography (AGS Map 602) covers the entire province of Alberta and was geostatistically modelled using a quality-weighted approach to acknowledge that some of the data are more accurate and reliable information than others (Figure 14).

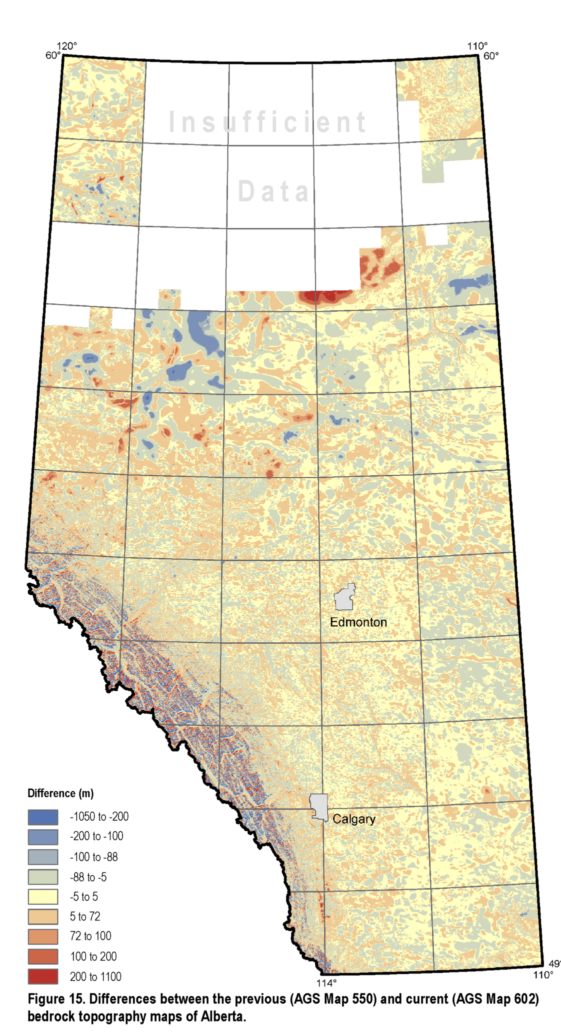

Figure 15. Differences between the previous (AGS Map 550) and current (AGS Map 602) bedrock topography maps of Alberta.

A residual map was produced by subtracting the bedrock topography surface of AGS Map 602 from that of AGS Map 550 to highlight the differences (Figure 15). The pale yellow regions indicate regions where there is little difference (less than 5 m) between the two maps. The blue regions show where AGS Map 602 has been updated to reflect a lower bedrock elevation, while the red portions indicate that the new bedrock surface is topographically higher than the previous version (Figure 15). The extreme high and low values occur in the Alberta Rocky Mountain and Foothills, and are primarily the result of differences between the SRD and SRTM DEMs used for AGS Map 602 and AGS Map 550 respectively (AGS Map 603; MacCormack et al., 2015).

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Acknowledgements

K. Mckay completed the digital cartography and GIS. Base data were modified from the Atlas of Canada (Natural Resources Canada, 2012) and the National Atlas of the United States of America® (United States Department of the Interior, 2003).

Recommended Reference Format

MacCormack, K.E., Atkinson, N. and Lyster, S. (2015): Bedrock topography of Alberta, Canada; Alberta Energy Regulator, AER/AGS Map 602, scale 1:1 000 000.