Cover Thickness across the Southern Interior Plateau, British Columbia (NTS 092O, P; 093A, B, C, F): Constraints from Water-Well Records

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Introduction

Basalts of the Chilcotin Group (CG), situated in the southern Interior Plateau physiographic region of central British Columbia, cover an area of over 30 000 km^2 (Figure 1). Their distribution is entirely within the region of BC that is most affected by mountain pine beetle (MPB) infestation (Figure 1). The CG is typically underlain by Paleozoic and Mesozoic basement rocks with high potential for Cu-Au-Mo deposits (e.g., Quesnel Trough), Eocene volcanic successions that host epithermal Au deposits (e.g., Blackdome), and Jurassic and Cretaceous sedimentary rocks of the Nechako Basin with hydrocarbon and possible mineral potential. In addition, the CG is itself, extensively overlain by late Quaternary glacial deposits of variable and unknown thickness.

The distribution of known mineral resources and prospects on the periphery of the CG (e.g., Blackdome, Gibraltar, Mount Polley, Prosperity and Vidette) makes the potential for unexploited mineral resources extending beneath the CG compelling (e.g., Mihalynuk, 2007a). However, there is currently little coherent data on the spatial distribution (e.g., thicknesses), the lithostratigraphy (facies variations) and physical properties (density, porosity, magnetic susceptibility and conductivity) of the CG and overlying Quaternary deposits. The incompleteness of geoscience information is one of the greatest impediments to successful exploration for resources beneath the CG. One aspect of this incomplete dataset is the depth through cover (glacial and CG) to basement, which is largely unknown. Previous workers have suggested that the CG can reach a thickness of ~200 m and averages ~100 m in thickness (e.g., Mathews, 1989); however, the authors have suggested that the CG is comparatively thin (<50 m) across most of its distribution and only thick (>100 m) in paleochannels (Andrews and Russell, 2007). This initial hypothesis is supported by field observations from key vertical sections exposed in present-day drainages and canyons (e.g., Farrell et al., 2007; Gordee et al., 2007) and from analysis of volcanic facies and map unit geometries (Andrews and Russell, 2007; Gordee et al., 2007).

Herein is the analysis of geological information (lithology, thickness) available from the WELLS database, as it pertains to the southern Interior Plateau. This database comprises depth and lithology information recorded as water wells were drilled and is maintained by the BC Ministry of Environment (2007). In addition, thickness estimates for the CG from exposed sections and hydrocarbon exploration wells are included. This work forms part of Geoscience BC project 2006-003, which aims to produce 3-D facies and thickness models for the CG that can be used to 1) extrapolate regional geology, metallogeny and structure beneath the CG cover; 2) find windows to the basement and identify the basement geology; 3) delineate areas where the CG is thin or absent; and 4) provide a 3-D representation of physical property variations to allow the signature of the CG to be accurately stripped from total-field geophysical datasets.

Geological Setting

The Neogene Chilcotin Group (28–1 Ma) of south-central BC covers an area of over 30 000 km^2 (Figure 1), beneath an extensive blanket of Quaternary deposits. The region is characterized by moderately dissected, valley-incised plateaus, mainly composed of basaltic successions varying in thickness from 5 to 200 m (Andrews and Russell, 2007). Estimates of total volume are as high as 3500 km^3 (Bevier, 1983; Mathews, 1989). The CG basalts are typically flat to shallow dipping, massive to columnar jointed, olivine-phyric basalt lavas with lesser volumes of pillow basalt and hyaloclastite (Gordee et al., 2007), occasional red-weathering paleosols (Farrell et al., 2007) and rare, intercalated felsic tephra (Mathews, 1989).

Keywords: Chilcotin Group, water wells, thickness models, GIS, paleotopography, Interior Plateau, Quaternary deposits

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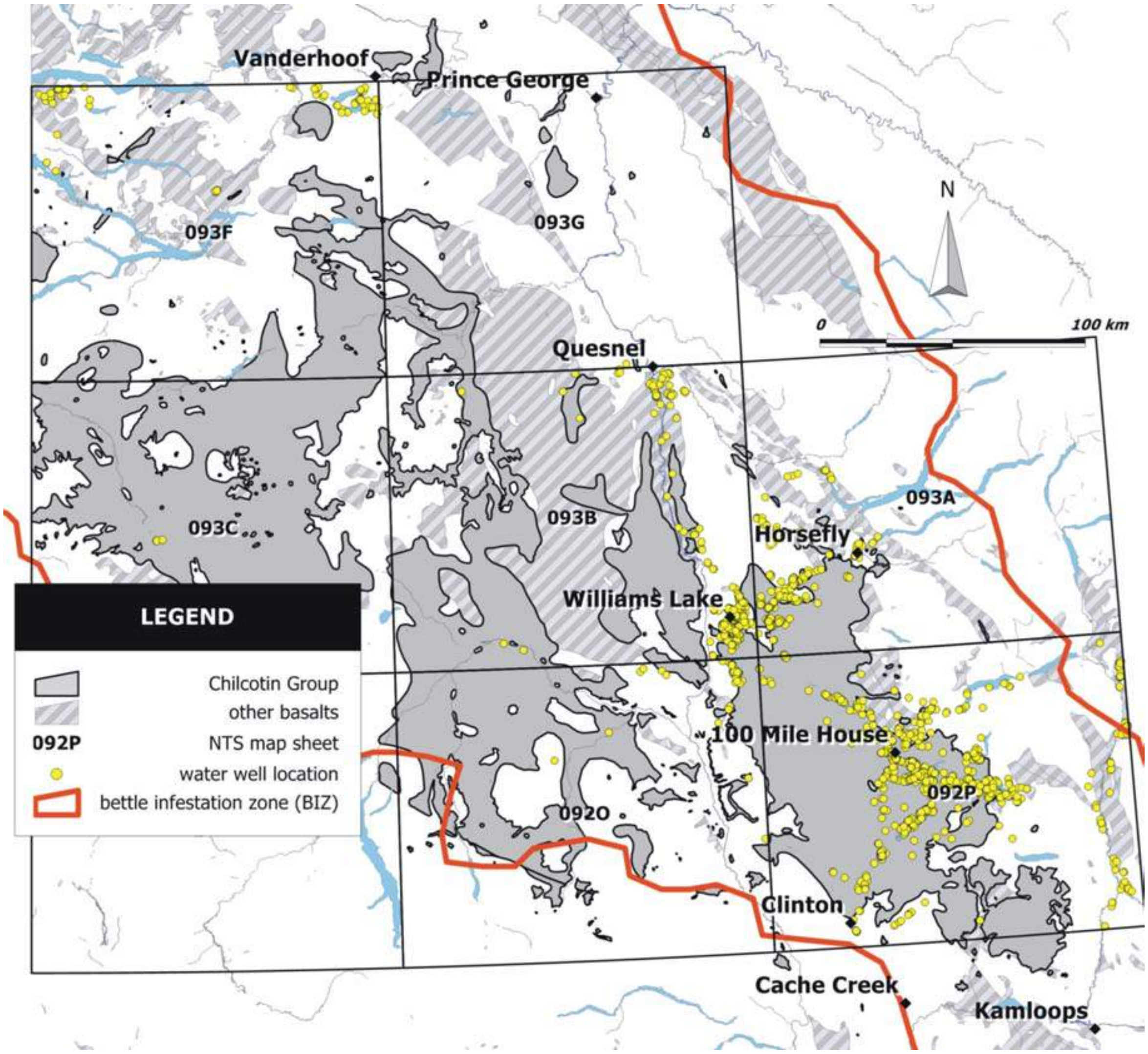

Figure 1. Simplified geological map of the southern Interior Plateau (NTS 092O, P, 093A, B, C, F) depicting the distribution of the Chilcotin Group and adjacent basaltic and basalt-hosting stratigraphic units (Massey et al., 2005a, b), major settlements and the margin of the mountain pine beetle infestation zone (BIZ). The locations of the water wells analyzed are shown as yellow dots.

The CG unconformably overlies a diverse range of rock types and stratigraphic packages, potentially the most economically important of which are the

- Upper Paleozoic limestone and phyllite of the Cache Creek Terrane;
- Triassic volcanic (including basalt) and volcaniclastic rocks of the Nicola Group (Quesnel Trough) that host granitic intrusions and extensive Cu-Au-Mo mineralization;
- Mesozoic marine sedimentary deposits of the Nechako Basin;
- Lower Eocene clastic sedimentary, volcanic (including basalt) and volcaniclastic rocks that host localized epithermal Au deposits; and
- Upper Eocene, Oligocene and Lower Miocene sandstone and shale.

The sub-CG basement geology is observed in windows through the basalt, however, the combination of areally extensive, glacially derived, surficial Quaternary deposits and the CG means that such windows are far apart. The consequence is that the basement geology cannot be extrapolated with a large degree of confidence beneath these cover units.

Analysis of Water-Well Records

Rationale

The widespread distribution of Quaternary surficial deposits precludes direct observation of the CG basalt for much of the Interior Plateau. In many instances, the distribution and the thickness of the underlying basalts is completely unknown; the basalts are assumed to be uniform in thickness and distributed everywhere beneath the surficial deposits. However, the recent work of Gordee et al. (2007) and Farrell et al. (2007) has led Andrews and Russell (2007) to propose that the CG is relatively thin; on average (<50 m) and is only thick (>100 m) in paleochannels. This suggests that under the extensive Quaternary cover, the CG may be very thin (<25 m) or absent, despite existing regional geological maps indicating otherwise. This hypothesis has been partly confirmed by a preliminary GIS study (Mihalynuk, 2007b). To test this hypothesis further and to attempt to map the basement beneath the CG, over 8000 water-well records have been examined to extract lithological and thickness data.

Methodology

The top-most bedrock lithology has been identified and vertical thickness estimates of the CG have been collected from outcrops (i.e., measured vertical sections) and publicly maintained databases (i.e., WELLS database, BC Ministry of Environment [2007] and well reports, BC Ministry of Energy, Mines and Petroleum Resources [2007]).

Water-Well Records

Water-well records were obtained from the WELLS database, which contains in excess of 88 000 records covering all of BC. For the study area (NTS 092O, P; 093A, B, C, F), there are records for over 8000 water wells, of which 1773 penetrate into bedrock (Figure 1). Only those wells that record lithological information and penetrate the bedrock are included in this analysis. The full array of geographic, hydrological and lithological data was downloaded, edited and entered into a Microsoft Excel® spreadsheet (Table 1). The well name, well location, drift thickness, bedrock type, minimum basalt thickness and maximum basalt thickness were recorded for each record.

In addition to the lithological and thickness data, a qualitative assessment of the lithological interpretation of each recorded unit was made; specifically, a certainty from 0 to 3 was ascribed, where 3 is the maximum confidence and 0 denotes no confidence in the identification of the rock type intersected. For example, a well report including 'bedrock' is assigned a certainty rank of 0 (it offers no information on rock type); in contrast a report including 'hard vesicular basalt' is assigned a rank of 3 (positive identification of basalt). A 'black rock' is assigned a rank of 1 and a 'grey volcanic rock' is assigned a rank of 2. It should be noted that

- The identification of 'basalt' does not necessarily indicate CG basalt.
- Lithological descriptions are provided by water-well drillers who may not be (and probably are not) qualified geologists. Therefore, any inferences made on these descriptions must not be taken as accurate geological observations.
- The certainty ranking is wholly qualitative. The authors have used their experience of the known geology in the area, and their personal judgment, in assigning rankings. For example, an alternating sequence of 'black volcanic rock and red breccia' is assigned a rank of 3 and is inferred to be a subsurface expression of the Chasm lithofacies within the CG (Farrell et al., 2007).

The water wells recorded are primarily domestic or agricultural water sources, and therefore, their distributions are strongly heterogeneous and clustered around population centres (e.g., 100 Mile House and Williams Lake) and along major highways. As a result, there are minimal (<50) well records for NTS 092O, and 093C and F. Collation of well records for NTS 093G (Prince George) is ongoing and they are not included in this analysis.

Results

The results of the analysis are presented as a series of simplified geological maps with coloured dots representing each well. The size of dots is an indication of the certainty ranking; in contrast, dot colour reflects the unit thickness, except in one figure where colour indicates rock type.

Quaternary Deposits — Drift

All the well records analyzed (*n* = 1773) provide an estimate of the maximum thickness of drift encountered. In the analysis, 'unconsolidated deposits', 'glacial sediment', 'mud', 'clay', 'sand', 'gravel', 'rocks', 'boulders' and 'till' were assigned to 'drift'. Drift thickness distributions are summarized in Figure 2, which shows the widespread presence of 11–50 m thick drift across NTS 092P, and 093A

Table 1. Example of the Microsoft Excel® data table created for water-well records from the WELLS database (Ministry of Environment, 2007). The well records are supplied in imperial units and are converted to metric in the Microsoft Excel® spreadsheet. Note that this is example data only and does not correspond to real well data.

NTS sheet	Water-well no.	Water-well depth (m)	Drift thickness (m)	Minimum bedrock thickness (m)	Topmost rock type	Certainty ranking	Minimum basalt thickness (m)	Rock type below basalt
092O	28269	33	8	25	basalt	2	23	granite
092O	46586	58	35	23	unknown	n/a	0	n/a
092O	54137	66	33	33	basalt	1	33	?
092O	30723	54	52	2	basalt	2	2	?
092O	55724	112	15	97	granite	1	n/a	n/a

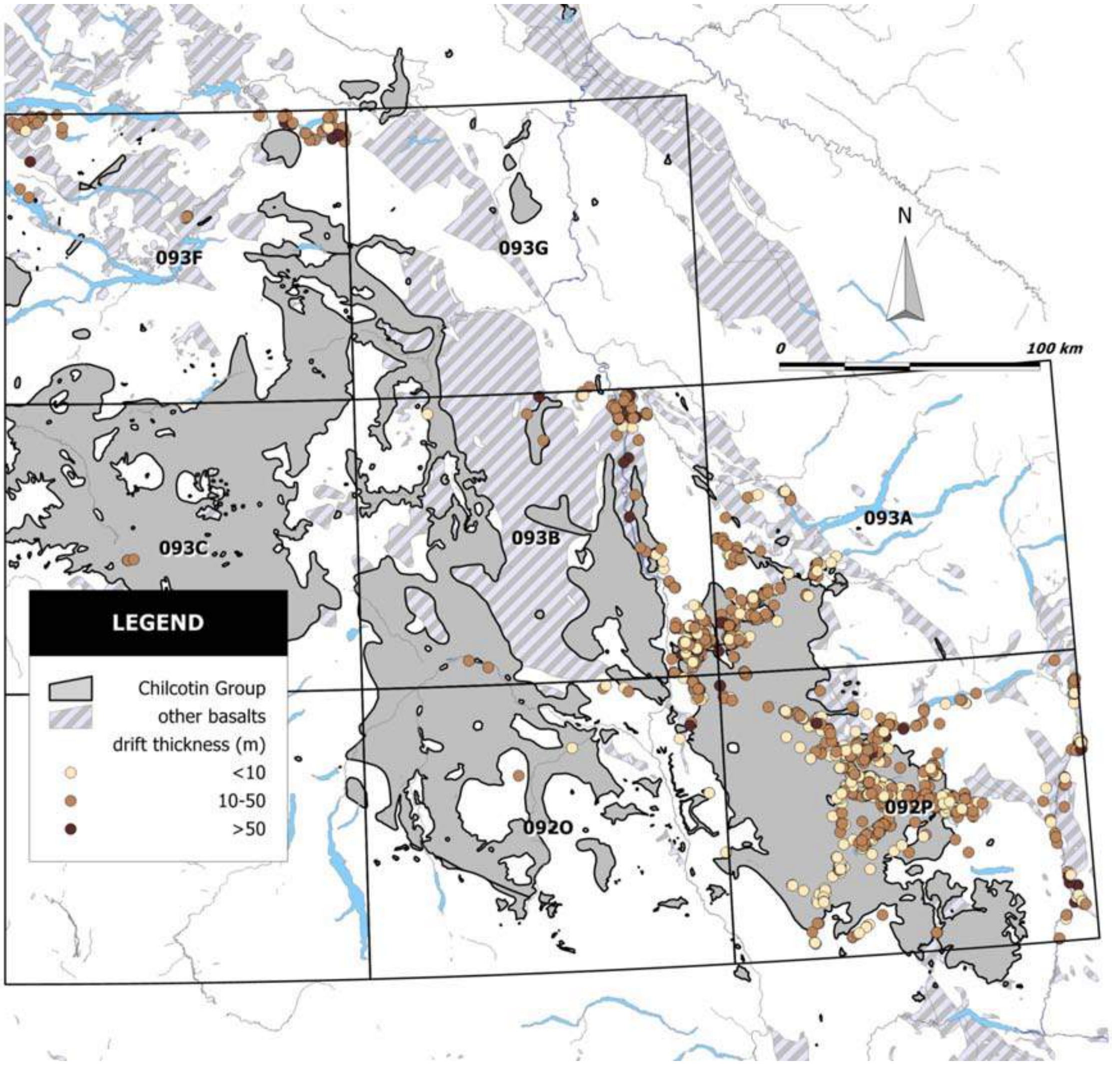

Figure 2. Quaternary drift thickness, southern Interior Plateau, BC (bedrock geology *after* Massey et al., 2005a, b).

and B. Drift less than 10 m thick is typical in the southwestern parts of NTS 092P around Clinton and in the areas bounding the Quesnel Highland around Horsefly (NTS 093A). Drift greater than 50 m thick is only extensive along the Fraser River valley between Quesnel and Williams Lake (NTS 093B). A preponderance of moderate thickness drift is demonstrated in Figure 3, where 66% of well reports record drift <70 m thick and 95% are <180 m (mainly around Williams Lake).

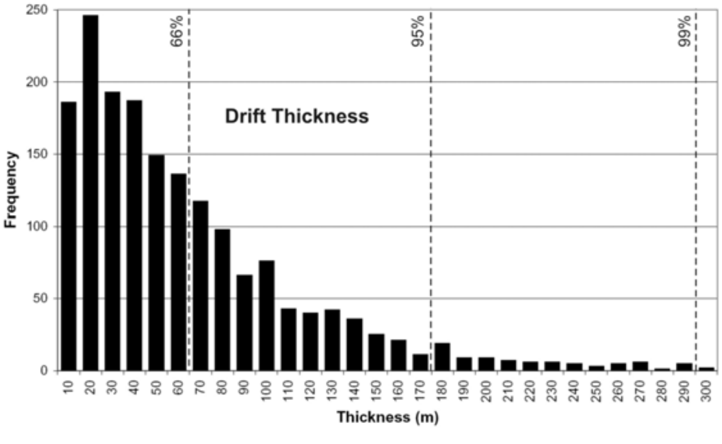

Figure 3. Histogram of drift thickness, southern Interior Plateau, BC. Note that the 66th, 95th and 99th percentiles are indicated.

Basalt

Most (1759) water wells penetrate bedrock that is inferred to be basalt in this study. The locations of those wells are displayed in Figure 1. Note that some of the wells displayed (≤20%) are located outside the margins of the CG; rather, several wells are located on pre- or post-Chilcotin Group bedrock that is, or may include, basalt (e.g., Triassic Nicola Group, Quaternary Wells-Grey basalt lavas). It is, however, impossible to distinguish between basalts of different stratigraphic packages. The majority of wells intercepting basalt correspond with mapped basalt occurrences with the exception of the cluster of 11 wells west of Prince George (NTS 093F), where basaltic bedrock appears to be present at ≤50 m depth.

Basalt thickness data is presented as both minimum thickness (*n* = 1585 wells) and maximum (i.e., true) thickness (*n* = 174 wells). Minimum thickness estimates come from those wells that penetrate into basalt and stop; therefore they only provide a minimum thickness constraint. In contrast, maximum thickness estimates come from wells that penetrate through basalt into a sub-basalt rock type.

The locations of minimum thickness estimates (*n* = 1585 wells) are displayed in Figure 4, where thicknesses are differentiated into unequal bins of <10 m, 10–50 m and >50 m. These bin sizes were chosen to best demonstrate critical basalt thicknesses pertaining to exploration and possible exploitation; where very thin basalt is effectively invisible to seismic and gravity survey, and where thick basalt is highly unfavourable for blind drilling or open-pit extraction. Wells penetrating into thick (>50 m thick) basalt are concentrated almost exclusively in the central portion of NTS 092P, under the town of 100 Mile House (minimum thickness 186 m) and immediately to the east (minimum thickness 124 m; Figure 4).

In addition, minimum basalt thickness derived from water-well records is supplemented by several field observations (measurement of vertical exposures). Although the number of measured sections included is small (*n* = 18 wells), they are located in areas not otherwise represented by water-well records, for example, along river valleys in NTS 092O and 093B (Figure 4).

The locations of maximum thickness estimates (*n* = 174 wells) and supplementary field observations (*n* = 6 wells) and hydrocarbon exploration wells (*n* = 1 well) are displayed in Figure 5. Again, thickness bins of <10 m, 10–

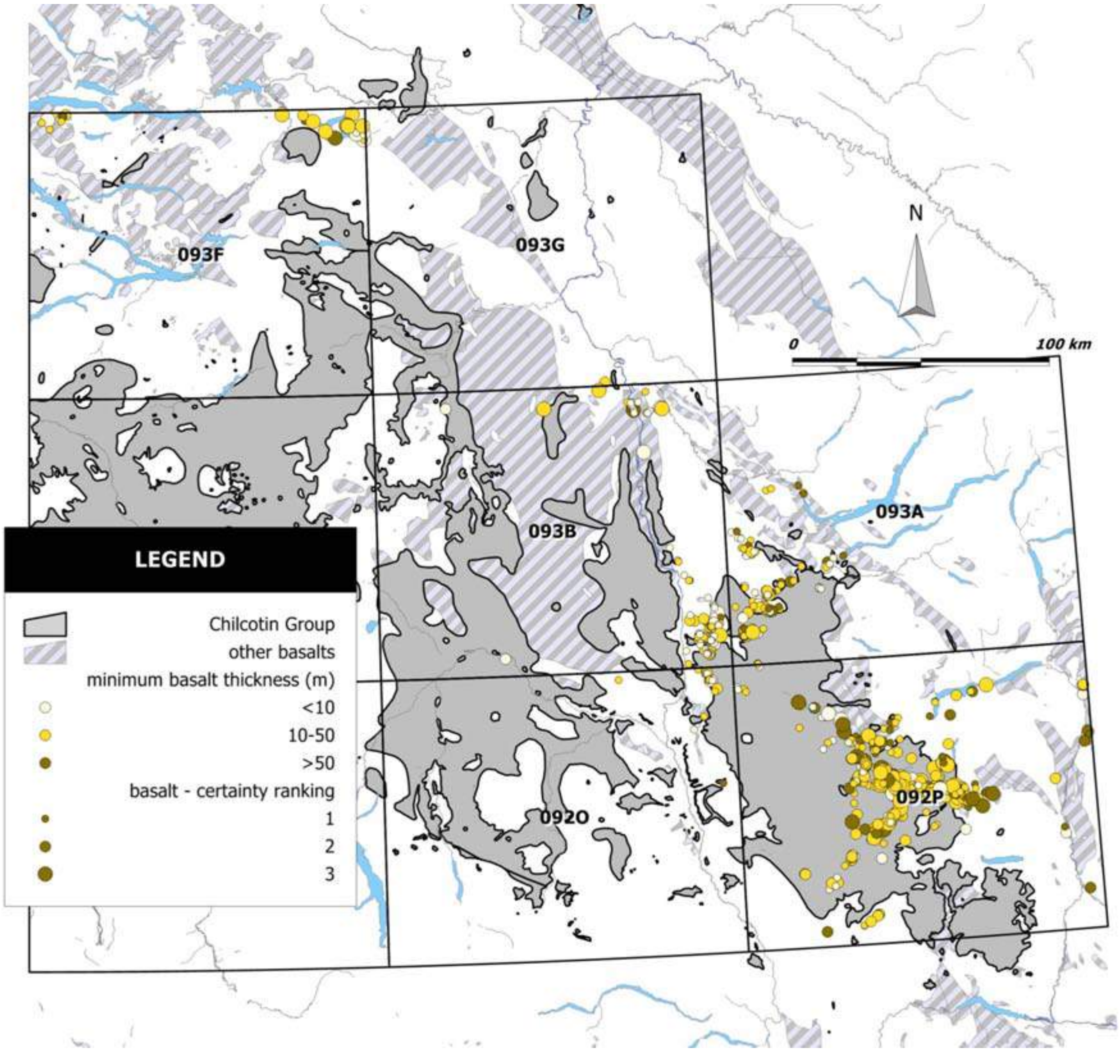

Figure 4. Minimum basalt thickness, southern Interior Plateau, BC (geology *after* Massey et al., 2005a, b).

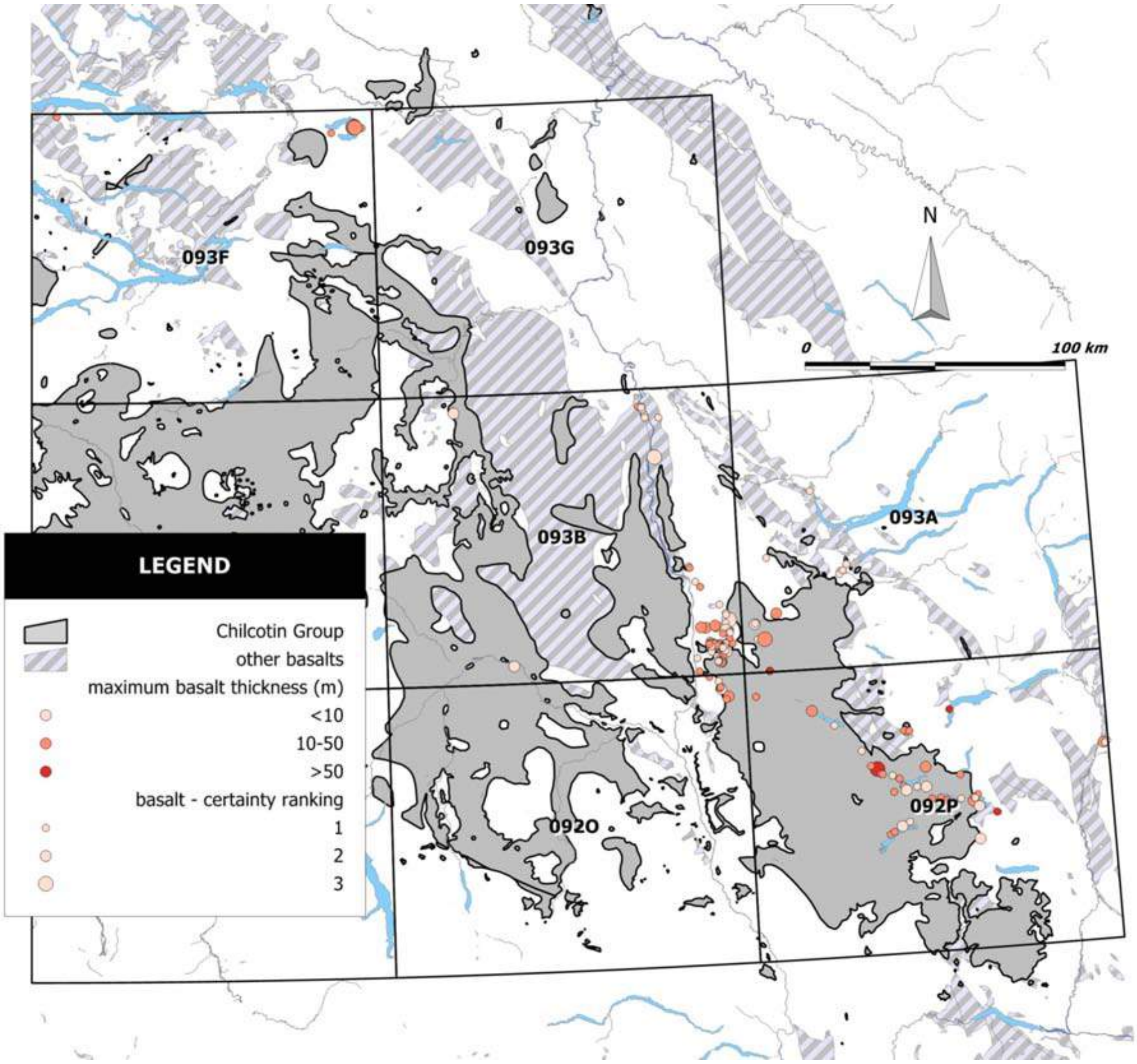

Figure 5. Maximum basalt thickness, southern Interior Plateau, BC (geology *after* Massey et al., 2005a, b).

50 m and >50 m are used. With far fewer maximum estimates than minimum estimates, the wells included tend to cluster more strongly around 100 Mile House (NTS 092P) and Williams Lake (NTS 093B); however, the thickest sections are still situated around 100 Mile House.

Not surprisingly, the typical maximum true thickness is less than that recorded in minimum thickness estimates because it is easier to penetrate through thinner basalt. The maximum true thickness recorded is 164 m (at 100 Mile House) and the mean is 16.2 m; 66% of basalt layers intercepted are <20 m thick and 95% are <50 m (Figure 6A). Thin basalt layers (≤20 m thick) are generally found around Williams Lake (Figure 5), between Williams Lake and 100 Mile House (NTS 092P) and central portions of NTS 093B. Minimum basalt thickness estimates are generally greater (Figure 6B): 66% of basalt layers intercepted are <40 m thick and 95% are <80 m thick; it is noteworthy that even minimum estimates still strongly suggest that the basalt layers are thinner than previously inferred.

Sub-Basalt and Other Rock Types

Non-basalt rock types encountered beneath Quaternary drift (*n* = 714 wells) and basalt (*n* = 174 wells) were recorded and are displayed in Figure 7. Rock types are presented as

- unknown/not classified (e.g., ‘bedrock’, ‘white rock’);
- clastic sedimentary (e.g., ‘shale’, ‘sandstone’, ‘conglomerate’);
- plutonic (e.g., ‘granite’, ‘diorite’);
- limestone; and
- metamorphic (e.g., ‘schist’, ‘chlorite rock’).

Clastic sedimentary rocks are prevalent across NTS 092P, and 093A and B, although it is not possible to correlate them to specific stratigraphic units or ages. Limestone, plutonic rocks and metamorphic rocks are restricted to NTS

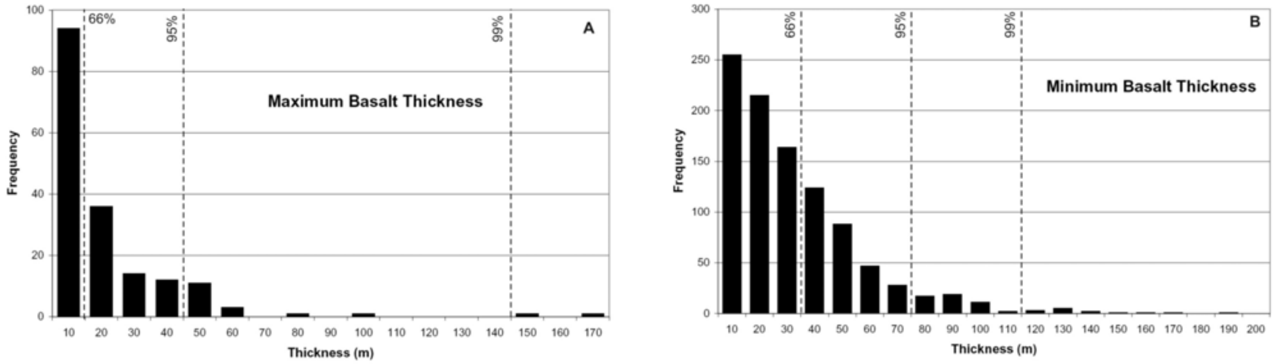

Figure 6. Histogram of basalt thickness, southern Interior Plateau, BC: A) maximum basalt thickness; B) minimum basalt thickness. Note that the 66th, 95th and 99th percentiles are indicated.

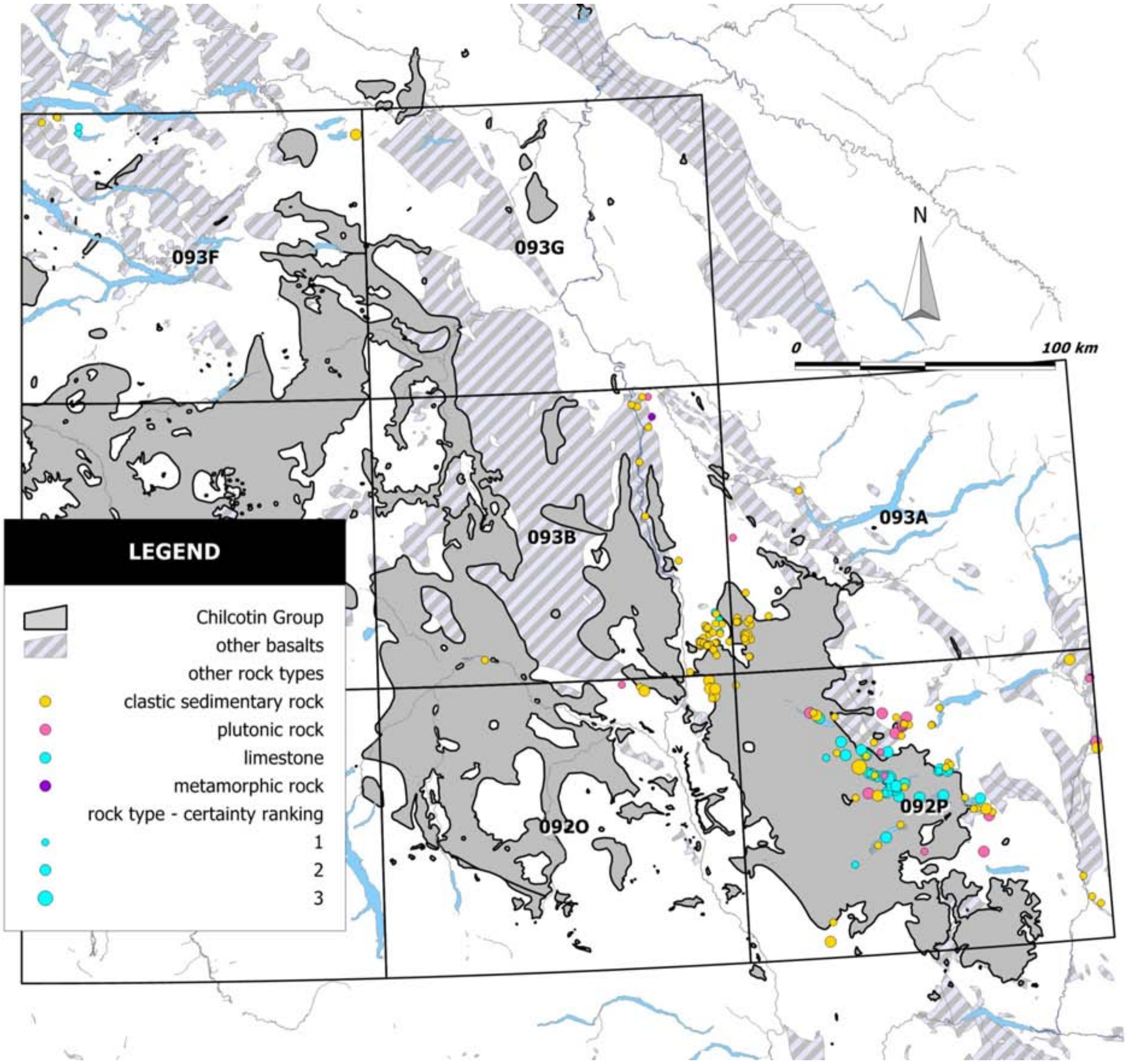

Figure 7. Non-basalt rock types encountered below drift and/or basalt (bedrock geology *after* Massey et al., 2005a, b).

092P, where they possibly represent the basement geology along the inferred margin between the Cache Creek Terrane (limestone-dominated) and the Quesnel Terrane (granite-hosting), beneath 100 Mile House. Known geology is probably represented by granite-penetrating wells east of 100 Mile House (NTS 092P; possibly the Takomane batholith) and limestone-penetrating wells near Clinton (NTS 092P). Elsewhere, the abundant clastic sedimentary rocks between Williams Lake and Quesnel probably represents the Upper Eocene–Lower Miocene succession along the Fraser River (Rouse and Mathews, 1979).

The occurrence of clastic sedimentary rocks, plutonic rocks and limestone as the uppermost bedrock within the presently mapped boundaries of the CG (Figure 7) indicates the presence of previously undetected basement windows. These are most common in the central portions of NTS 092P, the southwestern corner of NTS 093A and the southeastern corner of NTS 093B; areas where the typical basalt thickness is <50 m.

Discussion

The Thickness of the Chilcotin Group

Analysis of water-well records supports the assertion (Andrews and Russell, 2007) that the Chilcotin Group is typically thin (<50 m thick, probably <25 m thick; Figures 4–6) across most of its mapped distribution, and moreover, that in many areas its actual subdrift distribution is very patchy. Most of the thickest sections (>50 m) recorded are restricted to the central and southern parts of NTS 092P, where several water wells are located beyond the presently mapped boundary of the CG, where in fact they may penetrate into older, Eocene basalt (Endako Group).

Previously, Andrews and Russell (2007) proposed that significant thickness variations within the CG were the result of paleotopography, with thick sections filling ancient drainage systems and thin sections covering, or partially covering, ancient high ground. The variations in maximum CG thickness, revealed by analysis of water-well records, may be explained in this way, for example the thickest sections (>150 m thick) and many of the thinnest sections (<5 m) and basement windows (i.e., 0 m thickness of CG) are found adjacent to one another under the town of 100 Mile House (NTS 092P). It is not possible to positively identify paleodrainage systems by the analysis of water-well records alone, the number of wells is too low and they are not distributed widely enough. However, further detailed fieldwork to understand the architecture of the CG through studying its component lithofacies assemblages may allow this hypothesis to be tested and paleodrainages to be mapped.

Exploration Potential Beneath the Chilcotin Group

The unconstrained thicknesses and areal distributions of the Chilcotin Group and overlying Quaternary deposits have impeded mineral and hydrocarbon exploration for decades. The general consensus has been that the CG is uniformly thick (i.e., >100 m thick) everywhere across its mapped distribution (e.g., Bevier, 1983; Mathews, 1989). This common wisdom is based largely on a few thick but well-exposed outcrops around the margins of, and within, the Interior Plateau. Overestimation of the thickness of the CG, and therefore, the depth to basement, has discouraged conventional exploration activity (e.g., prospecting, staking, geochemical sampling) and has also discouraged higher cost exploration activities (drilling, geophysical surveys; e.g., Mihalynuk 2007a). Indeed, if geophysical surveys (e.g., seismic, gravity, aeromagnetic, radiometric) are to be useful to exploration they will require either 1) accurate estimation of CG thickness to produce realistic geophysical models and/or 2) complex data processing to remove the CG.

In this paper, evidence is presented in support of the hypothesis (Andrews and Russell, 2007) that the CG is generally thin (<50 m thick; probably <25 m thick) across most of its known and inferred distribution. Furthermore, it was found that excessively thick CG (>100 m) is localized, and appears to be restricted to the 100 Mile House area. The observation that the CG is generally thin across a large area increases the likelihood of basement windows being close to surface, and therefore more accessible to blind-drilling and identification by soil-, lake- and bio-geochemical surveys. Moreover, these observations further constrain the thickness of the CG in NTS 092P, and 093A and B; therefore, there is hope that these observations can be extrapolated across the remainder of the CG.

These results and interpretations of the thickness of the CG should be incorporated in ongoing and future research and exploration projects in areas underlain, or possibly underlain, by the CG. The authors believe that by incorporating their findings, exploration projects can be enhanced, and new areas of the Interior Plateau can be added to the provincial exploration portfolio.

Conclusions

1) The Chilcotin Group is typically <25 m thick across the area represented by the well records analyzed.
2) Localized sections that are >100 m thick are encountered in NTS 092P, some or all may include older basalt in addition to the CG.
3) A diverse range of basement rock types are identified at the bedrock-drift interface (in the absence of CG) and immediately below the CG. This suggests that

- the basement is widely accessible (<50 m depth) through drift only, or through drift and thin CG in many areas;
- the areal distribution of the CG under Quaternary cover is overestimated; and
- basement windows are more common, and larger, than previously thought.

4) Quaternary drift is typically <50 m thick across the area surveyed. Sections that are >50 m thick may be of interest to industrial mineral companies.
5) The realization that the CG is typically thin should be incorporated into exploration projects, allowing for simpler and cheaper geophysical and geochemical surveys, and increasing the area likely to be prospective.

Acknowledgments

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