Ancestral buried valleys of the Peace River: Effects on the Town of Peace River

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ABSTRACT
The Peace River Lowlands of Alberta and British Columbia is one of the most historically active mass movement areas in western Canada. In this study area, the Peace River has incised through approximately 180 m of Quaternary sediments and 30 m into the underlying bedrock. Numerous failures continue to cause infrastructure problems for the town of Peace River. Failures of varying types have occurred in both the Quaternary sediments and the underlying shale bedrock. A bedrock surface model was generated from multiple data sources. This model shows that the ancestral Peace River formed a large valley, eroding the bedrock surface almost to the same base level as the modern Peace River. During glacial times, the advancing Laurentide Ice Sheet dammed and inundated the Peace River valley and its tributaries, depositing a thick and complex sequence of glacial sediments. Chronologically, the Quaternary stratigraphy consists of fluvial sediments derived from the Cordillera, aggrading fluvial and glaciofluvial sediments, grading up into glaciolacustrine deposits, till and other glacial sediments and, within the greater Peace River valley, deglacial sediments of glacial Lake Peace. The deep seated landslides at the Town of Peace River have a strong spatial correlation with the buried valleys and tributaries of the ancestral Peace River. This may be, in part, due to groundwater in the basal sediments of these buried valleys penetrating the bedrock. However, the glaciolacustrine sediments deposited in advance of, and subsequently overridden and overconsolidated by, the Laurentide Ice Sheet are also suspect for a number of failures.

RÉSUMÉ
Les basses-terres de la rivière de la Paix de l'Alberta et de la Colombie-Britannique sont l'une des régions où l'on retrouve des mouvements de terrain les plus actifs sur le plan historique dans l'Ouest canadien. Dans cette région d'étude, la rivière de la Paix a incisé dans environ 180 mètres de sédiments du Quaternaire et 30 mètres dans le substrat rocheux sous-jacent. De nombreuses ruptures continuent de causer des problèmes au niveau de l'infrastructure pour la ville de Peace River. Des ruptures de divers types sont survenues dans les sédiments du Quaternaire et le substrat rocheux de schiste argileux sous-jacent. Un modèle surfacique de substrat rocheux a été généré depuis plusieurs sources de données. Ce modèle démontre que la rivière de la Paix ancestrale a formé une large vallée, érodant la surface de substrat rocheux quasi au même niveau de la base que de la rivière de la Paix moderne. À l'époque glaciale, la nappe glacière Laurentide progressive a endigué et inondé la vallée de la rivière de la Paix et ses affluents, déposant une séquence épaisse et complexe de sédiments glaciaux. Chronologiquement, la stratigraphie du Quaternaire est constitué de sédiments fluviaux provenant de la Cordillère, des sédiments fluviaux et fluvioglaciaux alluviaux, se transformant en des dépôts glaciolacustres, till et autres sédiments glaciaux et, dans la merveilleuse vallée de la rivière de la Paix, des sédiments déglaciaires du lac de la Paix glacial. Les glissements de terrain profonds dans la ville de Peace River disposent d'une forte corrélation spatiale avec les vallées enfouies et les affluents de la rivière de la Paix ancestrale. Cela peut partiellement résulter de l'eau souterraine contenue dans les sédiments fondamentaux de ces vallées enfouies, pénétrant le substrat rocheux. Toutefois, les sédiments glaciolacustres déposés avant, et par la suite chevauchés et surcompactés par, la nappe glacière Laurentide sont possiblement à l'origine des nombreuses ruptures.

1 INTRODUCTION

The Peace River lowlands of Alberta and British Columbia are one of the most historically active mass movement areas of western Canada. Urban areas such as the Town of Peace River and their associated infrastructure have been, and continue to be affected by, these movements. The Alberta Geological Survey (AGS), with the support of various stakeholders, has initiated a multidisciplinary geohazard study (Froese, 2007) of an area centered on the Town of Peace River, Alberta, to develop a better understanding of the type and extent of landsliding within the Peace River valley. The results will provide stakeholders with information to aid municipal planning and reduce the landslide hazards risk to population and infrastructure within the bounds of the study area. This paper describes some of the work done to date, including the development of a bedrock surface model and the corresponding surficial digital terrain model, and the results of field based mapping of the overlying Quaternary sediment stratigraphy. This information, in turn, provides a geological framework for landsliding within the Peace River valley at the Town of Peace River.

1.1 Study Area & Physiography

The study area (NTS Map Sheet 84C; Figure 1) lies within the interior Plains of Canada (Bostock, 1981) within the Peace River Lowlands physiographic zone (Pettapiece, 1986). Much of the surface morphology in this area is the result of processes associated with the last glacial event (Late Wisconsin) and Holocene erosion. The Peace River valley is the dominant geomorphic feature of the region and was developed from incision of the Peace River through the Quaternary sediments and into the Cretaceous bedrock. The river valley is an important transportation corridor and includes highways and a railway line. The Peace River Lowlands separates the Buffalo Head Hills to the east and the Whitemud and Clear Hills to the west. The Peace River District is mainly fertile farmland characterized by flat topography and stone-free fields developed on sediments of the former lake bottom of Glacial Lake Peace, which inundated most of the region below 610 m above mean sea level (asl) (Mathews, 1980; Leslie and Fenton, 2001; Paulen, 2004; Paulen et al., 2004). Elevation within the study area ranges from 320 m at the floodplain in the Town Peace River to a maximum of 625 m in the northwest part of the study area.

Figure 1. Location of study area

1.2 Bedrock Geology

The study area is within the Western Canada Sedimentary Basin. The stratigraphic units relevant to landslide processes in the Peace River area occur within the Cretaceous Fort St. John Group of the Western Canada Sedimentary Basin (Hayes et al., 1994). Within the study area, the Fort St. John Group consists of the Spirit River and Peace River formations overlain by the marine shale of the Shaftesbury Formation and the sandstone of the Dunvegan Formation respectively. The Smoky Group, which west of the Peace River consists of Kaskapau and Puskwaskau formations, is stratigraphically above the Dunvegan sandstone. The Shaftesbury Formation is an upper Lower Cretaceous unit that outcrops along the Peace River in the reach south of the town of Peace River (Hamilton et al., 1999). This formation consists of dark grey marine shale with bentonite partings and occasional sandy and silty interbeds. The upper contact is gradational into the regionally extensive Dunvegan Formation (Leckie et al., 1994). The most important influence on stability is lithology. Slope failures by translational and compound slides are very common in the thinly bedded shales of the Kaskapau and Shaftesbury formations (Cruden et al., 1990).

1.3 Quaternary Geology

The Peace River region of Alberta is historically characterized by a stratigraphy in which only one Laurentide glacial event, the late Wisconsin Lostwood Glaciation (Fenton, 1984), affected west-central Alberta (cf. Bayrock, 1969; Liverman et al., 1989). Recent research suggests that a previous glacial event may have advanced into the Peace River valley (Leslie and Fenton, 2001; Hartman, 2005; Botterill, 2007). Recent work by Leslie and Fenton (2001) described the surface stratigraphy and overall distribution of the surficial deposits for the Peace River area of Alberta. Stratigraphic correlations of these Quaternary sediments, with sediments documented in the Peace River District of British Columbia (Bobrowsky et al., 1991), have been suggested by Miller and Cruden (2002).

The oldest Quaternary sediments in the Peace River valley of Alberta are the pre-Laurentide gravels. These sediments are preserved in preglacial valleys and on the upland west of Peace River near the town of Grimshaw (Paulen, 2004). The age of these sediments has yet to be confirmed but they are interpreted to be sediments reworked from Paleogene (Tertiary) quartzite gravels that occur in Clear Hills to the northwest and deposited in an nonglacial Peace River drainage system during the Sangamon or possibly earlier (Churcher and Wilson, 1979).

The Lostwood Glacial deposits include proglacial lacustrine sediments that developed as the advancing ice dammed drainage (Bobrowsky et al., 1991; Catto et al., 1996), advance outwash glaciofluvial sediments (Leslie and Fenton, 2001), till and glacial Lake Peace sediments (Mathews, 1980). Late Wisconsin ice advanced into the region approximately 22,000 years BP (Dyke et al., 2002). Regional deglaciation is estimated to have occurred sometime after 11,000 ± 200 years BP (Dyke, 2004). Till is ubiquitous at surface throughout the region and forms a thick (2 to >25 m) continuous blanket over large parts of western Alberta. During early deglaciation, the Laurentide Ice Sheet retreated northward and down-drainage, essentially blocking drainage and ponding the glacial meltwaters at the ice margin. Glacial Lake Peace was one of the larger glacial lakes that developed; it extended into British Columbia to the west and reached as far north as High Level in Alberta (Mathews, 1980). In the study area, glacial Lake Peace silt, clay and minor sand of varying thickness blankets the area below 610 m asl, (Paulen, 2004; Paulen et al., 2004).

Glacial Lake Peace drained in the early Holocene and the Peace River immediately began incising through the Quaternary sediments. There are several terrace levels that record the rapid rate of incision. Landslides also occurred throughout the Holocene and continue to affect the region. Along the Peace River and its tributaries, slope failure and mass movement has resulted in thick accumulations of colluvium. Holocene deposits include organic sediments, fluvial terraces from river incisions, loess deposits and colluvial deposits from landslide processes.

2 PREVIOUS WORK

A number of projects investigating bedrock, Quaternary and surficial geology in the Peace River area provide a wealth of information. Much of the previous work was at a regional scale and provides a good understanding of the general geology within the study area. Previous investigations into bedrock topography of the Peace River area were developed and updated by various authors over the years, culminating in the most recent 1:1,000,000 bedrock map by Hamilton et al., (1999). Tokarsky (1971) and Borneuf (1981) reported on the hydrogeology of the area. Recent work by Leslie and Fenton (2001) described the surface stratigraphy for the Peace River area of Alberta. Stratigraphic correlations of these Quaternary sediments, with sediments documented in the Peace River District of British Columbia (Bobrowsky et al. 1991; Catto et al., 1996), have been suggested by Miller and Cruden (2002). Detailed sedimentology of the lowermost valley stratigraphy was described by Botterill (2007). Additional information and stratigraphic information exists in unpublished geotechnical and consulting reports. Mapping of the surficial geology was recently completed by Paulen (2004) and Paulen et al. (2004).

2.1 Landslide Documentation

Landslides occurring along the Peace River and its tributaries have been well documented. Regional studies detailing the activity of failures within the buried ancestral valley of the Peace River and its tributaries have been documented by Bobrowsky and Smith (1992), Cruden et al. (1993) and Miller and Cruden (2001). Typical earth movements within the Peace Valley fail along weak layers of overconsolidated ice-advance phase glaciolacustrine sediments. These sediments were deposited in ice-dammed valleys proximal to the advancing Late Wisconsin Laurentide Ice Sheet and subsequently overridden and overconsolidated. Many of the larger documented failures are seated within these sub-till glaciolacustrine deposits within west-central Alberta. Examples include the Rycroft (Saddle River) landslide (Cruden et al., 1993), the Montagneuse River slide (Cruden et al., 1997), the Eureka River slide (Miller, 2002) and the Attachie landslide (Fletcher et al., 2002). Note that not all rupture surfaces in the Peace region are limited to the sub-till glaciolacustrine sediments. Earth movements with failure surfaces have occurred in weak Shaftesbury Formation marine shale, and have been documented south of the study area at the Little Smokey River (Thomson and Hayley, 1975).

A digital inventory of Holocene landslides in and around the Town of Peace River, derived from surficial geology maps, was created by Davies et al. (2005). The inventory report provides a summary of the geology in the study area, photos of landslides, as well as scarp locations and classification of slope movement, as outlined by Cruden and Varnes (1996).

3 METHODOLOGY

Analysis of landslides and failure potential within the ancestral buried Peace River valley relied on the preparation of a bedrock surface model, the incorporation of two digital terrain models of varying resolution, and a detailed examination of the valley-fill Quaternary stratigraphy and sediments.

3.1 Bedrock and Terrain Surface Models

The bedrock surface model was created from multiple lithologic and stratigraphic data sources. Approximately 1400 environmental water well logs, oil and gas geophysical logs and geotechnical logs were examined. This data was further supplemented by 62 field surveyed outcrop locations where geologic features such as bedrock contacts and surface elevations were described and recorded. Different lithologic and stratigraphic data sources were integrated into a geodatabase of the study area and provided the basis for the creation of the bedrock surface using the software application VIEWLOG® Borehole GIS.

A ground surface model was produced using a 60 m Shuttle Radar Terrain Model (SRTM) for the entire study area of approximately 2500 km^2. As part of this study, a high resolution (1 m) bare earth Light Detection and Ranging (LiDAR) survey was conducted over a 100 km^2 region centred on the Town of Peace River. LiDAR data shows the ground surface stripped of vegetation and buildings, centered on the townsite and covering the municipal area (Figure 2). These digital elevation models (DEM) were supplemented with satellite imagery, including a QuickBird high resolution satellite colour image for the townsite.

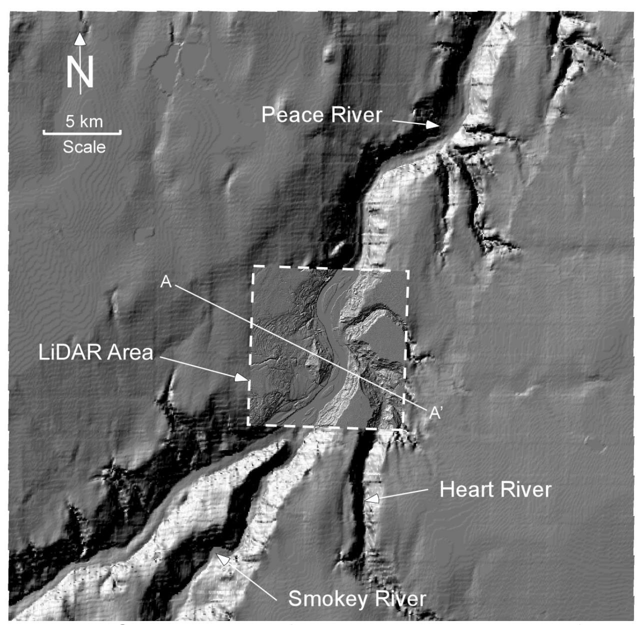

Figure 2. Shaded DEM of the study area, derived from SRTM and LiDAR datasets.

The bedrock surface was generated using boreholes which penetrated through the overlying Quaternary sediments. Selection of the bedrock surface was based on the description of lithologic units where available, or characteristic log responses in the case of geophysical boreholes. Bedrock selections, or picks, were checked against the stratigraphy of surrounding boreholes, and the interpreted trend of erosional surfaces. The confidence of the bedrock picks in holes with little or no lithological descriptions and poorly defined stratigraphy often relied on the density and quality of the surrounding borehole data. Creation of a gridded raster bedrock surface was accomplished in VIEWLOG® using those boreholes which had bedrock picks, field observations and interpreted user-defined bedrock surface in areas where there was little borehole coverage.

3.2 Composite Quaternary Stratigraphy

The Quaternary stratigraphy was compiled from field mapping and from unpublished geotechnical core log data, provided by Alberta Transportation, CN Rail and the Town of Peace River.

Key exposures from the Heart River, Peace River and roadcuts provided information on the Quaternary sediment column near the surface and within the base of the valley. This information was augmented by shallow boreholes (Pawlowicz et al., 1996; Leslie and Fenton, 2001) geotechnical logs to fill in the knowledge gaps and provide the first detailed, complete composite Quaternary stratigraphy for the Peace River valley at the Town of Peace River. Key stratigraphic units and contacts established for the town of Peace River may, in part, be applicable in other locales, but not with significant heterogeneity.

3.3 Landslide Morphology

A unique review of morphology and extent of the Holocene landslides was conducted within the area covered by the high resolution LiDAR data and QuickBird imagery. The high resolution DEM facilitated the viewing of the bare earth LiDAR in plan view or at various angles in 3D. In addition, vertical sections of the slide areas were created in VIEWLOG®, which incorporated nearby borehole data. The combination of the available data sources provided a powerful means with which to assess the extent of different slide masses and make interpretations as to intact versus failed material (colluvium). By overlaying the composite geological section, we can show which material the landslide appears to be seated within.

4 RESULTS

4.1 Bedrock Topography

The present day rivers have incised through the Quaternary sediments and are currently eroding the bedrock surface of the river valley. The present day Peace River meanders within the thalweg of the ancestral Peace River valley. Due to the variability of the available data, the bedrock surface is best defined within the study area covered by the LiDAR. The portion of the study area covered by the SRTM contains a lower density of boreholes defining the bedrock surface, with the exception of the western uplands, and the confidence of the modelled bedrock surface is therefore lower.

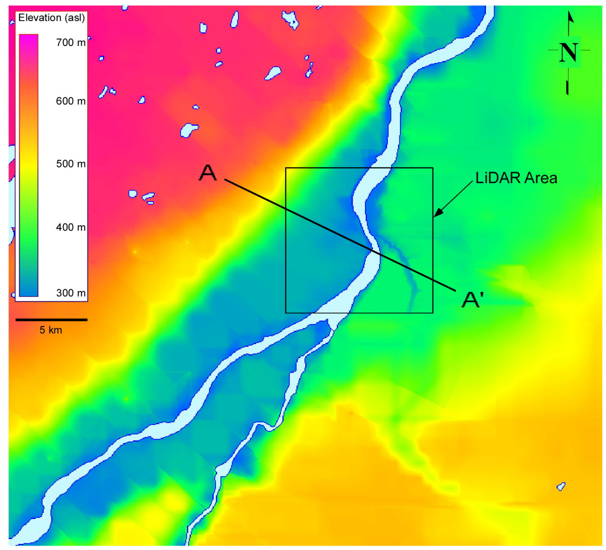

Figure 3. Generated bedrock topography model for the study area.

4.2 Quaternary Stratigraphy

The Quaternary stratigraphy, while probably incompletely documented and poorly understood in central Alberta, is best preserved in the ancestral buried valleys of the Peace River and its paleo-tributaries. The stratigraphy is summarized in Figure 4. The lowermost Quaternary stratigraphy is dominated by heavily oxidized, sandy, planar bedded pebble gravels that are entirely comprised of Cordilleran lithologies. This unit was observed up to 8 m thick in places. These sediments, due to the complete lack of Canadian Shield clast lithologies, predate glaciation in central Alberta.

A pebbly sand unit, approximately 5 m thick, overlies the oxidized gravels. This unit is tabular and trough cross-bedded with coarser gravels defining the channel beds. It is within this sediment package, that rare (<0.5 %) Canadian Shield lithologies are documented. A similar sedimentary package was described by Botterill (2007) at an exposure approximately 20 km upstream.

A coarse gravel package approximately 10 to 12 m thick occurs above the sandy unit, with increasing concentrations of Canadian Shield pebbles grading upwards. The gravel beds are clast-supported with massive to tabular structure. A fragment of barren-ground caribou antler was found in a similar sedimentary package described by Botterill (2007) which produced a Middle Wisconsin AMS radiocarbon date of 25,120 +/- 140 ^{14}C BP (Beta – 226811).

A thick (20 to 22 m) stratified sandy unit overlies the gravels. The sands are mainly medium to fine grained but a slight fining upward sequence is visible. Trough cross bedding and high angle planar cross bedding is seen in the lower portion of the unit. In the upper part of the unit planar bedding is the dominant structure, but thin horizons of low angle cross bedding are present.

At the onset of Late Wisconsin glaciation, advancing ice dammed regional drainage outlets and a lake formed in the Peace River valley. This lake was quite pervasive and deep (Mathews, 1980), depositing almost 100 m of sorted fine sand, silt and clay. Dropstones are common in the upper part of the unit and there is a gradual coarsening upward in the uppermost 15 metres. This thick, overconsolidated package of glacial lake sediments is probably responsible for the majority of the deep-seated failures in the Peace River valley and was the focus of field mapping as a possible rupture surface for large upper valley wall translational earth slides.

Glacial sediments cap the thick glaciolacustrine package. In places where the glacier has not eroded the previously deposited sediments, the complete stratigraphy includes chaotic stratified and weakly deformed glaciofluvial pebble sand and granule gravel with interbeds of diamicton and silt. This unit is interpreted as advance phase glaciofluvial subaqueous outwash that was subsequently overridden by the Laurentide Ice Sheet during the Late Wisconsin.

Dense, fissile, massive dark grey diamicton of variable thickness overlies the outwash unit. The diamicton overall contains a sandy silt matrix with approximately 5 percent clast content. There are occasional interbeds and discontinuous stringers of (<10 cm thick) of silt and/or sand occurring throughout this unit. This diamicton is typical of the surface tills of the region and is interpreted as a till sheet from the late Wisconsin glacial event (Lostwood Glaciation).

Glaciolacustrine processes subsequently winnowed and redeposited diamicton-derived sediments. Horizontally stratified proglacial lacustrine sands were deposited as the Laurentide Ice Sheet retreated to the north. This facies consists of a fining upward sequence of bedded and laminated silt and sand. Glaciolacustrine silt and laminated silt and clay were conformably deposited as the ice margin continued to retreat and glacial Lake Peace continued to inundate the region. Glacial Lake Peace sediments occur below 610 m asl, commonly as weakly bedded and laminated silty clay, in places up to 30 m thick (Leslie and Fenton, 2001). These distal sediments are the product of quiet water suspension settling which occur between periods of active current traction (Ashley 1996).

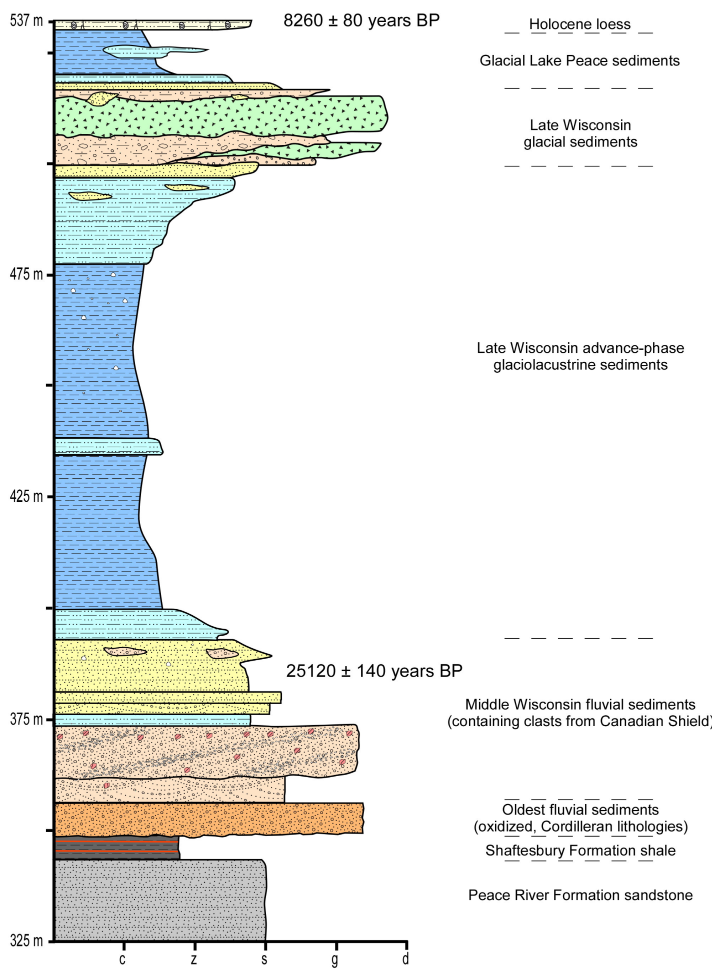

Figure 3. Composite Quaternary geology section as mapped at the confluence of the Heart and Peace Rivers.

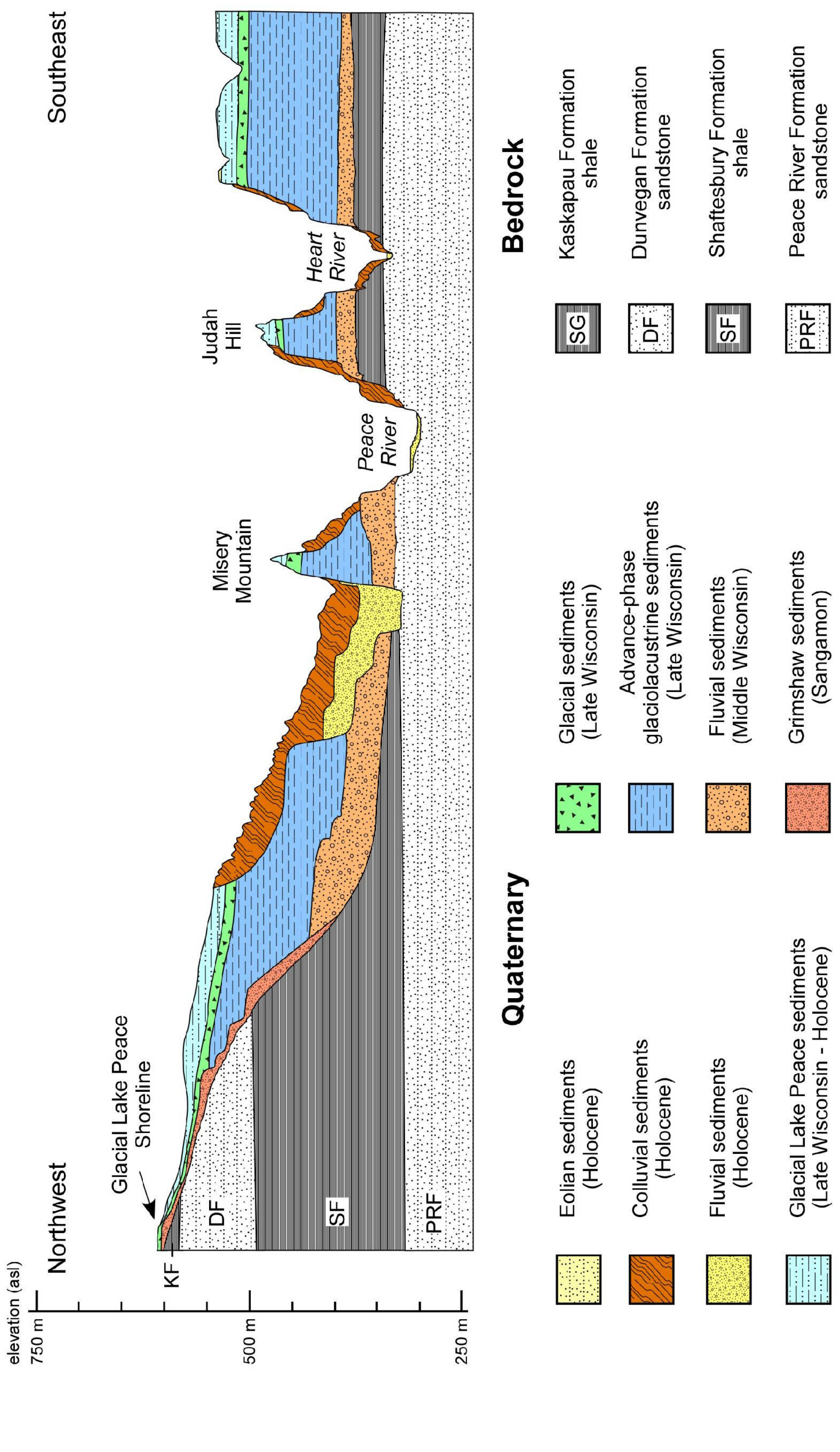

Figure 5. Vertical cross section A-A' as shown in plan on Figures 2 & 4. Horizontal distance 18 km, 12X Vertical exaggeration.

The loess is massive to finely laminated, medium brown with a sandy silt matrix and varies in thickness from <0.5 m to 2.5 m. Colour is due in part to its rich organic content. Abundant terrestrial mollusks, seeds and charcoal are present throughout the unit. A basal date from wood fragments yielded an AMS radiocarbon date of 8260 +/- 80 ^{14}C BP (TO-11927), providing a minimum age for drainage of glacial Lake Peace.

4.3 Cross Section

A vertical cross-section was generated through the study area (Figure 5, previous page). The cross-section shows the erosional bedrock surface which defines the buried preglacial Peace River valley, the contacts between the bedrock units and the approximate and inferred Quaternary stratigraphy. Borehole geophysical logs and geotechnical borehole logs aided in interpretation of the Quaternary sediments, yet the Quaternary stratigraphy lacks detail in places.

5 DISCUSSION AND CONCLUSIONS

Over the past 50 years there have been a significant number of published and unpublished case histories documenting slope movements in and around the Town of Peace River. While each of these studies generated a site specific interpretation of the geological setting in order to generate a model for interpretation and mitigation of the slope movements, the overall geological model and setting for landslides was not well understood. In fact, recent review of previous reports in light of the new geologic model has found that many of the previous reports misinterpreted the geological model.

With the emergence of the use of databases, new modelling tools and high resolution remote sensing data, detailed models of the bedrock surface and surface morphology have been tied in with regional and site specific mapping in order to come up with a refined model for the glacial stratrigraphy and landslide mechanisms in the Town of Peace River. Coupling the bedrock topography model with the surface DEMs show a positive correlation between large landslides and preglacial valleys infilled with thick Quaternary sediments. Coupling surface models with stratigraphy allows us to estimate where the majority of the deep-seated failures are occurring. A unit of ice-advance glaciolacustrine sediments, between elevation 420 and 460 m (asl) controls the large majority of the deep seated movements that impact on municipal development, residential development and infrastructure in and around the town. Many of the exsting slowly moving landslides in the town are seated in colluvium that has been generated from first time slides based in this unit.

The updated model for the geological setting for landsliding in the Town of Peace River provides a basis for better informed planning for investigation and mitigation of landslides. With the knowledge that thinly bedded (centimetres thick) layers of lacustrine sediments occur between elevations 420 and 460 m (asl) it allows for careful consideration of drilling and sampling techniques and a more realistic basis for modelling of movements to plan mitigative measures.

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