Kelsey MacCormack , Steven Lyster
Nigel Atkinson, Kirk McKay

Alberta Geological Survey
402, Twin Atria Building
4999-98 Avenue
Edmonton, AB
www.ags.gov.ab.ca

Recent Updates to the Bedrock Topography of Alberta

Introduction

The bedrock topography of Alberta is the surface between the top of Upper Cretaceous and Paleogene bedrock and the modern land surface, and contains geomorphic features created by Paleogene to Recent river systems as well as the advance and retreat of the Laurentide and Cordilleran ice sheets during the Quaternary glaciation, resulting in a complex and highly variable topography (Figure 1).

The bedrock topography is an important surface that can have significant implications on aggregate resource assessments, groundwater studies, and land-use applications. This surface also represents an important unconformity surface of the Alberta Geological Survey's 3-D Geological Framework (Figure 2). It was determined that a new bedrock topography surface should be developed to include a data-quality weighting mechanism and prediction assessments to facilitate communication of model uncertainty with our stakeholders.

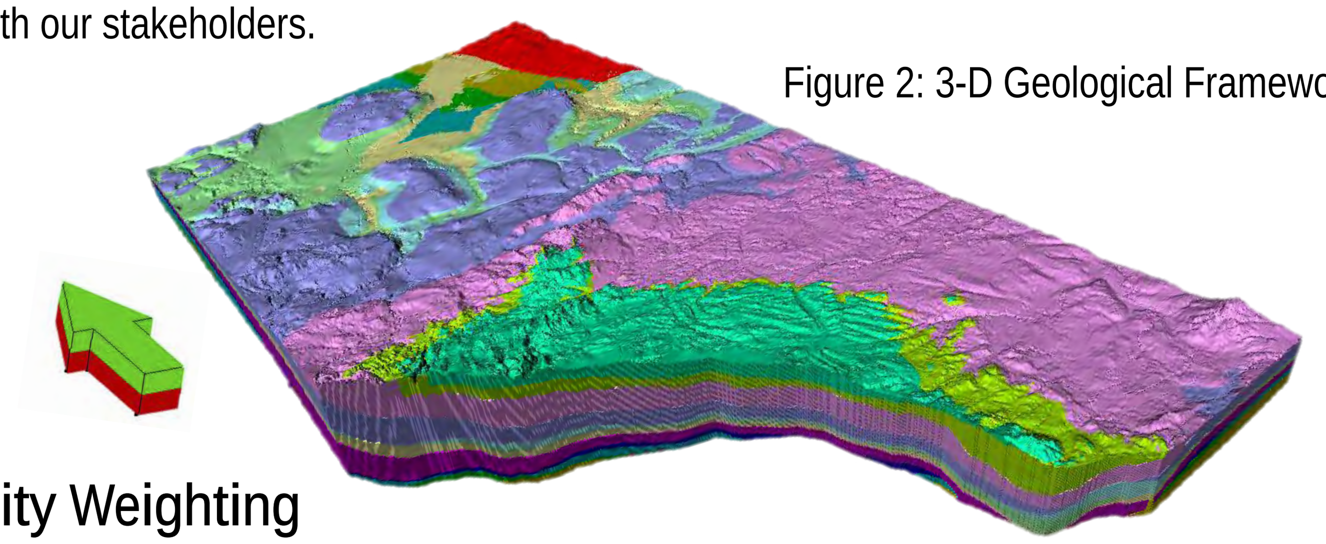

Figure 2: 3-D Geological Framework

Data Quality Weighting

Datasets with information on the top of bedrock were collected from all available sources and categorized based on quality (Table 1). Data from all high quality sources were combined to form the high-quality dataset that contain 72,131 data points.

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.	
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.	
AGS Map 601 Outcrop	3746	Polygons from AGS Map 601 delineating areas of bedrock outcrop identified by AGS geologists and converted to point data.	
AGS Map 600 Outcrop	4	Polygons from AGS Map 600 delineating areas of bedrock outcrop identified by AGS geologists and converted to point data.	
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).	
Water Well	7976	Picks from water well boreholes drilled to bedrock that were identified by an AGS geologist to be from somewhat reliable sources.	
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.	
250K Contours	24 738	Bedrock elevation data generated from the 1:250 000 topographic contour maps.	
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.	

Table 1: Count and quality of data available used to model the bedrock topography

Data from all medium quality sources were filtered to remove any points that are within 1000 m (equivalent to two grid cells; Figure 3) of any high-quality data points, reducing the number of medium-quality points used for interpolation from 119,005 to 32,720.

The remaining data points were then used to filter the low-quality dataset removing any data points that were within 2500 m of any high- or medium-quality data points, reducing the number of low-quality data points from 253,824 to 67,989.

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.

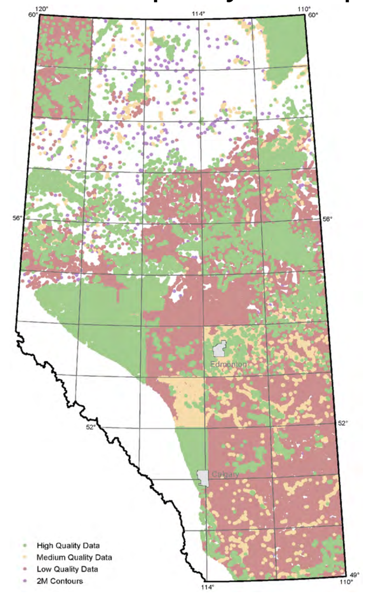

Figure 3: Distribution of variable quality data

Modelling Proceedures and Results

Exploratory data analysis revealed that the variability of the data within the Alberta Rocky Mountains and Foothills needed to be interpolated separately from that within Alberta Plains (Plains) to avoid 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 (Mountains) due to the overwhelming proportion of the model that is covered by the less topographically variable Alberta Plains (Figure 1). The quality-filtered top of bedrock elevation data was detrended and geostatistically interpolated in ArcGIS 10.1 using the ordinary kriging algorithm. Variogram parameters used to create both the Plains and Mountains models are provided in Tables 2 and 4. The cross-validation statistics were used to identify potential outliers and to assess the accuracy of the model results (Tables 3 and 5).

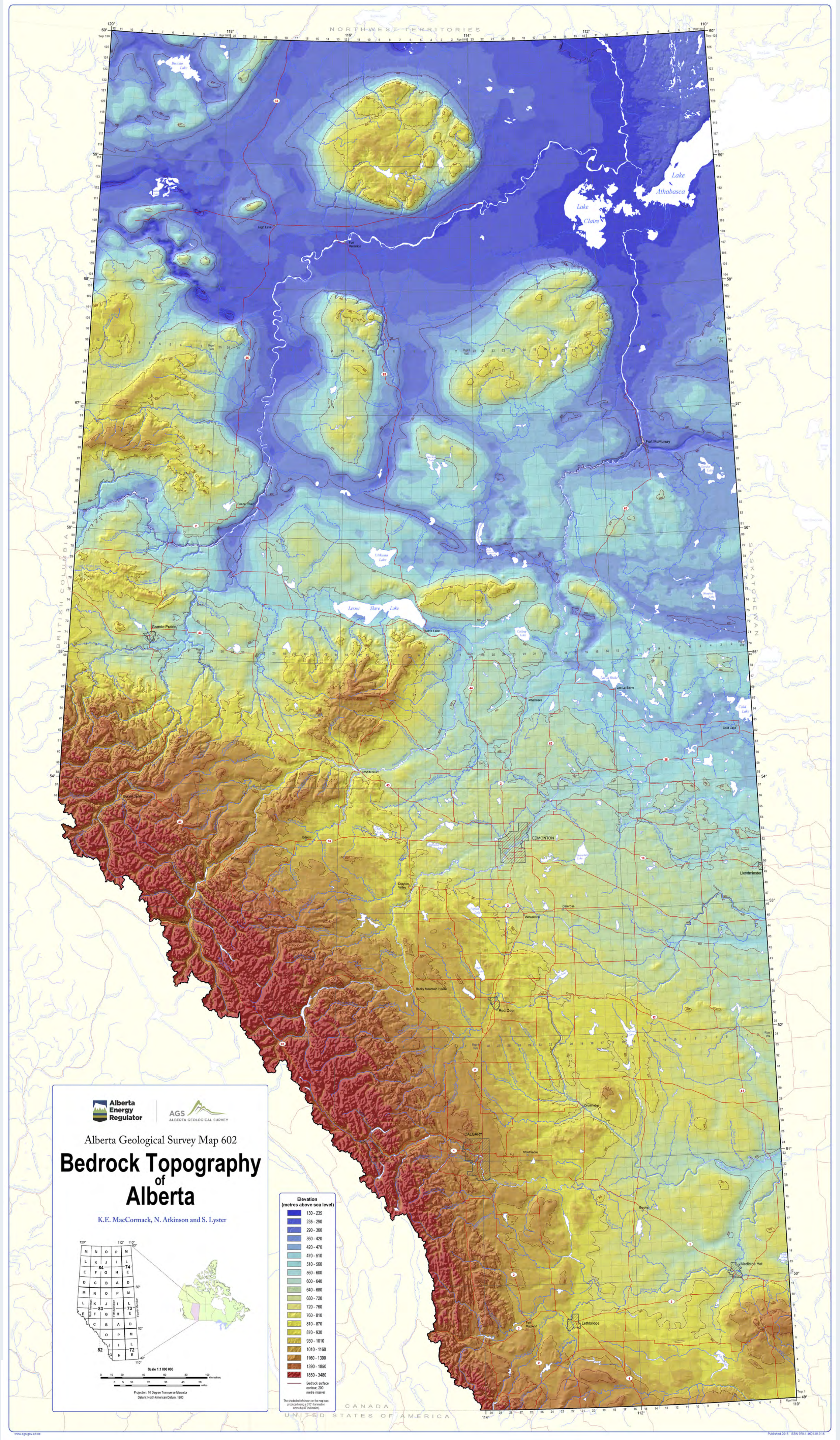

Figure 1: Bedrock topography of Alberta

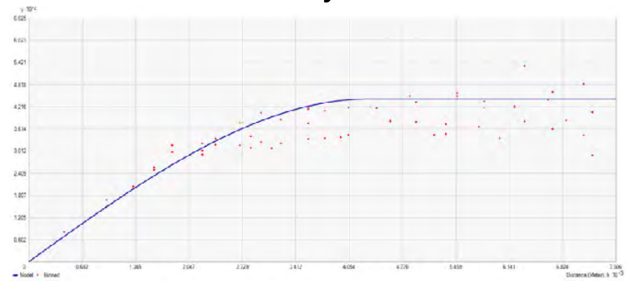

Figure 4: Sample Variogram

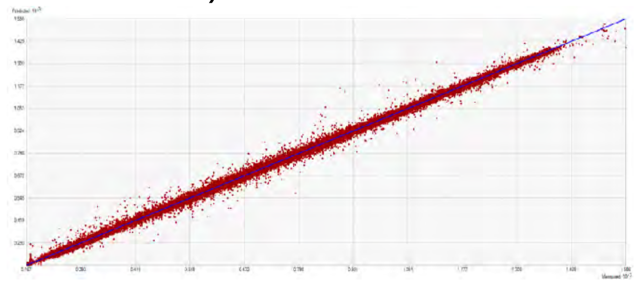

Figure 5: Cross-validation plot

Variogram	Range (m)	Sill (m²)	Nugget (m²)	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 2: Plains variogram parameters

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

Table 3: Plains model statistics

Variogram	Range (m)	Sill (m²)	Nugget (m²)	Lag Size (m)
1	4200	41 384	446	500

Table 4: Mountains variogram parameters

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

Table 5: Mountains model statistics

Root-Mean-Square-Error (RMSE) results provide a global estimate of the predicted model accuracy. RMSE standardized results greater than 1.0 indicate the predicted surface is likely underestimating the true variability, and values less than 1.0 indicate an overestimate of the variability. Cross-validation results for the final surface produced an RMSE of 7.4 m and a RMSE standardized error of 1.02, indicating the model results are valid and accurately characterize the uncertainty (Table 3). The Mountains model resulted in a high RMSE and low RMSE standarized suggesting inaccuracy in the model results and an underestimation in the uncertainty characterization, however the extreme topographic variability in the Mountains, this results was expected.

Understanding Uncertainty and Variability within Modelled Results

Standard error maps are useful for quickly assessing those regions where the predicted surface has high uncertainty (Figure 6). Multiple factors can affect the uncertainty associated with a predicted surface. For the bedrock topography, the most likely causes are data availability and topographic variability (Figures 7 and 8). In areas of increased topographic variability, there is a greater likelihood that there will be greater uncertainty at that location (Figure 6). However, it is also necessary to have sufficient data in order to determine if the topography of an area is highly variable (Figure 8). To evaluate these components of topographic uncertainty, maps displaying the local data variability and data density were compared to the standard error map.

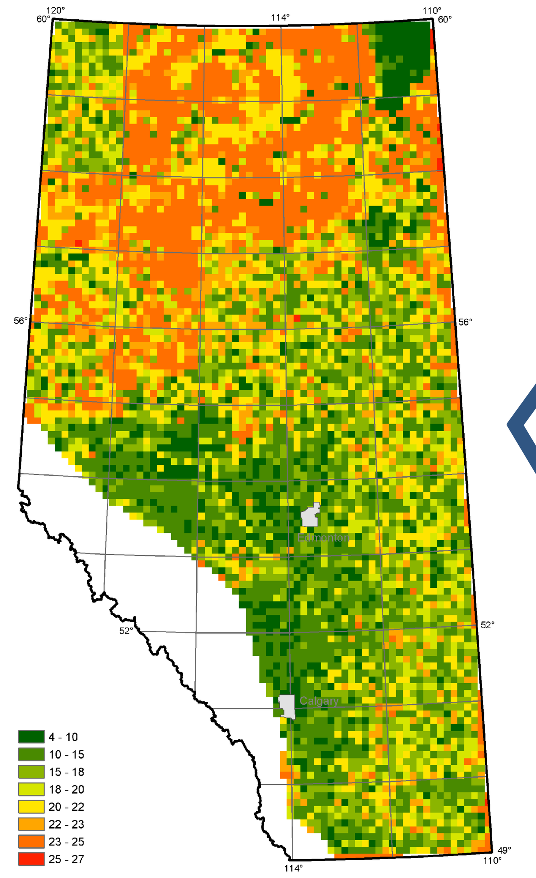

Figure 6: Standard error

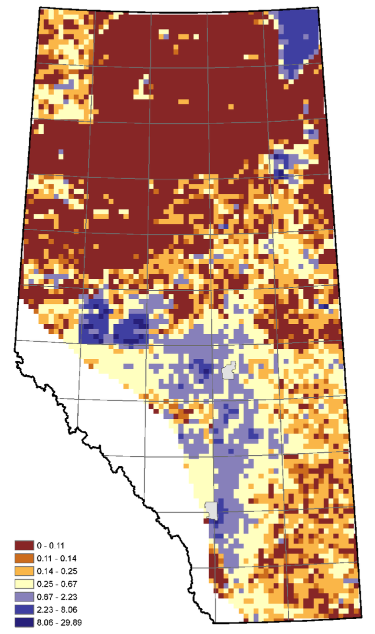

Figure 7: Data Density

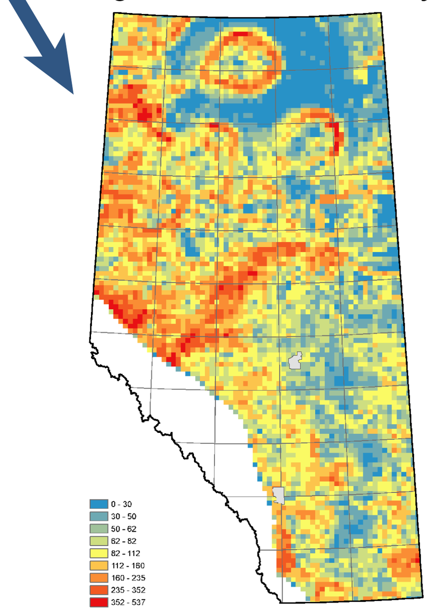

Figure 8: Topographic variability

The kernel density map (Figure 7) shows that the majority of data points (greater than 70 points per grid cell) are located 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 6).

Areas with the greatest variability in topography (Figure 8) occur in isolated regions, typically in the western and central portions of the province, or in areas of known topographic highs. Data density appears to have the greatest impact on reducing standard error in the predictions due to the similarities between the map of standard error and the map of data density (Figure 6 and 7) versus the map of data variability (Figure 6). Areas of the kernel density map showing the higher data densities coincide with the regions showing the lower standard errors (Figure 6). 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.

Conclusions

The bedrock topography is an important surface that can have significant implications on aggregate resource assessments, groundwater studies, and land-use applications. This surface is also used as a critical unconformity surface in the Alberta Geological Survey's 3-D Geological Framework. Modelling the bedrock topography surface throughout the province required an adaptive quality-weighting methodology that was able to account for variations in data distribution and topographic releif. This update to the bedrock topgraphy includes details on the methodology, variogram parameters, model statistics, and an evaluation of the model uncertainty. This information has been included to ensure transparency in the interpretation of our data, and to facilitate communication of the model results with our stakeholders.