BEDROCK TOPOGRAPHY MAPPING AND SHALLOW GAS IN NORTHEASTERN BC

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ABSTRACT

The British Columbia Resource Development and Geoscience Branch is conducting a bedrock topography and drift thickness mapping program in northeast British Columbia. The program is to provide a basic understanding of the Quaternary geology and shallow gas potential in the northeastern region of the province. This paper outlines the methodology proposed for the program. The process involves: 1) compile all available data sources; 2) standardize the data in a database; 3) analyze data spatially and model subsurface horizons; and 4) add geological interpretation. The program will result in the production of 1:250 000 scale bedrock topography and drift thickness maps for the plains region of northeastern BC. The maps provide a framework for interpreting the glacial history of the area, assist in seismic interpretation and drilling logistics, and identify buried paleovalleys that have the potential to host Quaternary gas deposits.

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INTRODUCTION

The British Columbia Resource Development and Geoscience Branch (RDGB) has established a bedrock topography and drift thickness mapping program to provide a basic understanding of the Quaternary geology and shallow gas potential of northeast British Columbia (NEBC).

The bedrock topography mapping program is focused on providing 1) the stratigraphic framework for “shallow gas” plays in NEBC; 2) identifying areas with thick unconsolidated deposits in order to assist with seismic interpretation (slow velocity zones); 3) identify areas where artesian aquifers may cause significant drilling problems; and 4) provide estimates of casing depths to minimize environmental impact and mitigate against well cave-ins. Gas from Quaternary hosted reservoirs has been known in northwest Alberta since the 1993 discovery at Sousa (Canadian Discovery Digest, 2001). Unfortunately, at that time the host strata of this shallow discovery was not recognized as Quaternary in age and consequently further exploration for this type of play received little attention. Quaternary plays only gained momentum as an exploration target in the late 1990’s (e.g. the Sousa and Rainbow fields have produced since 1998). In BC there are no reported perforations in Quaternary age deposits, but it is likely that any Quaternary reservoir may have been misidentified as a near surface bedrock formation, such as is the case in the Desan shallow gas field. In this field the Ish Desan d-81-K (WA# 14894) well reports gas in the Dunvegan Formation. However, lithologic logs show the top of the Dunvegan Formation ~300 m lower in elevation than would be expected for the area (Stott, 1982). It is possible that shallow gas in this area is hosted in the Quaternary fill of a buried paleovalley.

In this paper we propose a methodology for bedrock topography mapping in NEBC. The objectives of the mapping program are:

- Provide 1:250 000 scale bedrock topography and drift thickness maps,
- Identify areas where buried paleovalleys may potentially host Quaternary gas deposits,
- Provide a framework for interpreting the glacial history and exploring for buried sand and gravel in NEBC.

Previous Work

The BC Oil and Gas Division began drift thickness and bedrock topography initiatives in 2003 as part of an inter-governmental project that includes the Alberta Geological Survey (AGS) and the Geological Survey of Canada (GSC) as part of Northern Resource Development Project 4450. Initial work was directed at identifying bedrock top picks in gamma logs for map sheets 94I and 94P. The initial data compilation identified several depressions believed to represent paleovalleys that presently have no surface expression (Levson *et al*., 2004). Continuing work in these map sheets has been expanded to include additional datasets and incorporates bedrock topography and drift thickness mapping methods established by Hickin *et al.* (2004a, 2004b) and Pawlowicz *et al.* (2004).

Study Area

The study area is located in the Boreal Plains of northeastern British Columbia and includes the Fontas River (NTS 94I) and Petitot River (NTS 94P) map sheets (Figure 1). Low relief and clay-rich surficial deposits typify the area resulting in poor drainage. Lakes, marshes, fens, and peat bogs are common and the vegetation can be characterized largely as a mix of young aspen forest and black spruce bog. Areas slightly elevated above the surrounding terrain are commonly vegetated with trembling aspen (*Populus tremuloides*), lodgepole pine (*Pinus contorta*), and white spruce (*Picea glauca*). Black spruce (*Picea mariana*) is dominant in the lower, wetter areas. Permafrost is present, particularly in the muskeg and peat-rich areas and both active and relict thermokarst is responsible for many of the lakes.

BEDROCK GEOLOGY

The upper most bedrock units in the study area include of Lower to Upper Cretaceous shale and sandstone of the Fort St. John Group and Dunvegan Formation (Thompson, 1977; Stott, 1982). The subsurface units relevant to this study (to a depth of ~800m) include the Banff Formation (Mississippian), Rundle Group (Mississippian), Diaber Group (Triassic), Bullhead Group (Lower Cretaceous), Fort St. John Group (Lower to Mid Cretaceous), and the Dunvegan Formation (Upper Cretaceous). The following units descriptions are from Glass (1997) (Figure 2).

The Banff Formation consists of shale and marlstone that grade upward and eastward into spiculite, bedded chert, and carbonates. The upper portion of the unit, which is truncated by a regionally extensive sub-Cretaceous unconformity in northwestern Alberta, occurs as a succession of interbedded sandstones, siltstones, and shales.

The Rundle Group includes the Pekisko, Shunda, and Debolt formations. The Pekisko is a crinoidal to fine-grained dense limestone. The Shunda consists of interbedded limestone, dolostone, siltstone, sandstone, shale and breccia. The type section for the Debolt consists of cherty, massive bioclastic limestone and dolomite. In northeast BC, it is mainly limestone with less dolomite and shale.

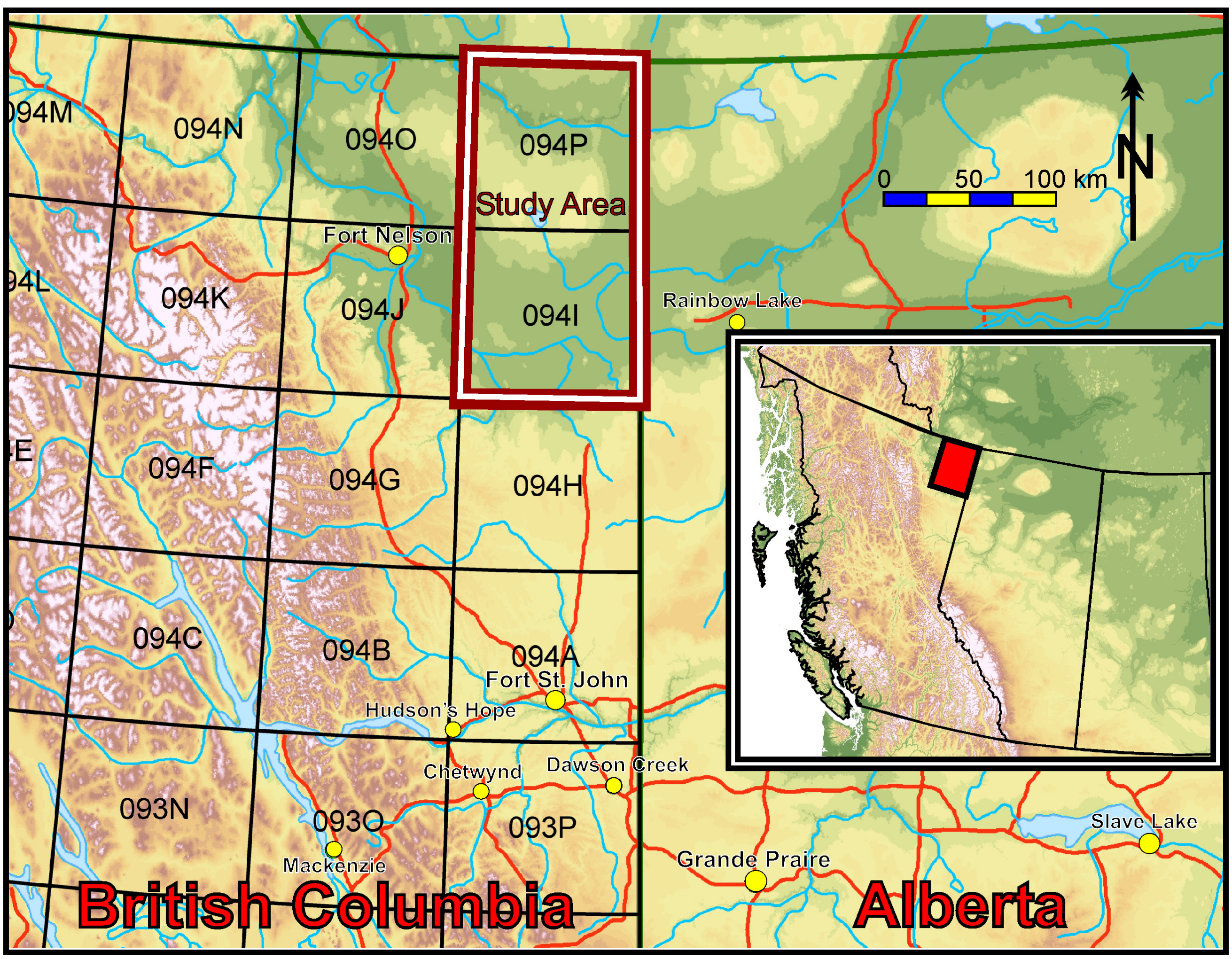

Figure 1. The study area is located in the northeastern corner of the province in the Western Canadian Sedimentary Basin. Preliminary bedrock topography mapping has focused on NTS map sheets 94P and 94I.

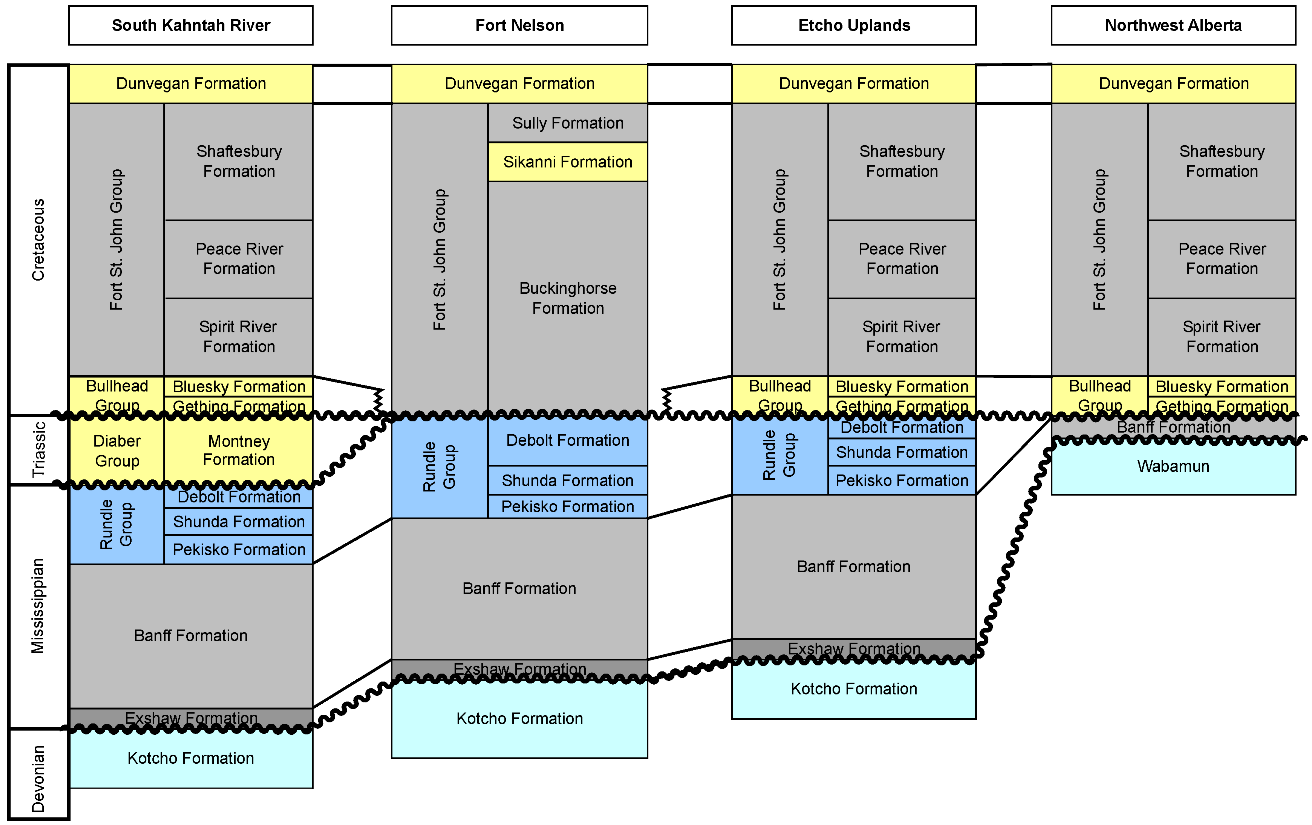

Figure 2. The bedrock stratigraphy of the area is transitional between the nomenclature from the northwestern plains of Alberta and that of the Fort Nelson area (after Stott, 1982 and Thompson, 1977).

The Monteney is the only formation of the Diaber Group identified in the map area. The Montney is an important unit as it occurs in the southern portion of the of the map area (Kahntah River area) as a gas bearing sandstone. The Montney typically consists of siltstone and shale with the arenaceous content increasing in the eastern portion of the study area. The Montney is also truncated by the sub-Cretaceous unconformity and is not present to the north of the Hay and Fontas rivers.

The Bullhead Group is represented by the Gething/Bluesky Formations (undifferentiated in this study). The Bluesky Formation is a fine to medium sandstone, usually glauconitic, and may contain chert pebbles. The unit is typically thin, ranging from absent to 46 m, though not typically more then 10 m thick where present in the map area. The Bluesky is a well known gas bearing unit in Alberta. The Gething Formation is a heterogeneous stratigraphic unit consisting of conglomerate, coarse to fine grained sandstone and marine siltstone and mudstone. The formation has been extensively study south of the study area as it is a well known coal bearing unit. The Bullhead Group has only been identified in the southern and southeastern portions of the study area.

The Cretaceous rocks of the Fort St. John Group and Bullhead Group (where present) are separated from the Mississipian rocks by the sub-Cretaceous unconformity. The lower Fort St. John Group includes the Spirit River and Peace River formations, which are equivalent to the Buckinghorse Formation around the Fort Nelson area. The upper Fort St John Group includes the Shaftesbury Formation. All of these units occur as shale or siltstone in the map area.

The upper most unit in the area is the Dunvegan Formation, which outcrops on the Etsho Plateau. The Dunvegan consists of marine, deltaic and channel sandstone, conglomerate, and shale.

PRE-GLACIAL AND PLEISTOCENE HISTORY

Tertiary and Pleistocene processes have played an important role in shaping the Boreal Plains. Tertiary erosion and deposition began influencing the landscape following regression of the Cretaceous seas. During the Pleistocene, climate cooled and glaciers advanced into the area. Pleistocene glaciers are responsible for most of the surficial sedimentary cover and current landscape of NEBC (Ferbey *et al.*, this volume).

The late Tertiary and early Pleistocene was a period of significant erosion in NEBC. During this time, drainage systems from the Rockies carved valleys that extended east from the mountains, transporting and depositing sediment as far as central Alberta (Edwards, 1994).

As the climate deteriorated, Laurentide ice advanced up the regional slope from the northeast. Large proglacial lakes formed as the advancing ice impounded drainage.

The ice eventually overrode the lake sediments, depositing a thick blanket of till masking the older valleys with as much as 300 m of sediment. At glacial maximum, Cordilleran and montane ice also played a role in depositing sediment, though their influence was generally restricted west of the study area along the Rocky Mountain foothills (Trommelen *et al.*, this volume). As the climate warmed the ice retreated, again impounding drainage and forming large recessional proglacial lakes (e.g. Glacial Lake Peace and Glacial Lake Hay) (Mathews, 1980). The area was ice free by the Holocene (~10, 000 years ago).

METHODS

The process used to map the bedrock topography is summarized in 4 steps (Hickin *et al*, 2004a, 2004b; Pawlowicz *et al*., 2004): 1) compile all available data sources; 2) standardize the data in a database; 3) analyze data spatially and model subsurface horizons; and 4) add geological interpretation.

Data Sources

A variety of data sources are available for mapping key subsurface horizons. These include oil and gas well petrophysical logs, drill cuttings, surficial and bedrock geology maps, and water well lithology logs.

The bulk of the subsurface data comes from the downhole petrophysical logs collected by the oil and gas industry (Figure 3). From these data, depth to bedrock and other key horizons can be extracted. The most commonly used logs in this study are gamma and neutron density logs, as they can provide lithologic information for both the cased and uncased portions of the wells. Prior to 2003, surface casing was required to be set at a depth of 15% of the planned total depth of the well or 150 m, whichever was greater. Current BC regulations require casing to be set below all strata expected for drinking water and at least 25 m into a competent horizon for blowout prevention (*Petroleum and Natural Gas Act*, 1998). As a result, wells are often cased into bedrock with the drift contact occurring at some depth behind the casing. This contact will manifest as a suppressed gamma or neutron shift. Unfortunately there are circumstances when the contact may be undetectable, for example where the contact is coincident with the bottom of the casing or where clay rich drift sediment is in contact with clayey, weathered bedrock shale (both with similar radioactive properties). It is, therefore, important to determine the bedrock stratigraphy so that the absence of key radioactive or density markers can be used to infer an erosion contact between the bedrock and the drift.

Drill cuttings can also provide an estimate of the depth to bedrock. The contact between the drift and the bedrock surface is marked by a shift from granitic and metamorphic fragments associated with Laurentide till, to shale and sandstone associated with the Cretaceous Fort St John Group and Dunvegan Sandstone (Figure 4). The contacts determined from drill cuttings should be considered an estimate as several factors can contribute to changes in fragment lithology. Contamination, loss of

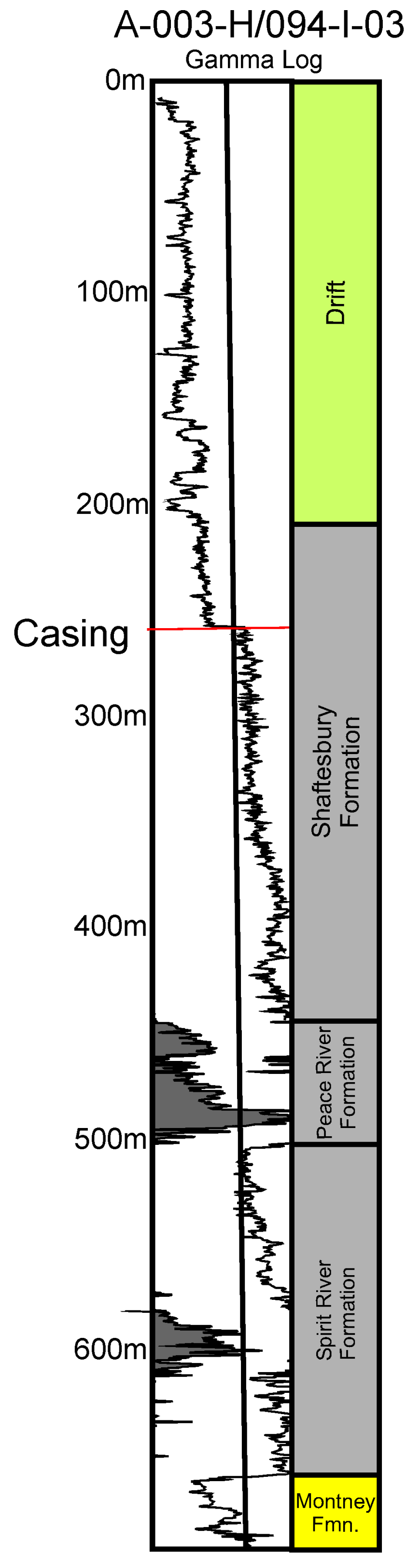

Figure 3. Gamma logs are the most common petrophysical log used in this study. Despite the contact occurring behind the casing, the bedrock-drift interface can easily be identified. In this example (A-003-H/094-I-03; WA# 8977), the base of drift occurs where there is a shift from a relatively high, uniform gamma response in the Shaftesbury marine shale to a prominent decrease in radioactivity associated with coarser terrestrial sediments in the drift.

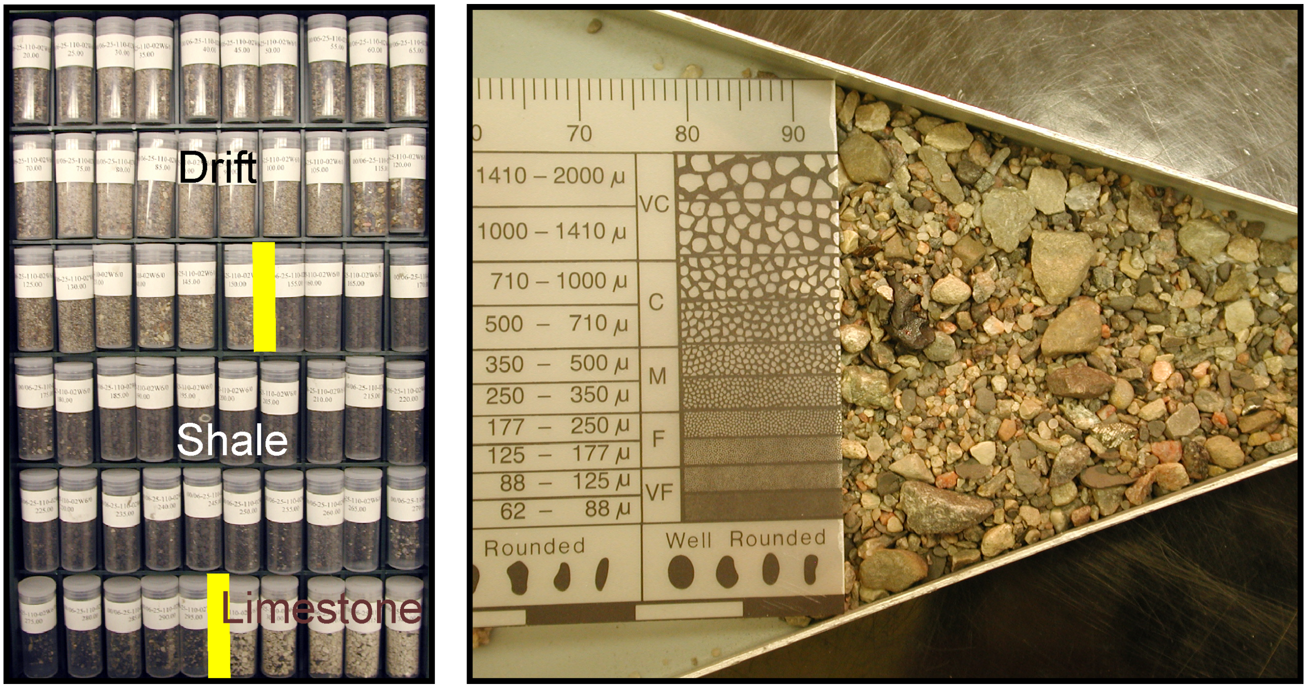

Figure 4. Drill cuttings can also provide an estimate of the depth to bedrock. Drift drill cuttings contain an abundance of granitic and metamorphic fragments often dominated by feldspar. These lithologies are derived from the Canadian Shield, deposited as till after being transported by glaciers. Bedrock chips contain shale, siltstone, and sandstone fragments as all local bedrock has a sedimentary origin (photo on left courtesy of John Pawlowicz).

circulation, gradational contacts, and lag time can all contribute to ambiguity in the precise depth of a contact. Whenever possible, a drill cutting lithologic contact should be confirmed by a geophysical log.

Currently, the Oil and Gas Division of the BC Ministry of Energy and Mines is working cooperatively with the GSC to map the surficial geology of northeastern BC. These maps will be incorporated into the subsurface program as an additional source of information. The surficial geology maps help to anchor the bedrock topography model to the surface digital elevation models (DEMs). This is achieved by including mapped areas noted as having thin drift or bedrock outcrops into the generated bedrock topography model. The result is that elevations in the bedrock topography model and the DEM will be similar in areas of thin drift or identical where bedrock outcrops.

The final source of data collected for this program is lithology logs provided by the water well drilling industry. Typically, companies drilling water wells record general comments regarding the lithologic observations (often in lay terms). This data, though not definitive, can provide information such as depth to bedrock, or the absence of bedrock over a stated interval (Figure 5). The Ministry of Water, Land and Air Protection's aquifer and water well database has, in the past, been the major source for water well data for the province. However, as there is a limited populous in map sheets 94I and 94P, there is little data available for this area. To augment provincially held data, lithologic information has been provided by drilling companies contracted to drill water wells to support remote oil and gas camps, or to access water for drilling fluid, and shotholes drilled to set seismic charges.

Data Entry

To properly manage and utilize the various datasets, it is important to compile and standardize the data. This is achieved by entering the data into a pre-structured database that the RDGB has developed in *MS Access*. All data is entered using menu entry forms that make certain the data is entered consistently. This ensures that the information required for querying and geostatistical analysis is available for the modeling software.

The data can be separated into two types, lithologic and stratigraphic. Lithologic data from a water well may describe the material drilled over a 30 m interval as: 0-10 m of sand; 10-20 m gravel; 20-30 m shale. Units are simply described, but are not related from one well to another, nor is an age relationships implied. Stratigraphic data assigns a unit an age and name placing it within the stratigraphic framework of the area. The stratigraphy of the same interval described above would be: 0-20 m Quaternary Drift; 20-30 m lower to upper Albian Shaftesbury Formation.

Spatial Data Analysis and Modeling Subsurface Horizons

Once the data has been sorted and extracted from the database it can be spatially analyzed. Histograms and semivariogram/covariance clouds are used to investigate the distribution of the data. These characteristics provide insight into the most suitable interpolation method for the data. Interpolation is a statistical method of predicting values between known points. (*c.f.* Bailey and Gatrell, 1995). Parameters used in the interpolation are then fine

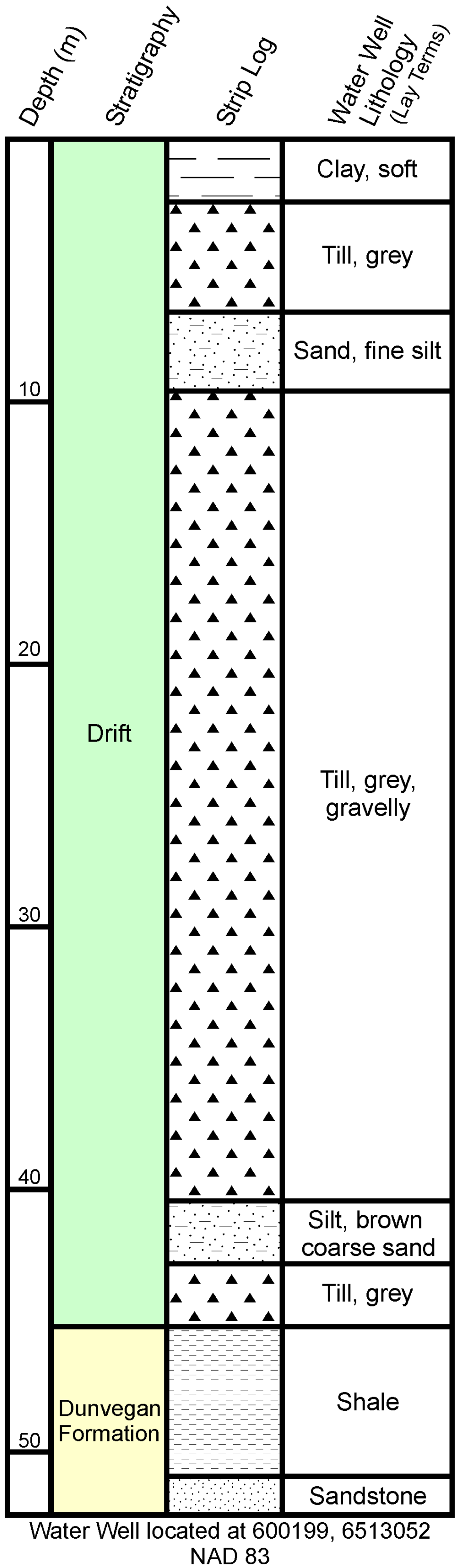

Figure 5. A typical water well log will describe the materials encountered during drilling. The descriptions are generally in lay terms therefore the cautions should be exercised when assigning the material to a genetic sediment type (e.g. till vs. diamict). Strip logs

tuned in an iterative process in an attempt to minimize the root-mean-square error (the difference between the predicted values for the surface and the known data points).

Adding Geological Interpretation

As interpolated surfaces are generated from point data by the interpolation algorithms built into the gridding software, they do not always represent the real geological situation. Therefore it is important not to accept the generated surface without appropriate quality control. Furthermore, the modeled geological surfaces should include the valuable non-point data and incorporate the geologist's geologic/geomorphologic experience in order to ensure the interpretation reflects the true nature of the subsurface.

Interpolated surfaces are generated from point data that contains *x*, *y* locations (UTM eastings and northings) and a *z* value (elevation above sea-level); however, some x, y locations will not contain a meaningful *z* value but still contain information that affects the model. This information is valuable and needs to be incorporated into the surface modeled for a geological horizon. An example of such a case is when the well or borehole ends before the horizon of interest is intersected. In this case the horizon of interest is known to be deeper than the bottom of the well. If the interpolated surface passes above or at the bottom of the well then it violates known information (although there is no real *z* value that the algorithm can invoke) and must be corrected to pass at a depth below the bottom of the well. Similarly, a well log may start at some depth below ground surface and contain data that clearly shows bedrock to the top of the log. From this data, it is known that the bedrock drift interface must occur above the top of the logged portion of the well and the projected surface must honour this condition.

The interpolated surfaces can be manipulated for quality control in a variety of ways. In this project, the gridded surfaces are brought into or generated in ViewLog™. Cross-sections are constructed at regular intervals displaying the stratigraphic horizons and well logs with both stratigraphic and lithologic strip logs are displayed. Polygons of thin drift and outcrop (from surficial geological mapping) are incorporated into the model and horizons visually inspected so that they do not violate any of the available data. Errors are corrected and new surfaces generated for contour maps of the bedrock topography. The drift thickness is a calculated surface generated by subtracting the bedrock topography from the surface DEM.

CONCLUSION

Rapid expansion of the oil and gas industry in northeast BC has increased the demand for baseline geological information. Bedrock topography mapping is one of the initiatives the British Columbia Resource Development and Geoscience Branch has under taken to support and develop the oil and gas industry. The primary objective of the bedrock topography mapping program is to provide the stratigraphic framework, geological setting, and potential target areas for shallow gas exploration in the BC portion of the Western Canadian Sedimentary Basin.

Preliminary studies have identified several areas in NTS map sheets 94I and 94P that may have buried paleovalleys. In an effort to verify and map these potential valleys, methodology adapted from collaborative work in Alberta is being utilized. The methodology incorporates several data sources including traditional point data from petrophysical logs, as well as non-point data such as surficial geology maps (outcrop maps), water well lithology logs, and drill cuttings. These data are managed in a database, standardizing information for later extraction into geological modeling software. The modeling software uses both statistically predicted surfaces and geologic/geomorphologic interpretations to produce the best representation of the available data.

The final contour maps will depict the bedrock surface with the Tertiary and Quaternary cover removed as well as isopach maps of the drift thickness. This information can then be used to identify areas of deep incision that may have shallow gas potential, areas requiring deep casing, and potentially, stratigraphic information valuable for sand and gravel exploration, and other Quaternary studies.

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