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terranes and their successor rocks in Yukon and northern
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Geochemical data of Yukon-Tanana and Slide Mountain terranes and their successor rocks in Yukon and northern British Columbia

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Foreword

The Geo-mapping for Energy and Minerals (GEM) program is laying the foundation for sustainable economic development in the North. The Program provides modern public geoscience that will set the stage for long-term decision making related to responsible land-use and resource development. Geoscience knowledge produced by GEM supports evidence-based exploration for new energy and mineral resources and enables northern communities to make informed decisions about their land, economy and society. The ongoing GEM-Cordillera project will be completed in 2020, and is focused on improving the regional stratigraphy and tectonic models in Yukon and northern British Columbia, and producing publically available, regional-scale geoscience knowledge in Canada's North.

Geochemical data, presented in this open file release, have been collected over sixteen years from 2000 to 2016 as part of regional mapping projects conducted under the auspices of the Geological Survey of Canada's Ancient Pacific Margin (NATMAP) and Geo-mapping for Energy and Minerals (GEM) programs, in collaboration with the Yukon Geological Survey. The data include major and trace element analyses for 811 rock samples, from a wide range of geological units that range in age from pre-Late Devonian to Paleocene.

Introduction

The northern Cordillera of Alaska, Yukon and British Columbia represents a long-lived accretionary orogen (Monger and Price, 2002; Nelson et al., 2013). The northern Cordillera formed from the successive accretion of allochthonous terranes to the western margin of Laurentia, beginning as early as the Late Permian to Early Triassic (Beranek and Mortensen, 2011), and continuing through the Mesozoic until recent time (Nelson et al., 2013). The core of the northern Cordillera (Fig. 1) preserves long-lived Paleozoic to Early Mesozoic magmatic arcs (Quesnel and Stikine terranes) that are, in part, built on continental fragments (Yukon-Tanana terrane), and ocean basins (Slide Mountain and Cache Creek terranes). These terranes are collectively referred to as the Intermontane superterrane (Monger et al., 1982; Nelson et al., 2013). Of the 811 whole rock geochemical analyses we present in this report, 477 are from the Paleozoic to Early Mesozoic Yukon-Tanana, Stikine, and Quesnel terranes, 70 are from the Slide Mountain terrane, and 183 are from middle Cretaceous, Late Cretaceous and Paleocene successor magmatic suites. The geochemical data are presented in the Microsoft Excel® file *OF_8500_whole_rock.xls*, which

lists each rock sample's location (NAD83 projection), rock type, composition, year collected, and major and trace element analytical data. Where assessed to have an appropriate level of confidence based on field observations, the respective lithostratigraphic unit has been identified and entered in a unique column. Sample locations are plotted on a simplified terrane map of Figure 1, grouped by the year of sample analysis, generally reflecting the different project activities within which the fieldwork was carried out.

Regional Geology

The Yukon-Tanana terrane, the largest of the Intermontane terranes, is a composite, pericratonic terrane of Devonian-Triassic age (Nelson et al., 2006; 2013), exposed from eastern Alaska to northwestern British Columbia (Fig. 1). The Paleozoic evolution of the Yukon-Tanana terrane is subdivided into six tectono-magmatic cycles, which successively emplaced igneous suites into a rifted fragment of Laurentia's western margin (Nelson et al., 2006; Piercey et al., 2006). This rifted fragment provided the lithotectonic foundation of the Yukon-Tanana terrane as a siliciclastic assemblage of continental margin affinity known as the Snowcap assemblage. It includes metaclastic rocks, lesser carbonate mafic units, interpreted as deformed and metamorphosed sills or volcanic rocks (Colpron et al., 2006; Piercey and Colpron, 2009). One of the more regionally extensive units represented in the samples reported herein are metavolcanic rocks of the Late Devonian to Early Mississippian Finlayson assemblage and coeval Simpson Range suite plutonic rocks. These rocks correspond to the Finlayson and Wolverine tectono-magmatic cycles (Colpron et al., 2006). Many of the samples in the dataset are collected from the Permian Klondike assemblage volcanic rocks and coeval Sulphur Creek suite plutonic rocks (see also Milidragovic et al., 2016), formed during the Klondike magmatic cycle (Colpron et al., 2006). The Klondike cycle rocks have a narrow age range (ca. 265-254 Ma) and are generally interpreted to have formed in an arc setting above west-dipping subduction of Slide Mountain ocean crust. This subduction led to accretion of the Yukon-Tanana terrane to Laurentia (e.g., Nelson et al., 2006).

Samples from mafic to ultramafic ophiolite complexes are listed as Slide Mountain assemblage, or specific isolated massifs including the Harzburgite Peak complex, Dunite Peak complex and Sylvester allochthon. These ophiolitic rocks have been classically interpreted to represent mid-Paleozoic marginal back arc ocean floor that formed during the departure of the Yukon-Tanana terrane from the Laurentian margin (e.g., Nelson et al., 2013). However, recent studies indicate that some of these ophiolitic rocks are too young to form part of the purported Slide Mountain ocean and formed in an arc setting (e.g., Parsons et al., 2018; van Staal et al., 2018). As such, their affiliation with the Slide Mountain assemblage may be revised in future classification efforts.

A significant number of samples included in this report come from Late Mesozoic to Cenozoic magmatic rocks that intrude or overlie the Intermontane terranes. These include the middle Cretaceous Whitehorse plutonic suite and Mount Nansen Group volcanic rocks; the Late Cretaceous Casino suite; the Late Cretaceous Carmacks Group volcanic rocks and the co-magmatic Prospector Mountain suite; and the Paleocene Rhyolite Creek volcanic complex and the Ruby Range plutonic suite.

Methodology and data quality

Data included in this report are a result of a multi-year effort by the Geological Survey of Canada and the Yukon Geological Survey to understand the geological history, architecture, and

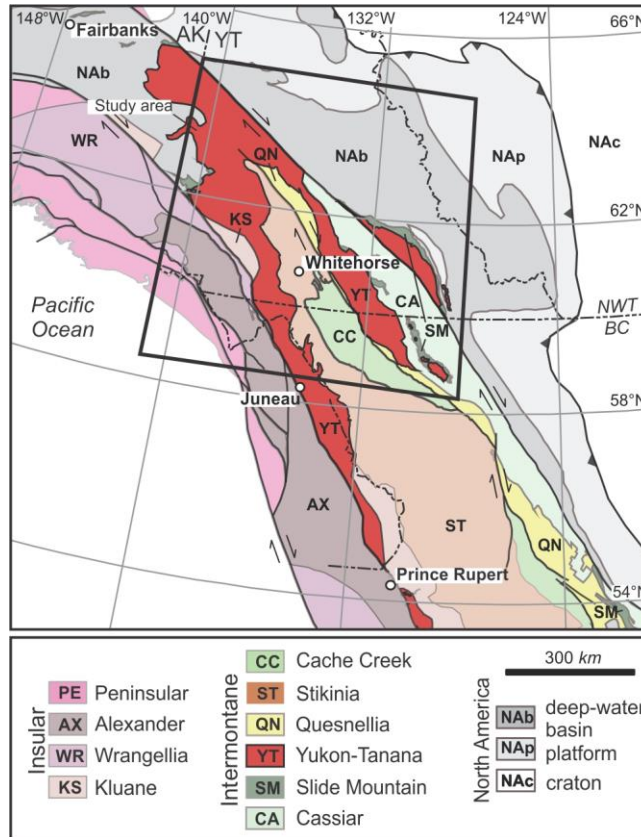


Figure 1. Terranes of the northern Cordillera modified from Nelson et al. (2013).

mineral potential of the Intermontane terranes in southern Yukon and northernmost British Columbia. The data were acquired between 2002 and 2016 through multiple funding programs, and over the course of this period four analytical laboratories were used for geochemical analyses. The various projects under which these samples were collected and analysed are listed in *of_8500_whole_rock.xlsx*. The table also lists the analytical method by which the major and trace element chemistry was acquired for each sample. Samples collected during the Ancient Pacific Margin NATMAP project (2002 to 2003) were analyzed at the University of Western Ontario (London, ON) and at the Ontario Geoscience Laboratories (Sudbury, ON). These were collected predominantly in the Stewart River map area, and are depicted on Figure 2 with purple and blue symbols. Samples from southwest McQuesten map area in 2009 and northern Stevenson Ridge area in 2010 were collected under the GEM1 program, depicted on Figure 2 as red and light green symbols respectively, were analyzed by Activation Laboratories Ltd. (Ancaster, ON). Samples collected in 2011 from the northern Stevenson Ridge area, also under the GEM1 program (brown symbols on Figure 2), were analyzed by ACME Analytical Laboratories (Vancouver, BC). During start-up of the GEM2 program, a reconnaissance sampling program was carried out across a very widespread area in 2014 (yellow symbols on Figure 2), and these sample were analyzed by Bureau Veritas Commodities Canada Ltd. (Vancouver, BC), which acquired ACME Analytical Laboratories in 2011. Samples collected in the Mount Nansen – Nisling River area under GEM2 in 2015 (dark green symbol on Figure 2), as well as a selection of archived samples from previous years (magenta symbols on Figure 2), were analyzed in 2015 at Bureau Veritas Commodities

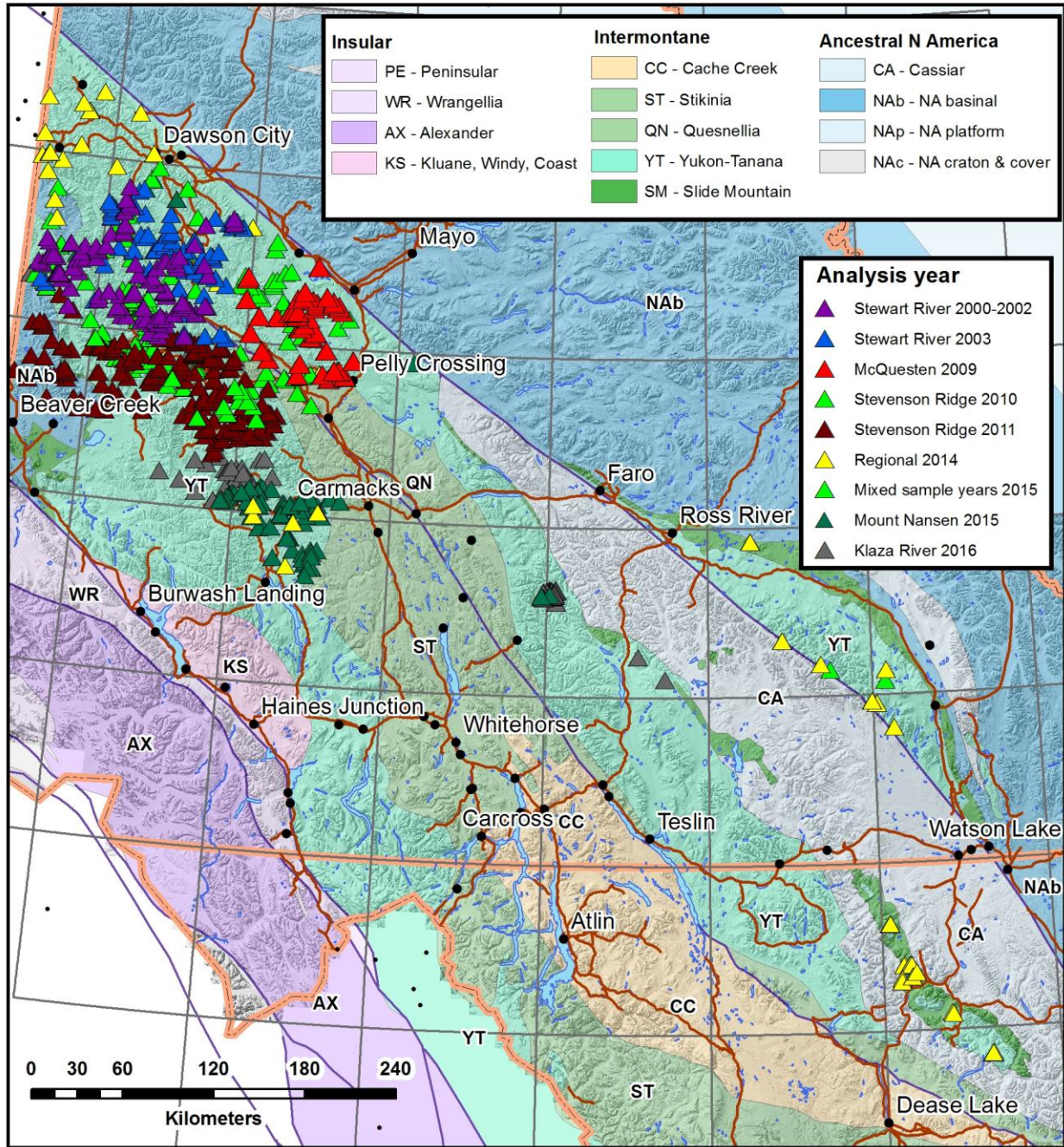


Figure 2. Sample location map of southern Yukon and northernmost British Columbia, depicted on the major terranes of the northern Cordillera (modified from Nelson et al., 2013). Samples are colour coded by the year the samples were analysed, as indicated original data tables in the *Unprocessed Analytical Data* directory associated with this report.

Canada Ltd. (Vancouver, BC). Samples collected in the Klaza River area and Dunite Peak area under GEM2 in 2016 (represented by the dark grey symbols on Figure 2), were analyzed by Activation Laboratories Ltd. (Ancaster, ON).

Data acquired at Laurentian University

Major element analyses were performed using X-ray fluorescence (XRF) on fused discs at the University of Western Ontario (UWO). Trace element concentrations were determined using XRF on pressed pellets at UWO, and by inductively coupled plasma–emission spectrometry (ICP-ES) and inductively coupled plasma–mass spectrometry (ICP-MS) at the Ontario Geoscience Laboratories. Analyses of 4 duplicate samples suggest absolute errors in major element measurements are <0.4 wt. %, which in most cases is $\leq 2\%$ relative. At concentrations approaching the limit of quantification (3.3 x limit of detection) the relative uncertainty in measurement of major elements is $\leq 20\%$. A review of data acquired at Laurentian University during the period 2002-2003 is available from MacDonald et al. (2005).

Data acquired at Activation Laboratories

Samples analyzed at Activation Laboratories (Ancaster, Ontario) were crushed and processed using lithium metaborate/tetraborate fusion and nitric acid dissolution. Analyses were performed by ICP-ES and ICP-MS (4Lithores analytical package). At a 95% confidence level, the uncertainty in measurement of major elements exceeding their limit of quantification is $\leq 3\%$ relative. The less abundant major elements (TiO_2 and P_2O_5) are exceptions, with relative uncertainties of $\leq 10\%$ and $\leq 15\%$, respectively. The uncertainty in measurement of most trace elements is $\leq 15\%$ relative, at a 95% confidence level.

Data acquired at ACME Laboratories

Samples analyzed at ACME Analytical Laboratories (Vancouver, BC) were crushed and processed using lithium metaborate/tetraborate fusion and dilute nitric acid dissolution. Major element and trace element analyses were performed by ICP-OES and ICP-MS, respectively (analytical package 4A-4B). At a 95% confidence level, the uncertainty in measurement of most major elements exceeding their limit of quantification is $\leq 10\%$ relative. The relative uncertainty in measurement of TiO_2 and MgO is $\leq 20\%$, whereas the relative uncertainty in measurement of MnO and P_2O_5 is $\leq 25\%$, and $\leq 65\%$, respectively. The uncertainty in measurement of most trace elements is 10-25% relative, at a 95% confidence level. The relative uncertainties in the concentration of Th and U are $\leq 40\%$ and $\leq 150\%$, respectively.

Data acquired at Bureau Veritas

Samples analyzed at ACME and Bureau Veritas Minerals Laboratories (Vancouver, BC), after Bureau Veritas Minerals had acquired ACME Laboratories, were crushed and processed using lithium metaborate/tetraborate fusion and dilute nitric acid dissolution. Major element concentrations were determined using ICP-OES; the concentrations of trace elements were measured using ICP-MS (analytical package LF200). Trace metals were liberated using aqua regia and analyzed using ICP-MS (analytical package AQ200). The uncertainty in measurement of most major elements, at a 95% confidence level, is $\leq 5\%$, although at concentrations approaching the limit of quantification the relative uncertainties may be as high as 25-60%. The average relative uncertainty, at a 95% confidence level, for the less abundant MnO and P_2O_5 is 10-20%. The average uncertainty in measurement of most trace elements is 5-15% relative, at a 95% confidence level. However, the relative uncertainty in quoted measurements is $\leq 70\%$ near the limit of quantification.

Description of data

The samples in table *of_8500_whole_rock.xlsx* are listed in order of sample number, and by default, in order of the year they were mapped and collected. The user can choose to this table to whatever their purpose (e.g., by composition, by lithostratigraphic unit). Samples are divided into plutonic, volcanic and sedimentary rock classes and their metamorphic equivalents. A high degree of deformation and metamorphism in some Paleozoic units makes accurate identification of sample protoliths difficult and thus many samples are listed as metamorphic. Field-based mineralogical composition observations were used to classify each sample as felsic, intermediate, mafic, ultramafic or sedimentary. These are listed under the rock_composition column of table *of_8500_whole_rock.xlsx*. The kcode value was used in the software program Igpert). This basic compositional discrimination is plotted on Figure 3. In general, there is very good agreement between field-based mineralogical composition classification and their respective geochemically determined composition (Figs. 4a, 4b and 4c); however, care must be taken in their interpretation as the dataset includes plutonic rocks, some of which may be cumulates.

Rocks with a mafic mineralogical composition generally lie in the basalt and basalt+andesite fields on the Pearce (1996) geochemical rock type diagram and display a range of alkalinity from sub-alkaline to alkaline (Fig. 4a). They formed in a variety of tectonic settings as indicated by the range of geochemical compositions exhibited on immobile trace element tectonic discrimination plots of Cabanis and Lecolle (1989). Such plots indicate tectonic settings ranging from volcanic arc tholeiite, calc-alkali basalt, backarc basin basalt, to continental rifts (Fig. 5a).

Similarly, there is excellent agreement between intermediate and felsic field-based mineralogical composition classification and their respective geochemically determined composition (Fig. 4b, 4c). Felsic rocks have a wide range of geochemical compositions and range from sub-alkaline to alkaline. Immobile trace element tectonic discrimination diagrams (Fig. 4d) indicate that a majority of the felsic samples plot in the volcanic arc and syn-collisional granite fields but display enough variation that further refinement of the magmatic suites may be possible, including through major-element classification schemes.

Breakdown of the data by lithostratigraphic unit may assist in re-evaluation of the nature of many units. For example, mafic rocks from the Snowcap and Finlayson assemblages (Figs. 5b, 5c) display a wide range of tectonic settings suggesting either a very complex tectonic setting, a variety of ages of mafic magmatism, or a variety of unrelated rocks were mapped as a single unit. Regardless of the cause of this variation, geochemical data display enough variation to facilitate improvements in regional stratigraphy and tectonic models.

The dataset presented herein also allows the user to examine variation within lithostratigraphic units. For example, the Late Cretaceous Carmacks Group contains a variety of volcanic rock compositions ranging from basalt to trachyandesite and minor trachyte (Fig. 6a). With the exception of the most evolved sample, Carmacks Group volcanic rocks have narrow Zi/Ti and Nb/Y ratios (Fig. 6a) and these are reflected in their rather consistent pattern on N-MORB normalized extended trace element plots (Fig. 6b).

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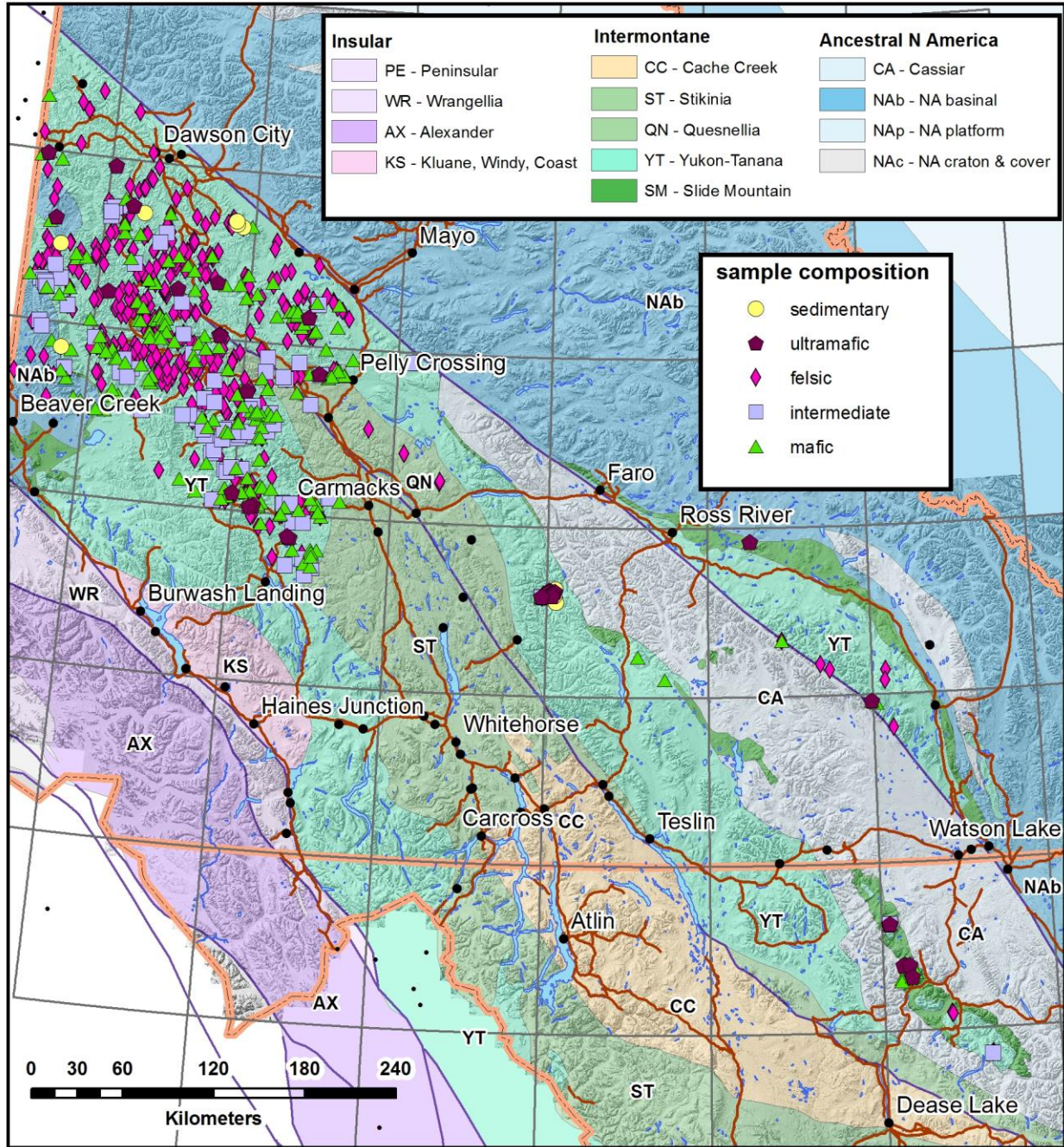


Figure 3. The distribution of the sample locations by composition in southern Yukon and northernmost British Columbia, depicted on the major terranes of the northern Cordillera (modified from Nelson et al., 2013). Samples are colour coded by field-based mineralogical composition, listed under the rock_composition column of table of_8500_whole_rock.xlsx.

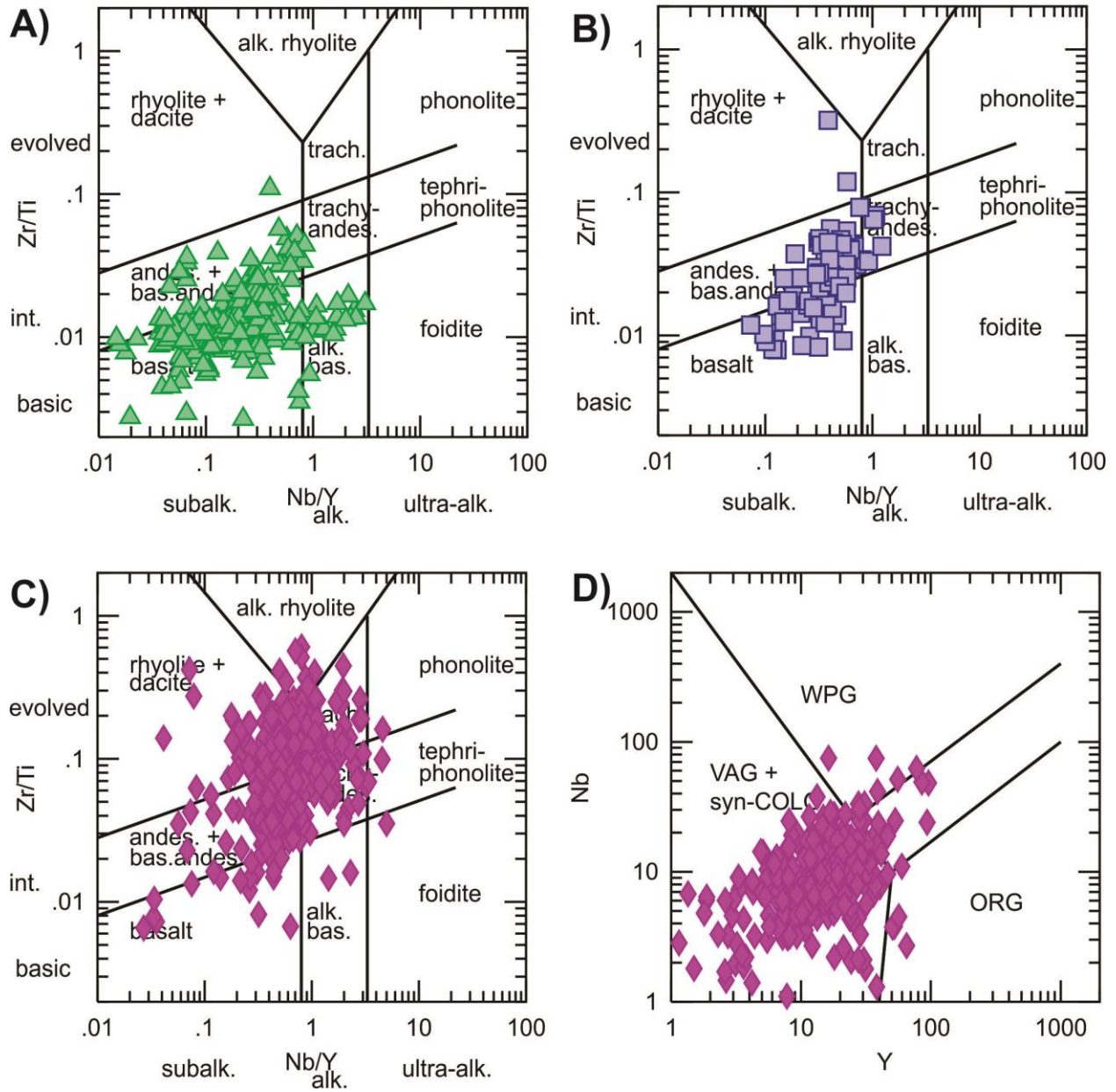


Figure 4. Geochemical characteristics of the rock samples. Rock type classification plots (Pearce, 1996) for A) mafic rocks, B) intermediate rocks and C) felsic rocks. D) Tectonic setting discrimination diagram for felsic rocks indicates a variety of predominantly volcanic arc and syn-collisional granite characteristics (Pearce et al., 1984).

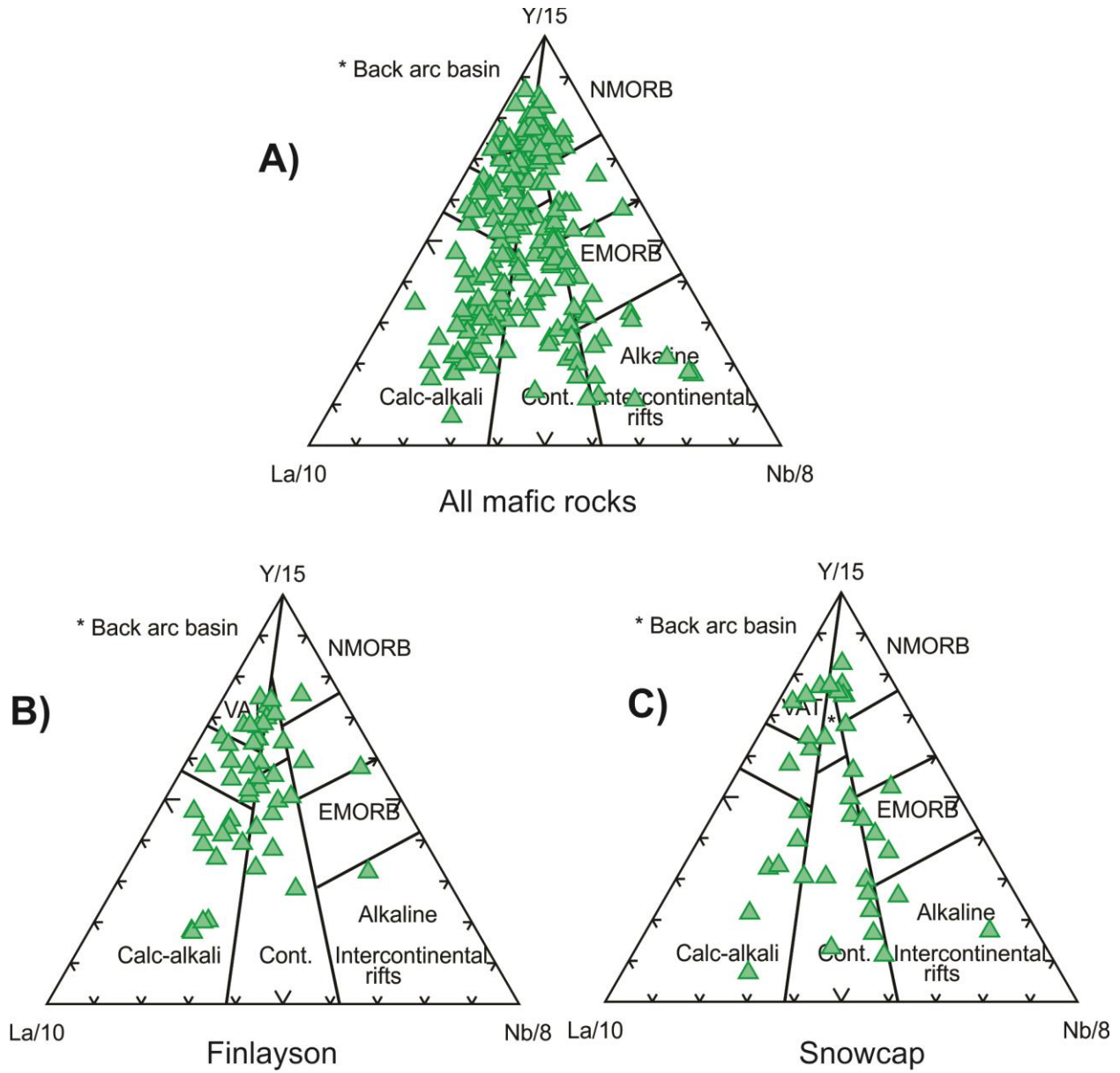


Figure 5. Geochemical characteristics of the mafic rock samples. Tectonic setting discrimination diagram (Cabanis and Lecolle, 1989) of A) all mafic rocks, B) mafic rocks of the Finlayson assemblage and C) the Snowcap assemblage.

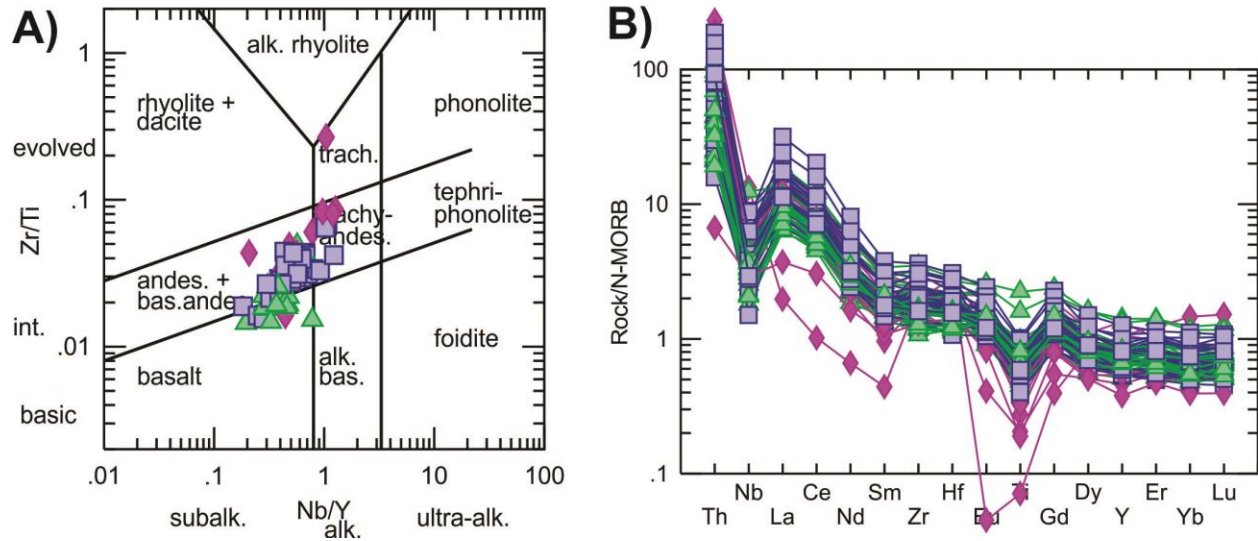


Figure 6. Geochemical characteristics of the Carmacks Group rock samples. A) Rock type classification plot (Pearce, 1996) for Carmacks Group, exhibiting fairly restricted chemistry. B) N-MORB normalized (Sun and McDonough, 1989) extended trace element plots for the Carmacks Group.

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