Chapter 5: The Alberta Geological Survey 3D Geological Modelling Program

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Introduction

The Alberta Geological Survey (AGS) is responsible for providing geological information and advice about the geology and resources to the Government of Alberta, the Alberta Energy Regulator (AER), industry, and the public to support public health and safety, exploration, sustainable development, regulation, and conservation of Alberta's resources. The AGS delivers geoscience in several key areas, including surficial mapping, bedrock mapping, geological modelling, resource evaluation (hydrocarbons, minerals), groundwater, and geological hazards. We also are responsible for providing geoscience outreach to stakeholders ranging from professional colleagues and academia to the general public.

The objective of our 3D Geological Framework program is to develop a single-source of geological truth for Alberta, and for the AGS and AER to provide a single location for accessing consistent and reliable geological data within a credible geospatial context. This operational approach allows for a more efficient and effective evaluation of the relationships between surface and subsurface properties and interactions ensuring that risk-based strategic and operational decisions are based on sound science and credible evidence.

We are making the 3D Geological Framework (including sub-models) accessible to our external stakeholders to improve regulatory efficiency and competitiveness by improving access and transparency of the data and information used to inform regulatory decisions. This will significantly improve our ability to effectively integrate and evaluate geospatial data to facilitate science-based decisions in support of land-use planning, safe and sustainable resource development, environmental protection, economic diversification and public safety.

Organizational Structure and Business Model

The AGS was created in 1921 by Order in Council of the Alberta Government, and was established as a core part of the Scientific and Industrial Research Council, and later the Alberta Research Council. In the late 1990s, the AGS was transferred to the Alberta Energy and Utilities Board to (1) provide geoscience expertise to support the regulatory process, (2) provide necessary geoscience information and knowledge to the Government of Alberta, and (3) fulfill the need for unbiased, credible public geoscience information. The AGS is the official provincial geological survey of Alberta and currently resides within the Alberta Energy Regulator (AER), providing world-class geoscience support for Alberta's regulatory processes.

The AGS has approximately 59 permanent full-time employees working on 4 teams (Figure 1). The majority of AGS and AER 3D modelling activities occur within the Modelling and Resources Team, which is composed of 15 geologists, geomodellers, geostatisticians and geophysicists.

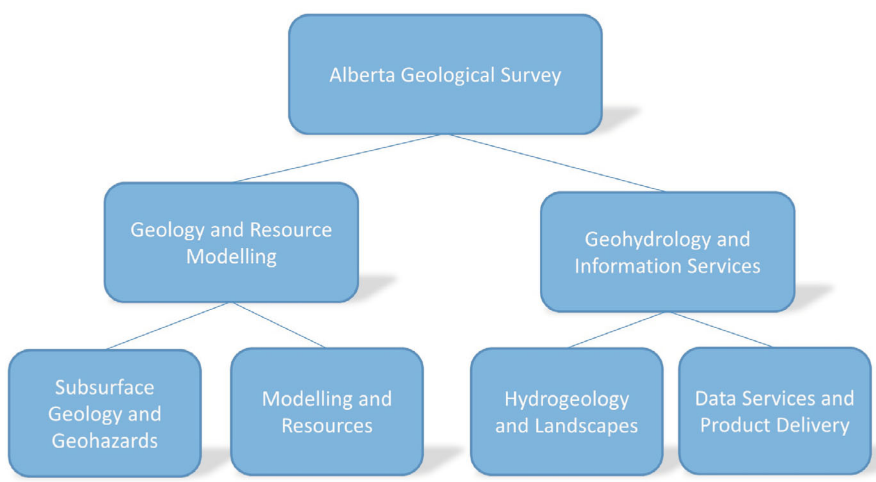

Figure 1: Overview of the organizational structure of groups and teams within the Alberta Geological Survey.

The AGS is responsible for describing the geology and resources in the province and provides information and knowledge to help resolve land use, environmental, public health, and safety issues related to the geosciences. Our work is primarily focused on enhancing the scientific understanding and characterization of Alberta's geology, resources, and environment. However, on occasion we will collaborate with neighbouring provinces, territories, and states to investigate cross-border geological entities, opportunities, or risks. In recent years, the collaborative studies that the AGS has participated in have been related to groundwater protection, distribution of shallow gas plays, and characterizing the susceptibility of certain regions to induced seismic events. We have also signed a number of Letters of Intent with other international geological surveys to formalize and facilitate the exchange of information and knowledge on strategic topics of mutual interest.

Overview of 3D Modelling Activities

The 3D Geological Framework modelling project was initiated in 2010 and began with the development of independent 2.5D grid surfaces for 8 well known geological units, and was resourced with a 0.25 FTE. In 2012, the project was resourced with 1.0 FTE, the number of 2.5D surfaces increased to 23, and the transition began toward development of a full 3D geological model (MacCormack, 2014). The current 3D Geological Framework model of Alberta covers 602,825 km^2 and includes both provincial- and local-scale 3D models (Figure 2). These models have been constructed at a grid cell resolution of 500 m x 500 m or less. Our current provincial-scale model (version 2) contains 62 geological units and was interpolated using approximately 1,235,761 data points (Figure 3), which represents a two-fold increase over Version 1 (released in 2018) that leveraged 620,812 data points to characterize 32 units (Alberta Geological Survey, 2019). Both of these provincial scale models are available at www.ags.aer.ca for download.

In conjunction with our provincial-scale model, the team is also developing local-scale models that cover smaller regions of the province. These local-scale models are typically built to support specific investigations that require either higher-resolution geological characterizations, or require additional geological units to be modelled that are not already available within the provincial-scale model. Although it is necessary to build models at a variety of scales to capture the required level of detail, a key objective of our 3D Geological Framework program is to combine and leverage all of the work done by our geologists and geoscientists on both local and provincial-scale models to combine them into 1 holistic model representing the most current single-source of geological truth for the province. Working towards this objective has spurred the team to make great strides towards developing sophisticated functions that have facilitated the integration of a variety of data types from multiple sources. This required the development of adaptable multi-scalar grids with built-in feedback mechanisms, and workflows to allow individual components of the model to efficiently adapt and evolve as our knowledge and understanding of the subsurface evolves and additional data and information becomes available.

As of 2018 our Geology and Resource Modelling Group (Figure 1) consists of 31 staff that work with teams consisting of geologists, geomodellers, groundwater numerical modellers, geostatisticians, and other scientists or data professionals that support building multi-scalar models for the following applications:

- Conventional and unconventional hydrocarbon resource characterization (Figure 4A),
- 3D hydrostratigraphic models to support groundwater quantity and quality assessments,
- 3D rock property characterization (Figure 4B),
- Subsurface cavern storage potential,
- Assessing the relationship between geological features and induced seismic susceptibility,
- Mineral potential,
- Stakeholder communication and geoscience education (Figure 5A and B),
- Holistic integration of Alberta's natural resources.

Resources Allocated to 3D Modelling Activities

When the 3D geological modelling program was initiated in 2010, the only costs to the program were the salary for 1 FTE and for a single GoCad license (approximately $5,000 CDN). As the program grew, it was discovered that the AER had access to 4 Petrel licenses, which although they were quite costly to maintain, were much better suited to the type of data we were using to build and integrate within our 3D models.

As of 2019, our Modelling and Resources team consists of 15 geomodellers, geostatisticians, geologists, and geophysicists that have access to multiple 3D modelling and visualization software packages including Rockworks, Viewlog, ArcPro, Petrel, and iMOD. Each software package has different strengths in how they allow the user to integrate, query, interpolate, and QA/QC the data and modelled horizons. Our geologists primarily use Rockworks and Viewlog to visualize, evaluate and model surficial geological units. ArcPro is used primarily to visualize and QA/QC the geological picks, horizons, extents, and visualize geospatial data within the 3D models. The majority of the 3D model construction is done by workflows that the team has built within Petrel. These 3D models and

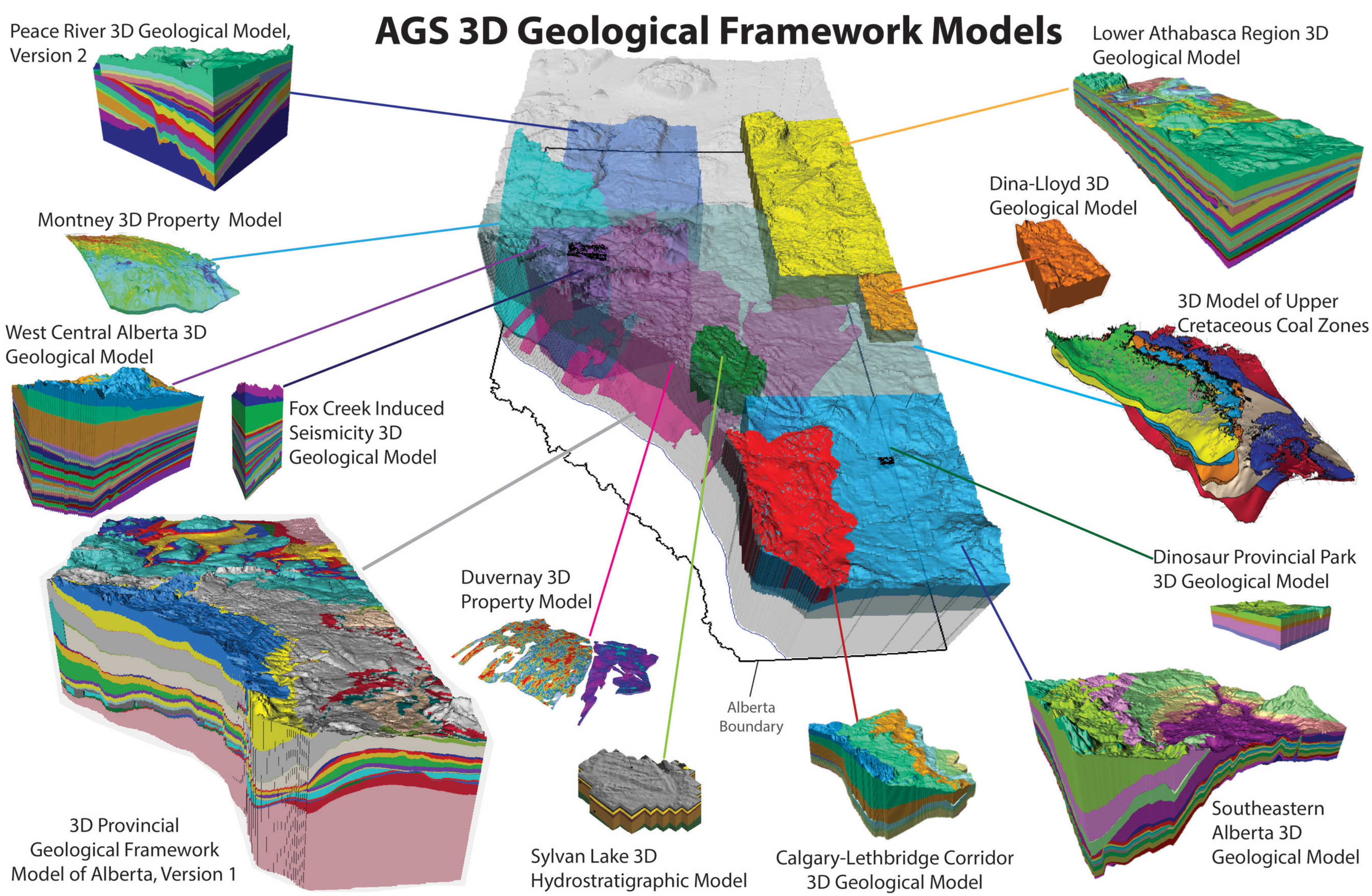

Figure 2: 3D geological and property models that are all contributing to the 3D Geological Framework of Alberta.

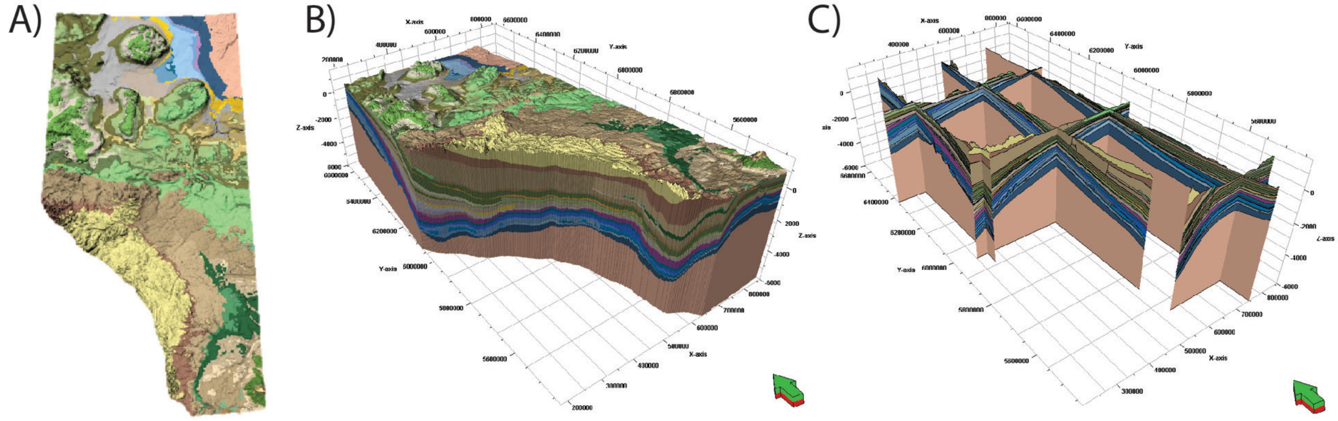

Figure 3: Version 2 of our 3D provincial-scale geological model from **A)** birds-eye view, **B)** oblique view, and **C)** cross-sections showing the internal stratigraphy.

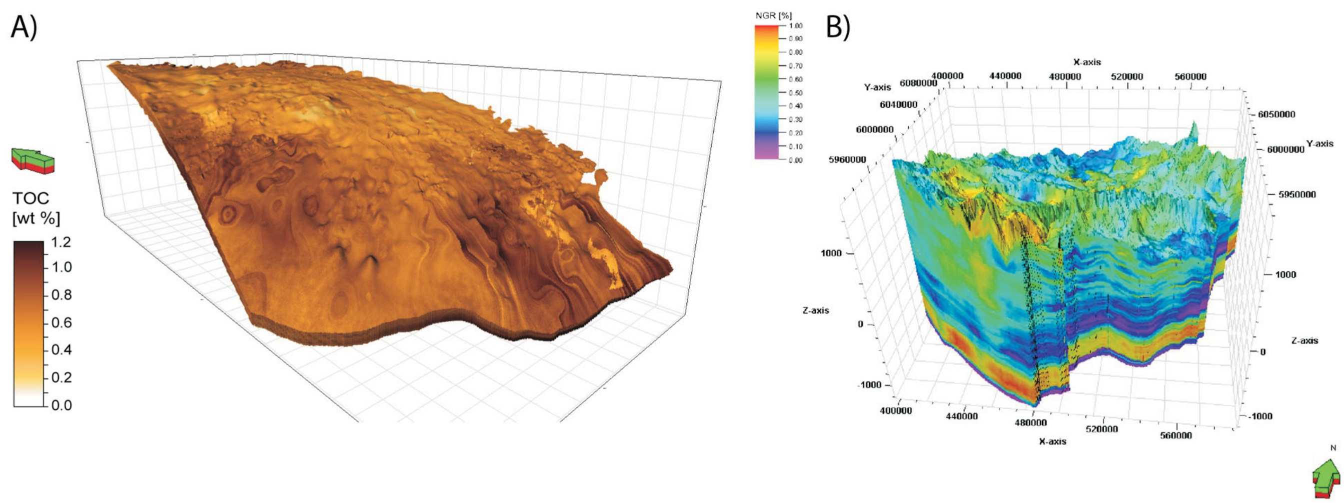

Figure 4: A) Three-dimensional property model of total organic carbon used to characterize resources within the Montney Formation (Lyster et al., 2019), **B)** 3D property model of porosity within the upper geological units of west-central Alberta to help identify potential groundwater aquifer units (Babakhani et al., 2019).

model components (horizons/grids, extents, and points) are exported from Petrel and saved in an ESRI compatible format. This model information is also made available in iMOD, which is a free open-source software program that allows users to visualize and interactively explore our 3D models, as well as import and visualize their own data and information within our models.

Overview of Regional Geological Setting

The geological units characterized within our 3D models range from the top of the Precambrian basement to the modern day ground surface (Figure 3B). The crystalline rocks of the Precambrian basement are more than 542 million years old and just over 5 km deep along the western edge of Alberta (Figure 3C). During the Paleozoic Era, Alberta was covered by warm water in which supported the growth of reefs and deposition of extensive carbonate units. Many of Alberta's deeper oil and gas reservoirs were emplaced during this time (Figure 6D). During the Mesozoic Era, Alberta's western edge was impacted during an extensive period of mountain building that resulted in the creation of the Rocky Mountains (Eyles and Miall, 2007). The Mesozoic Era was also a time when the inland seas retreated and much of the province was exposed resulting in a transition to the deposition of primarily clastic sediments with intermittent periods of erosion resulting in multiple extensive unconformities (Figure 6A, B and C). Overlaying the major unconformity surface of the bedrock topography are the deposits of the Neogene-Quaternary, which represent a relatively thin deposit (1/4 of the province is covered by 2 m of sediment or less), however can reach depths of over 400 m in some areas (MacCormack et al., 2015).

Although the majority of Alberta is a sedimentary basin, there are many areas of significant deformation and faulting, and complex features, such

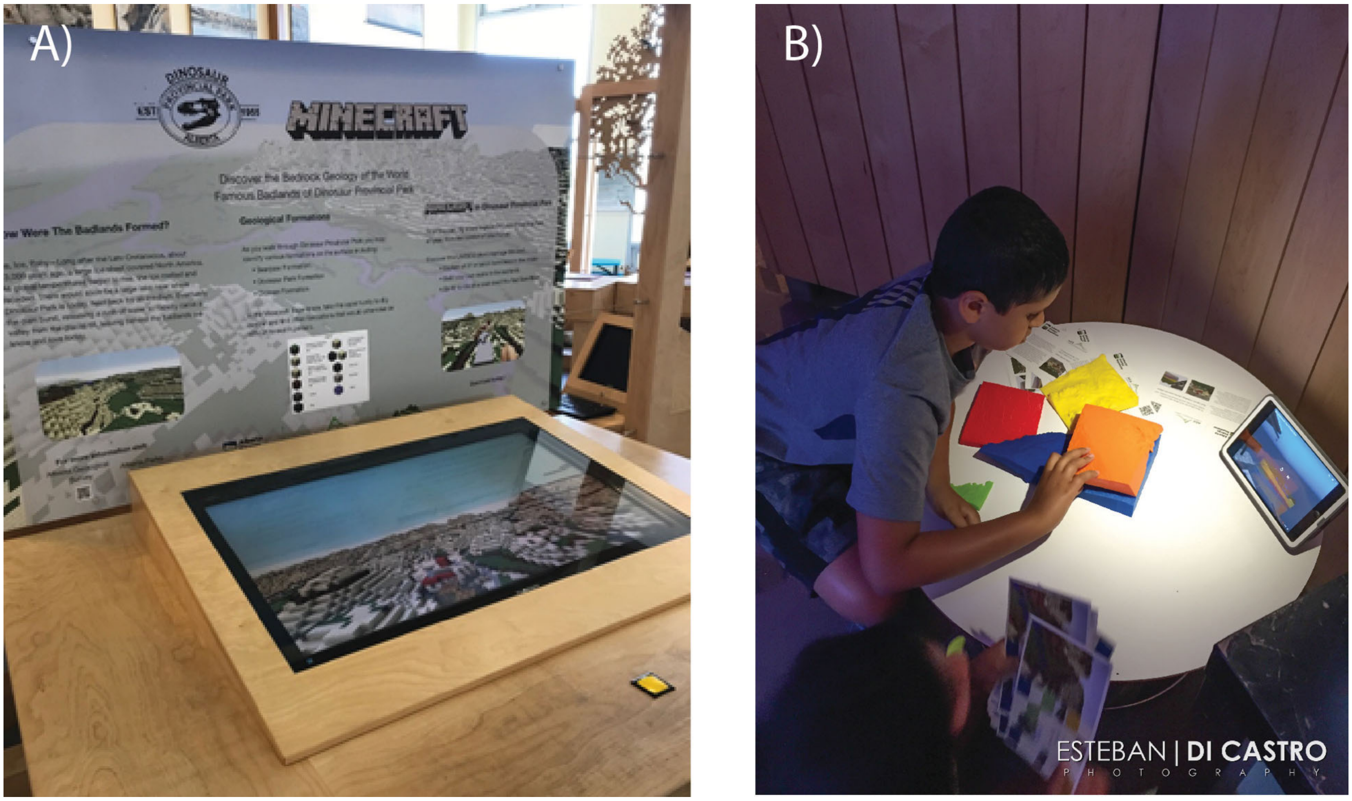

Figure 5: A) Picture of an exhibit at Dinosaur Provincial Park, a UNESCO World Heritage Site in southern Alberta showcasing the Minecraft model of the parks shallow geology, **B)** Child playing with Minecraft models and 3D prints of a 3D geological model at an Alberta science center.

as salt-dissolution induced collapse, caverns, reefs, folds, and faults. Alberta is also fortunate to have numerous natural resources such as oil, gas, coal, bitumen, condensates, groundwater, minerals (diamonds, lithium brines, rare earth metals), and geothermal potential.

Data Sources

The data used to build our models typically comes from stratigraphic picks from geophysical well logs (primarily oil and gas wells), maps, cross-sections, water wells, and seismic data where available. We have relied heavily upon the >500,000 wells that have been drilled throughout the province by the petroleum industry. Our staff are fortunate to be able to evaluate and compare well log profiles with core stored in our Core Research Centre (CRC; Figure 7). Core from over 70,847 of these wells (stored in over 1.6 million boxes), and drill cuttings from >159,500 wells are stored within the CRC. These wells range from shallow (tens of metres) to over 5 km deep with an average depth of 1.2 km. We provide users with all of the data that we use to build our models to encourage trust and transparency with our modelling processes. Therefore, it is important that we use data that is available to the public. Newly drilled wells have confidential status for 1 year and then are made publicly accessible unless a request for extension is requested, which rarely occurs.

The majority of seismic data within Alberta is not publicly accessible, and therefore AGS is only able to incorporate a small amount of information from seismic surveys during the construction of our 3D models. However, in a few places we have been able to acquire 2D and 3D seismic to support specific investigations. In most cases, we have been able to incorporate the derivative data from these seismic surveys into our 3D models.

To support shallow geology characterization and modelling, the AGS has access to approximately 430,000 water wells that have been drilled throughout the province. The difficulty with the water well data is that the quality of the information provided in the logs and reports is highly variable. Fortunately, many of the modern oil and gas wells are now being logged to land surface (rather than stopping the log data collection below the surface casing), and is providing another source of data to support characterization and modelling of Alberta's shallow geology (Mei, 2019).

3D Modelling Approach

Our approach to 3D geological modelling has been evolving over the past few years in response to the growing demand and diversity of requests for our 3D models. Previously, the geological horizons that we used to build our 3D models were implicit

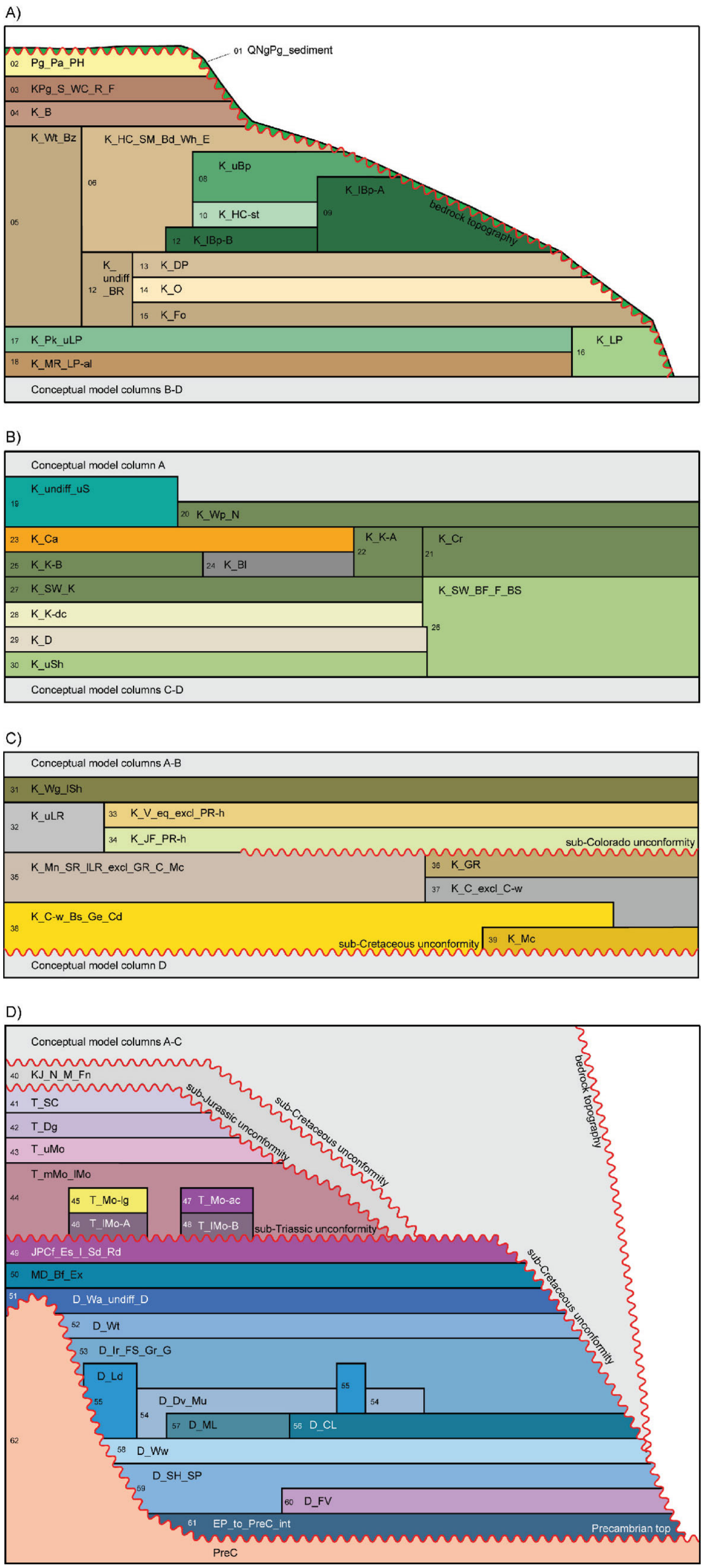

Figure 6: Schematic section showing the **A-C)** Mesozoic and **D)** Paleozoic geological units that are contained within version 2 of our provincial-scale geological model.

geostatistical algorithms, and with only minor modifications to incorporate unique geological characteristics for specific units. Today, we apply a wide range of algorithms depending on the amount of data that is available to model each geological unit, as well as the complexity of the surface being modelled in order to create the most realistic representation possible. Once the 2.5D grids for the top and base of each geological unit have been built, the grids were evaluated for fit with their neighbouring geological units. This can be challenging especially in areas of unconformities, faulting and deformation, or when modelling reefs or other geological units that exhibit significant variability over short distances. Ensuring that the geological surfaces (grids) fit together properly can require additional modification to the grids to make sure that they conform to the available data. These geological surfaces are then combined to create 3D geological models, for which we define the relationship of each surface to the others (conformable, erosional, etc.). This process can take a long time to complete, and therefore we have created workflows for each of our models to make model updates much more efficient. Generating workflows has reduced the amount of time required to rebuild some 3D models from 2 days to less than 2 hours, which represents an 87.5% reduction in time. The workflows have not only proven to save time, but also help reduce the chance of introducing user error by not requiring the modellers to manually recombine grids to build models every time we want to test or update a surface.

The modelling team has been working on developing and updating multiple 3D models within the province as new data becomes available. However this can lead to confusion and duplication of effort in areas where both provincial and sub-models exist. To avoid this, and ensure that we are as efficient as possible with our staff re-

Figure 7: Photo of core boxes stored at the Core Research Centre.

sources, we have started the process of combining all of our models into a single, multi-scalar geological model of the entire province.

The team is also building more 3D property models for geological units which require further investigation for resources (e.g., groundwater, oil and gas, or lithium) using a variety of geostatistical algorithms ranging from simple kriging to simulation algorithms such as Gaussian Random Function Simulation (Babakhani et al., 2019; Lyster et al., 2019; Figure 4A).

Another new development in our modelling program is the use of machine learning and deep learning to enhance our modelled results. The team has successfully applied machine learning techniques to predict areas of landslide susceptibility across the province (Map 605; Pawley et al., 2017), and evaluate the geological parameters associated with seismic susceptibility (Pawley et al., 2018). A machine learning approach was also used to leverage a variety of data from multiple sources to create a much improved bedrock topography for the province that used a randomized tree regression model trained to different subsets of predictors (Atkinson and Pawley, 2019). Although the root-mean-square-error (global measure of uncertainty) of the provincial bedrock topography created with a machine learning method is slightly better (11.8) than the surface interpolated using an Empirical Bayesian Kriging approach (12.8), a key benefit of the machine learning approach is that this methodology allowed terrain-related features to be included in the surface prediction, which resulted in a significant increase in spatial detail and geomorphic plausibility versus other interpolation algorithms that relied only on coordinate information (Figure 8).

Clients

Over the past few years we have seen increased uptake and usage of our 3D models to support a wide variety of investigations and applications from both internal and external clients and stakeholders.

Internally, our models are frequently used to support other teams within the AGS to conduct resource assessments, such as groundwater quantity, quality, and source water protection studies. The models are also shared with a variety of teams within the Alberta Energy Regulator to support science- and evidence-based decision making with respect to regulating and protecting Alberta's energy resources; for example, investigating the occurrence of natural and induced seismic events, and assessing the potential for subsurface gas migration in proximity to potable groundwater resources (see Case Study #2). We are also leveraging our 3D models to help communicate information about the subsurface to our stakeholder groups and the public, which often have quite variable levels of background knowledge, to facilitate understanding and enhance discussion in areas of concern, emerging opportunity, or to support decisions on land- and water-use or economic development.

Our external clients include a variety of groups within the Government of Alberta such as Economic Development and Trade, Alberta Environment and Parks, and Alberta Education, for which we provide information about the geology to highlight Alberta's natural resource potential, support environmental investigations and research, and provide information to enhance education about Alberta's subsurface geology, natural resources and environment. We are also in the process of engaging with science and education centers across Alberta to showcase our 3D models and some emerging technological developments from these models, such as virtual reality (VR) and augmented reality (AR) applications, Minecraft (Figure 9A), 360 videos of Alberta geology in Minecraft, and tactile 3D prints (Figure 9B and C). We have found that communicating information about Alberta's geology and en-

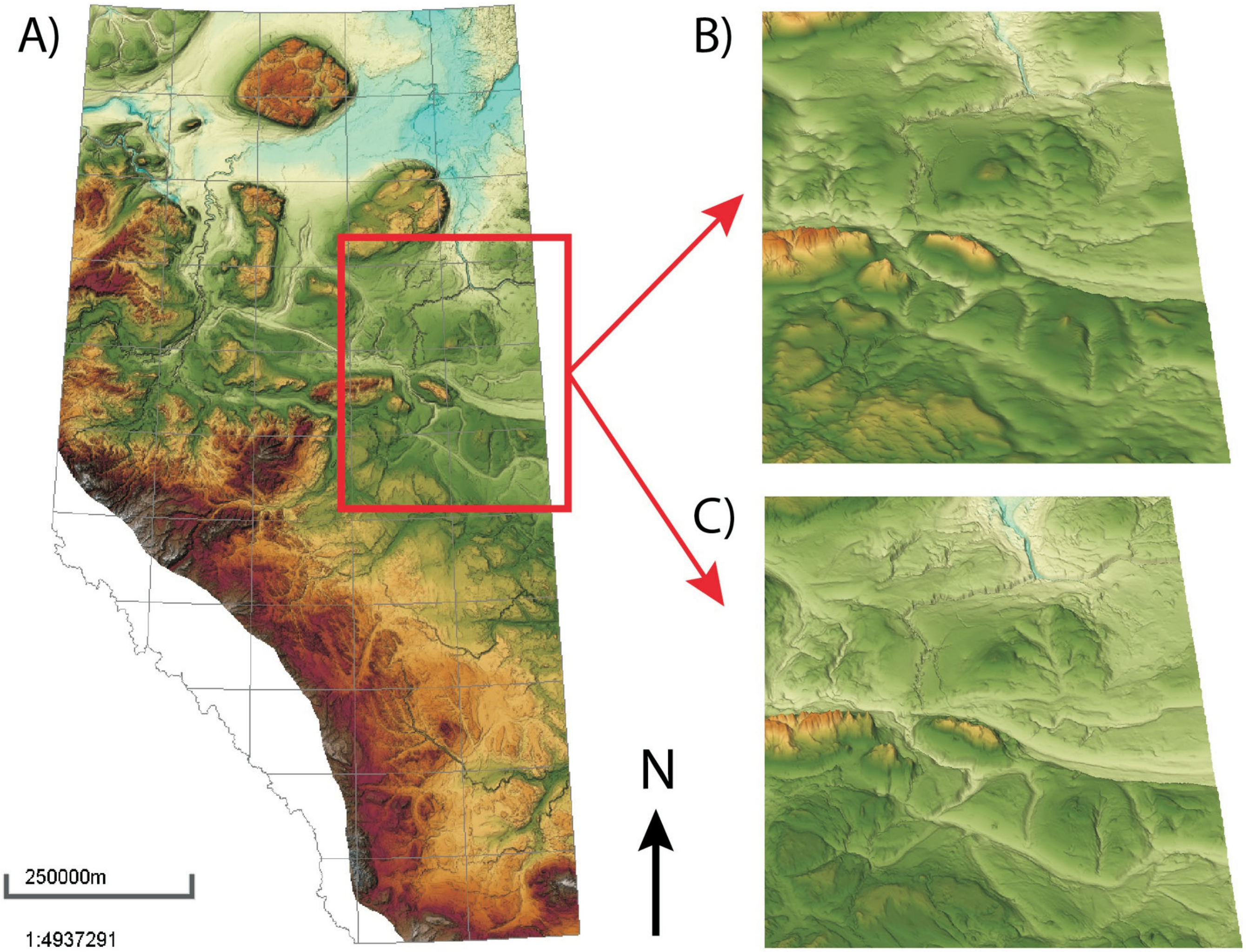

Figure 8: A) Provincial bedrock topography surface created using a machine learning approach. **B)** shows the previous surface from which the data was interpolated using a kriging algorithm, versus **C)** the improved characterization of surface features such as incised valleys delineated using a machine learning approach.

vironment using emerging and interactive technologies such as VR and AR has increased people's interest in the information and often leads to questions about how we collect information about the subsurface geology and create these models. Allowing stakeholders to engage and interact with the models and data has shown to increase their interest in the information and enhance our ability to communicate complex geological information to stakeholders with a variety of background knowledge.

Recent Jurisdictional-Scale Case Studies Showcasing Application of 3D Models

The case studies presented within this section were selected to highlight the diversity of applications in which our 3D models are being used to meet the needs of various clients and stakeholder groups.

Case Study #1: Investigating the Occurrence of Induced Seismic Events in West-Central Alberta

In 2015, the AGS initiated a study to investigate if there was a relationship between locally occurring seismic events, hydraulic fracturing operations, and subsurface geological features. This investigation required a detailed 3D geological model to be built for a 10,014 km^2 study area using 38,823 picks generated from 16,039 wells to characterize 50 geological units from the ground surface to the top of the Precambrian basement (Figure 10). We had access to some 2D and 3D seismic data which were used to help refine the geological model as well as identify 38 faults within the study area. The 3D model was used to integrate hydraulic fracture wells, seismic events, and faults to assess whether there was a

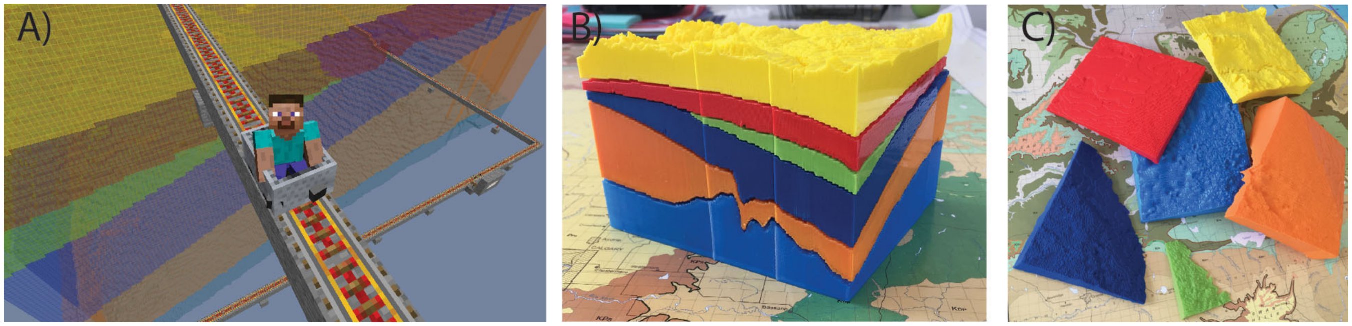

Figure 9: A) Minecraft character in mine cart on tour through our Peace River 3D model, **B)** 3D print of Peace River model put together and **C)** taken apart.

geospatial correlation between the location of induced seismic events and certain geological features, such as pre-existing faults or underlying reef structures in close proximity to the Precambrian basement.

The results of this investigation determined that based on the hydraulic fracturing operations in this region to date, there was little direct correlation between the hydraulic fracturing operational parameters and the occurrence of induced seismic events, however a relatively strong correlation was identified between the location of induced events and proximity to a reef-edge immediately underlying the target formation (Corlett et al., 2018). This information was critical to providing decision makers with the scientific data and evidence to support the development of a subsurface order and traffic light protocol to help manage the risk of large-magnitude induced earthquakes in the region (Shipman et al., 2018; Schultz et al., 2016). The 3D model proved to be an important component of this work as it allowed our scientists to efficiently integrate numerous geospatial datasets in order to assess spatial correlations, and it facilitated communication of the investigation results to regulatory decision-makers and the public. This work also provided information on other areas that could also have a higher potential likelihood for induced seismicity based on similarities in the subsurface geological conditions (Pawley et al., 2018).

The public was also quite concerned about whether hydraulic fracturing and induced seismic events were having an impact on their source of drinking water. We were able to leverage the 3D model to integrate and display all known water wells, oil and gas wells, faults, and the location of seismic events within a robust scientific 3D geological model to show the public the exact distance and number of confining layers between the target formation and the shallow aquifer (Figure 11). Rather than trying to communicate complex geoscience information and relationships using cartoons and hypothetical drawings, our 3D model enabled us to use visuals that were built using scientific data and evidence to communicate our understanding of the geological setting and seismic events based on the available data.

Case Study #2: Assessing the Impact of Commingled Well Abandonment on Nearby Groundwater Aquifers

In 2015 a small team consisting of a geologist, geomodeller, hydrogeologist, and groundwater modeller were tasked with doing a 30-day study to investigate the potential impact of well abandonment of 2 large commingled gas plays on a nearby groundwater aquifer. The first step in this project was to create a 3D geological model of the region (88,768 km^2) that included the pertinent geological units (Figure 12). Thankfully, a number of AGS geologists had previously done field work and evaluated thousands of well logs in this region; therefore, the team was able to leverage this high quality dataset to build their 3D geological model in just 7 days! With the geological model complete, the team integrated well production data and created a 3D representation of both gas plays, as well as integrated hydrologic and geochemistry data to evaluate and characterize the primary groundwater aquifers. The completed model was tremendously valuable for ensuring efficient and effective communication on the complexity of the geological setting (which included an unconformity, a meteorite impact structure, and 47 offset lineaments), and the geospatial relationship of the aquifers and gas plays to other subject matter experts working on the project. The results of this 30-day project were used to communicate our understanding of the subsurface conditions and areas of varying potential risks to executive decision-makers, industry partners, and stakeholders to gain support for a longer-term, more in-depth study into the risks of gas migration into aquifers in this region (Lemay et al., 2019).

This study highlighted the benefit of having a 3D model of the geology ready for use within a short period of time in order to quickly address an environmental investigation. This was only possible because many of the geological units had already been modelled in 3D, and the data for the other units were stored within a well managed database. It would not have been possible to provide a high-qual-

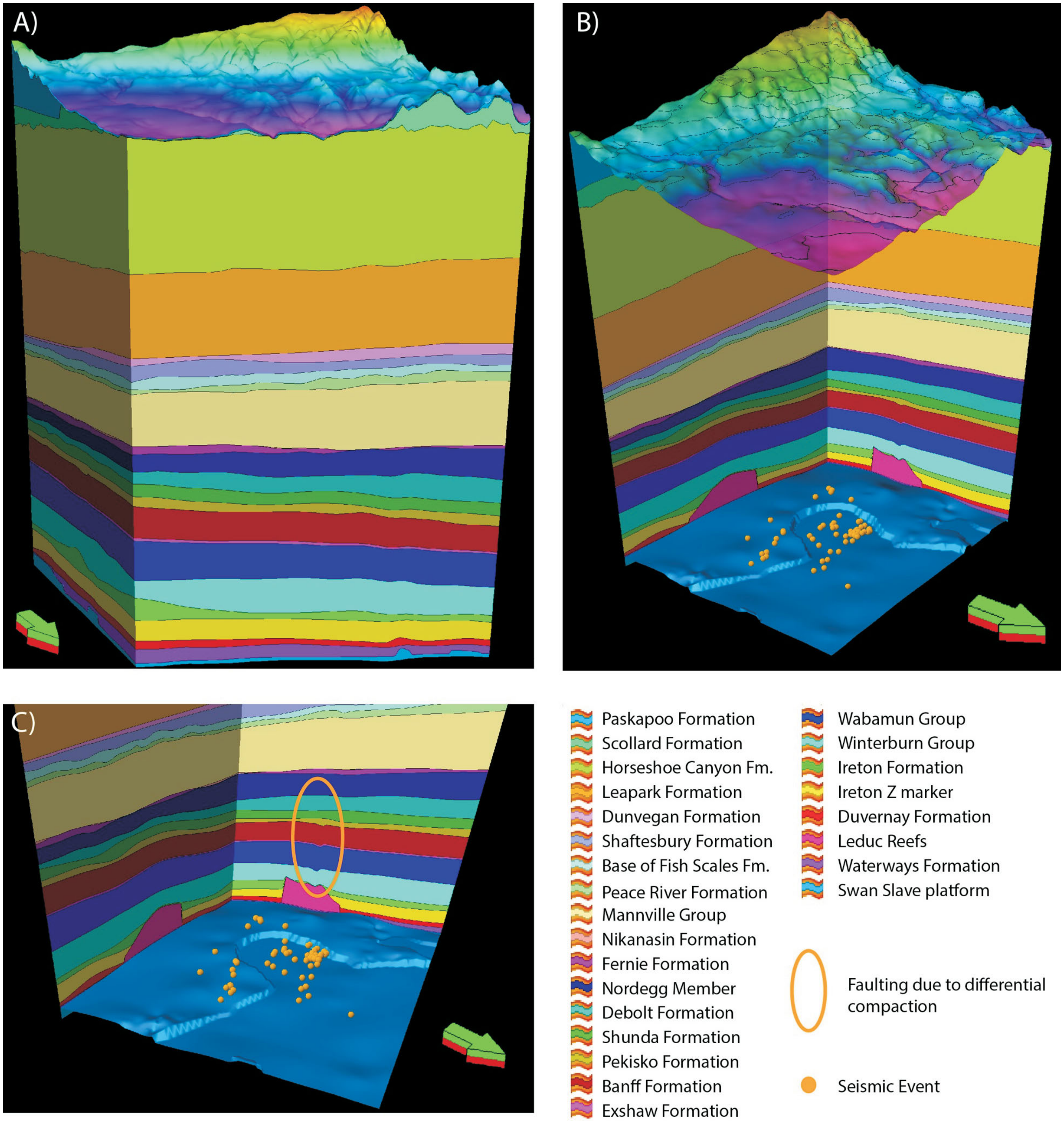

Figure 10: A) 3D geological model of the Fox Creek study area. **B)** Integration of seismic event data within the model showing the spatial distribution of the events within an embayment of the Swan Hills Formation. **C)** Cross-sections through Fox Creek study area showing the internal complexity of the 3D geological model. Areas of differential compaction faulting are highlighted within the orange circles. The model was created using a grid cell size of 100 m x 100 m, and is shown at a vertical resolution of 50 times.

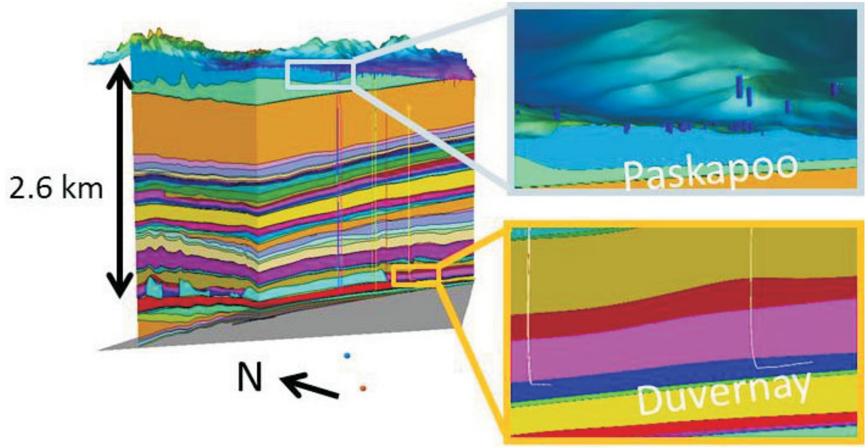

Figure 11: 3D geological model showing the location of wells that were hydraulically fractured in the Duvernay, location of seismic event in the Precambrian basement, and the location of municipal and private water wells.

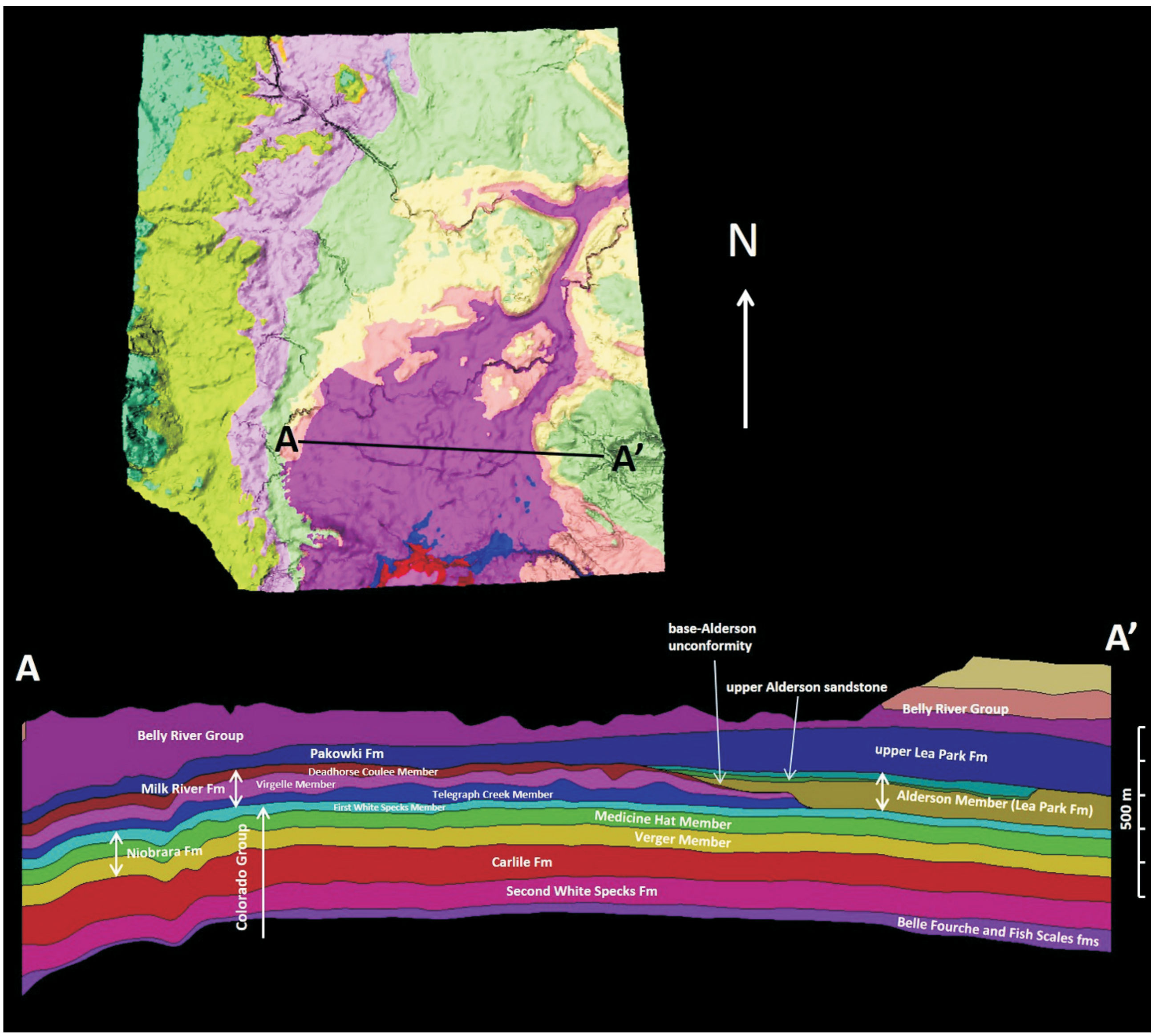

Figure 12: 3D geological model of southern Alberta and cross-section showing the internal stratigraphy. Model was built at a 500 m x 500 m resolution and is shown in a vertical resolution of 50 times.

ity model of the geological setting if we had needed to search for data, QA/QC, and create an entirely new model. Thus, this investigation highlighted the need for proper management of both raw data and 3D models to allow timely response to high-priority investigations.

Current Challenges

We have recently made a number of organizational changes to support the increased demand for 3D modelling, such as centralizing our modellers on 1 team. However, we are still working to overcome a number of challenges, which are primarily related to hardware, software, data, number of available geomodellers, and complexity of Alberta's geological setting.

Most of our geomodellers are using computers with a minimum of an Intel Xeon 8-12 core 2.9 GHz clock speed processor, 64GB RAM, and Invidia Quadro K5000 (4GB) GPU. However, our efforts to build higher resolution models in areas that are strategically important and where sufficient data exists, and to ensure they are integrated within the provincial-scale model, often supersedes the computational power of these machines. To ensure that our geomodellers are able to continue with their work, we are in the process of upgrading components (RAM and GPUs) within their computers, and evaluating options to move our geomodelling activities to the cloud environment.

Another challenge is software interoperability and ensuring that our models can be easily and accurately transferred to other software programs. Unfortunately, not having a standardized format for transferring (exporting and importing) 3D models between 3D software packages is a current limitation that we hope will be resolved by the 3D modelling community, including model and software developers. Getting our models into the hands of users can be very challenging, therefore improving software interoperability and web accessibility would likely result in a significant increase in the uptake and use of 3D geological models.

In Alberta, we are fortunate to have a large amount of subsurface data. However, a significant issue is that duplicate subsets of this data are often stored within multiple datasets in numerous locations within our organization. Thus, we are making great efforts to ensure that the AER, AGS, Government of Alberta, and Albertans have access to a single-source of current, and validated geological data that includes a quality assessment. This leads into another challenge, which is the need to build models at a variety of resolutions that support the multiple needs of various decision-makers. Our solution is to build multi-scalar models where the grid cell resolution is based on both the needs of our stakeholders and the availability and distribution of data. This will allow the models to be higher resolution in areas where it can be supported by sufficient data and is considered strategically valuable by our stakeholders, while maintaining a lower resolution model in areas with fewer data and of lower priority to our stakeholders.

A significant challenge that our modellers are working to overcome is integrating the highly deformed and faulted portion of western Alberta (Rocky Mountains), which covers approximately 78,000 km^2 (Figure 13). The Modelling and Resources Team is currently evaluating the best approach to modelling this region with the data that is currently available.

Lessons Learned

We have learned so much about the needs and requirements for building and disseminating 3D geological models to support geoscience applications, education, and decision-making. The demand for 3D geological models to support a wide variety of applications continues to grow. We are observing increased occurrences of competing interests in the subsurface (hydrocarbon extraction, mineral exploration, groundwater extraction, management, groundwater protection, waste disposal, carbon capture and sequestration, geothermal energy capture and storage, etc.) that has increasingly led to a necessity for pore-space management within a 3D context.

We use our models to build trust and confidence in regulatory systems to stakeholders, GoA, indigenous groups, and the general public by facilitating transparent communication of compiled geological and environmental issues using tangible graphics and visualizations, which are easy to understand and are based on the scientific evidence.

Creating semi-automated workflows is a major development that has allowed the team to significantly decrease the time and effort required to update our models with new information. Therefore, we are constantly looking for ways to increase the efficiency of our model construction phase.

We characterize the local and global uncertainty for every geological unit within our 3D models. This was initially done to help communicate areas of the model that the geologists and modellers were more or less comfortable (certain) in the model predictions. However, we found that the uncertainty models were also very helpful to identify areas of high uncertainty to management and justify the need to do additional geological work in areas of emerging development or geological sensitivity (Figure 14).

As we incorporate more data within our models, build more sub-models, and update our regional-scale models at a faster rate, we have realized that the necessity for good data and management practices are critical. To en-

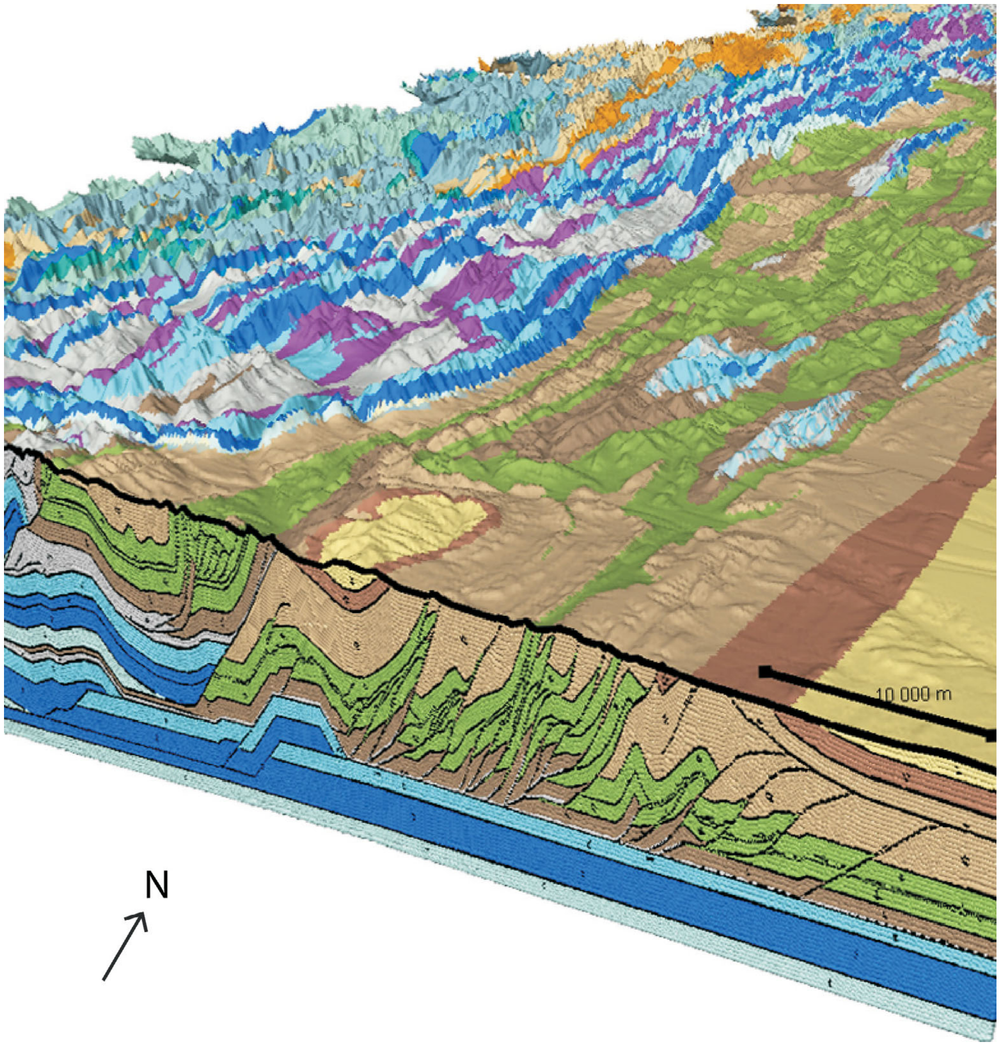

Figure 13: Cross-section through the Rocky Mountains of Alberta showing the complex and faulted geology of the mountains that the modelling team is working to integrate into our provincial-scale 3D model.

sure transparency in our models, we publish all of the data that is used to build our models. It is also important that our data management system is able to manage all of the points, extents, grids, and model files for all of the models and subsequent update versions. This has required us to develop data and model repositories to store and provide easy accessibility to all of our models and information. To make sure that users are able to assess the suitability of our models and are comfortable using our models will require us to provide informative metadata, which we currently provide in a report document that is published with all of our 3D models.

Next Steps

The AGS is initiating a number of projects within the Geological Framework Program to advance development and innovation of our 3D models and associated products. Some near-term objectives of the program include integrating all of our local-scale submodels within our large provincial-scale model to create a single multi-scalar source of geological information that can be easily updated as additional information becomes available. The team is also working to improve upon our current modelling methodologies and look for efficiencies within our workflows as we continue to refine our geological characterization in areas of strategic importance, and integrate surface and subsurface resources. Our plan is to continue to evaluate opportunities to leverage machine learning and deep learning methods to optimize our data and enhance our mapping and modelling products.

Similar to the competing interests in the deeper subsurface, Alberta is also seeing increased interest in creating shallow subsurface models in urban areas to support evaluation of surface water and groundwater interactions and availability, contaminant migration, urban infrastructure (planning new and replacing old), and near-sur-

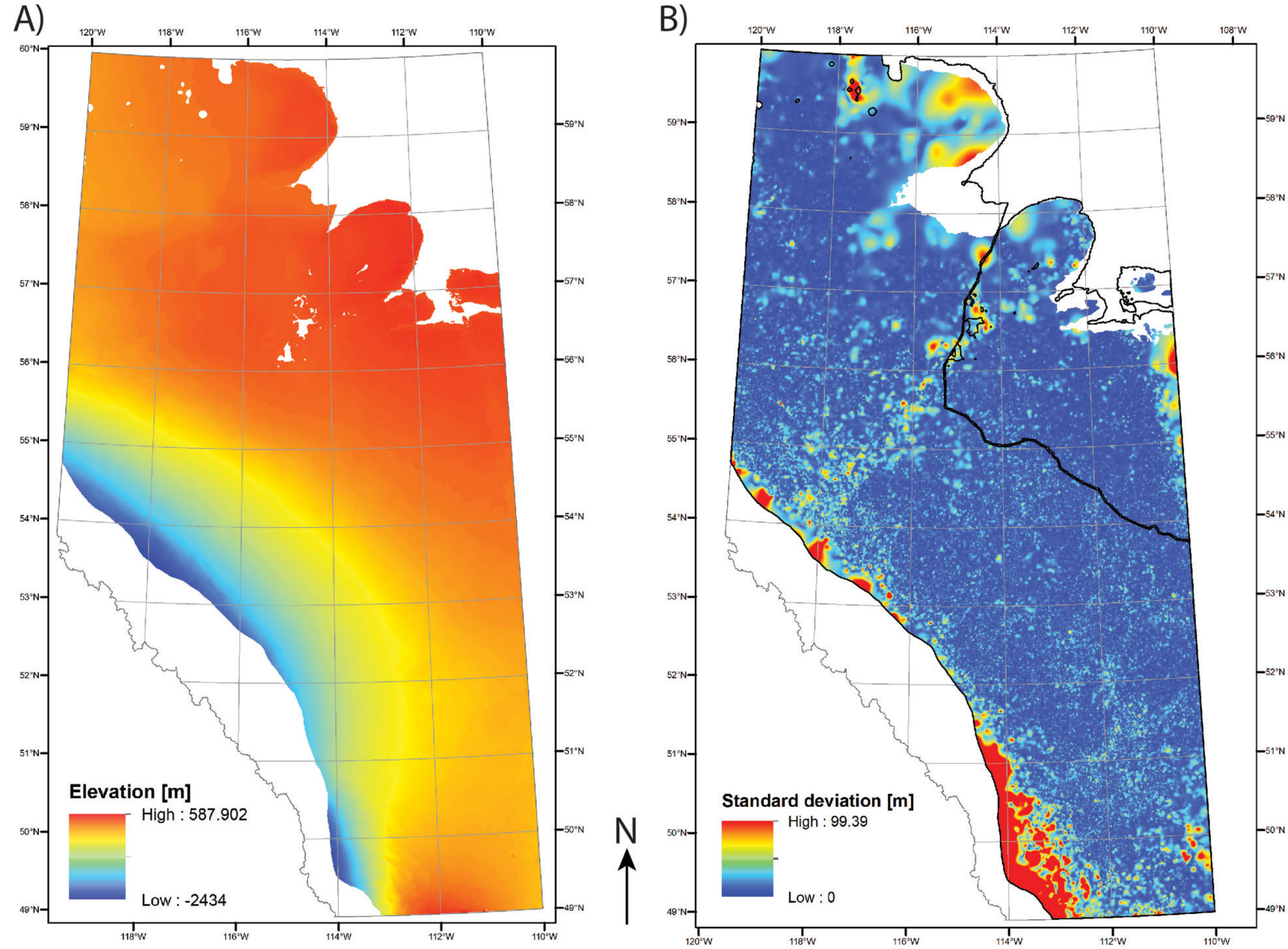

Figure 14: Map showing the **A)** elevation of a surface from the 3D model, and **B)** map of the local uncertainty (represented by the standard deviation) associated with the model prediction of the surface shown in A).

face geohazards such as landslide susceptibility.

In order for our 3D models to be used to support investigations and decision-making both within and outside our organization, we need to ensure that people have easy access to software programs or online applications that can be used to integrate, and evaluate a variety of geospatial data within our 3D geological models. The AGS will be identifying and evaluating open-access software or online options to increase accessibility and applicability of our maps, 3D models, and geospatial data. Another objective for the AGS is to leverage innovative and emerging technology (augmented reality, virtual reality, serious-gaming, and 3D prints) to enhance communication of our geoscience information and products to stakeholders.

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