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Preliminary Field Investigations of Sloquet Hot Springs, Southwestern British Columbia (NTS 092G)

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Introduction

Geothermal resources across the southern Canadian Cordillera are of increasing interest for provincial, national and Indigenous governments, researchers, and local communities. To date, research in the southern Canadian Cordillera has been focused on investigating the distribution of thermal spring systems and their relation to major geological features, as these structures are understood to control thermal fluid flow (Grasby and Hutcheon, 2001). Sloquet Hot Springs is one of the many thermal systems in southwestern British Columbia (BC) and is located within the western Coast Belt (Journeay and Cstontos, 1989). The area is characterized by steep terrain, with undulating slopes that are covered by dense vegetation and unconsolidated material. Bedrock exposures are localized along forest service roads and along Sloquet Creek, where numerous cold, warm and hot springs discharge near the creek. Due to the lack of access to the exposures, the hydrogeologic controls of the geothermal system at Sloquet remain poorly understood.

The purpose of the research presented in this paper was to work collaboratively with Xa'xtsa First Nations' TTQ Economic Development Corporation, and Recreation Sites and Trails BC to conceptualize the hydrogeologic and geothermal setting of Sloquet Hot Springs, which is located on the traditional territory of the St'at'imc peoples. Sloquet Hot Springs is a remote recreational area that has naturally occurring soaking pools. This summary highlights methods, results and future work after the first summer of fieldwork around Sloquet. The focus of this initial work was on investigating the localized system, to capture the relationship between topography, climate, geological setting, fluid flow and temperature gradients. This research will enhance understanding of geothermal resources in the southwestern Canadian Cordillera, while also contributing to future decision-making and capacity-building for the Xa'xtsa First Nation.

Community Collaboration

Research approaches were developed using protocols that honoured diverse perspectives and ways of life, to cultivate relationships on multiple levels, not only a business level. Community consultation initially began in May 2018 and included management from TTQ Economic Development Corporation as well as members from the community. Interactive community gatherings were held that included a feast, question period, and general discussion about potential project development. Community gatherings provided partners with an opportunity to build relationships amongst one another while also gaining perspective on the cultural significance of Sloquet Hot Springs. During this process, two documents were developed and signed in conjunction with the University of Victoria and TTQ Economic Development Corporation. First, a letter of intent approved site investigations, to conduct visual surveys, mapping, drilling and reporting into the location and availability of the resource. Second, an agreement between TTQ and the University of Victoria was signed regarding wells to be drilled near Sloquet, to establish purpose, consent for scientific monitoring, and protocols for well development if cultural artifacts are encountered.

Regional Setting

Sloquet Hot Springs are located in the Coast Mountain physiographic region on the edge of two biogeoclimatic zones: coastal western hemlock, with 2893 mm of mean annual precipitation and mean annual temperatures of 6.7°C; and mountain hemlock, with 3119 mm of mean annual precipitation and mean annual temperatures of 2.8°C (Moore et al., 2010). Biogeoclimatic zones and their associated climatic regime will be used as reference in this paper because of the limited local meteorological data.

The thermal system is situated adjacent to Sloquet Creek, at a topographic low of approximately 200 m above sea level (asl) and in steep terrain that rises to over 1500 m asl. Sloquet Hot Springs are located within the Coast Belt of south-

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western BC, which formed along the western edge of the Insular terrane during the Late Cretaceous (Journeay and Friedman, 1993). The contractional belt is composed of a frontal thrust system that imbricates supracrustal arc sequences and related plutonic suites from the Jurassic and Early Cretaceous, and is dominated by an array of fault-bounded island-arc and oceanic terranes that accreted along the continental margin in the Middle Jurassic to Early Cretaceous (Journeay and Friedman, 1993). Due to the size and extent of the Coast Belt, Journeay and Friedman (1993) further subdivided the system into three distinct tectonic domains that included the western, central and eastern Coast belts.

Sloquet Hot Springs are located within the western Coast Belt, which is composed of Middle Jurassic to Miocene age magmatic suites of the Coast Plutonic Complex (Journeay and Friedman, 1993). The plutonic suites have intruded arc sequences such as the Gambier–Fire Lake Group and Harrison Lake Formation (Journeay and Friedman, 1993). Gambier Group rocks have been considered part of the Fire Lake Group because of their lithological similarities (Lynch, 1990; Journeay and Friedman, 1993), however, the Gambier Group contains a larger proportion of volcanic rocks (Roddick, 1965). Studies conducted by Lynch (1990) suggest that the Fire Lake Group may be broken into the older Peninsula Formation (primarily conglomerate and arkosic sandstone) and the younger Brokenback Hill Formation (four primarily volcanic members) as shown in Figure 1.

Field Methods

Exposures of surficial deposits, bedrock and geological structures are limited in the area, therefore field reconnaissance and geological mapping was focused along the north and south sides of Sloquet Creek. Field methodologies included local-scale (hundreds of metres) site investigations that comprised the following steps:

1) mapping of bedrock, geological structures, and hot springs along portions of the northern and southern sides of Sloquet Creek at the main recreation site. Each side of the creek was evaluated along a set transect line. Data collected included length of bedrock exposure, temperature of the spring, conductivity of the bedrock, flow rate of the springs, and structural measurements that included orientation of joints and fractures. Where possible, water temperature and conductivity data were collected with a Hach HQ40D Portable Multi Meter. Measurements could not be taken at some springs, as flow was too low, or the probe could not be submerged deep enough to collect an accurate reading. Flow rates were assessed both semiquantitatively and through bucket tests, where the time it takes water to fill a container with known volume is recorded. Ninety-eight structural measurements were plotted using Stereonet software to visualize data density patterns.
2) equipment installation to monitor water levels and temperature at various locations over time. DS1922L-F5 Thermochron iButtons and Solinst leveloggers were installed in discreet areas to record water fluctuations and temperature over time. Solinst leveloggers record pressure and temperature, to interpret water level changes over time, and are being used to calculate discharge rates at the source spring. A small V-notch weir was also installed within a tributary that discharges thermal water from the main source spring, labelled HS138 on Figure 2, into Sloquet Creek. A Solinst Levelogger® and Thermochron iButton® were installed at the base of the weir.
3) well development planning, to site future well installation locations. The well will be used for evaluating the local lithology and hydraulic properties of the subsurface, while also monitoring groundwater levels at depth and the geothermal gradient of the subsurface. Possible locations for well installation were evaluated during fieldwork to allow for the most accessible and practical location.

Results

Five lithological units were identified along Sloquet Creek: unconsolidated material, clast-supported conglomerate,

Figure 1. Geological units within the Gambier–Fire Lake Group (based on Lynch, 1990).

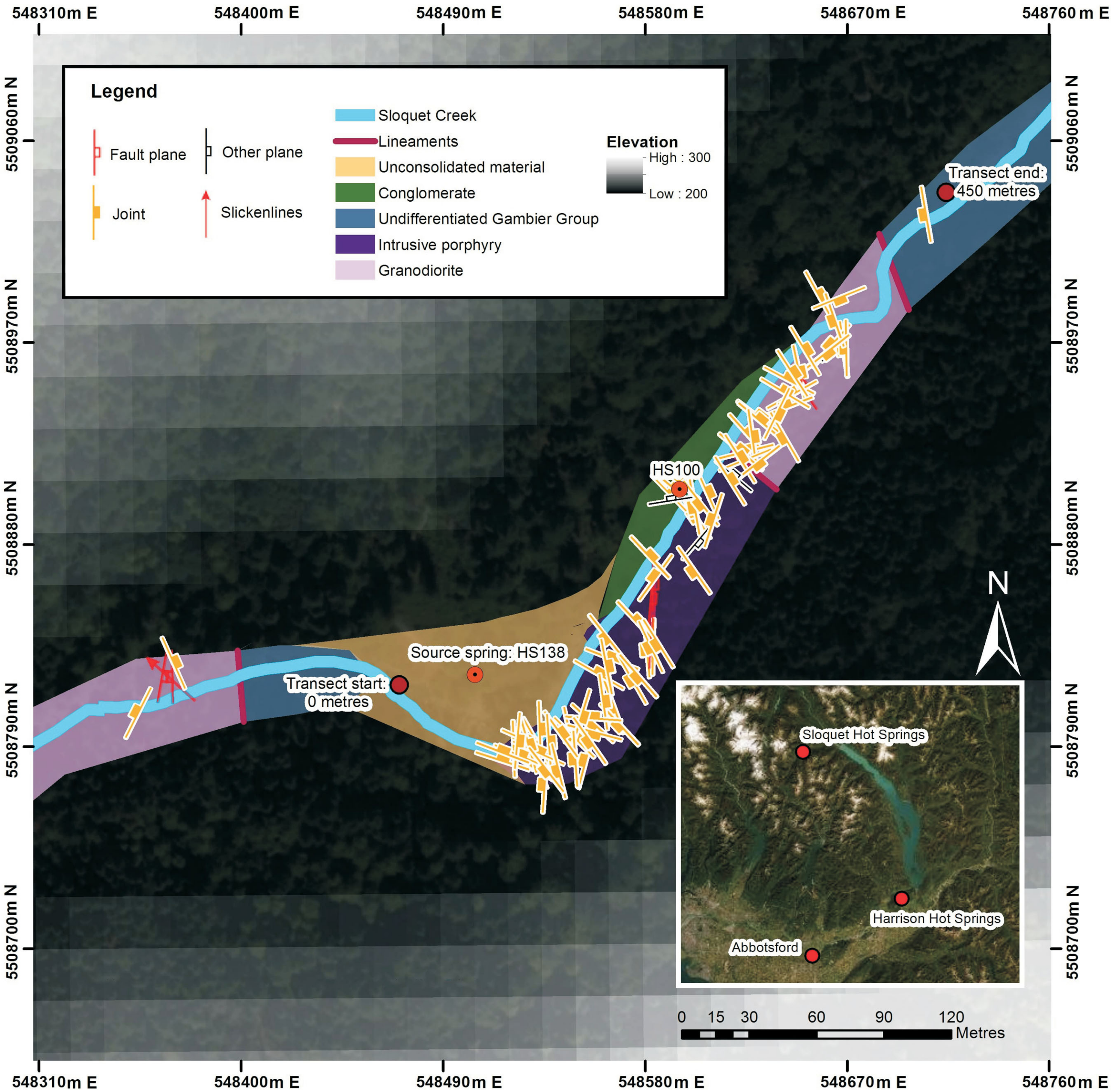

Figure 2. Details from bedrock and structural mapping in the area surrounding the Sloquet recreation site. Features were mapped along set transect lines, to gather a more detailed understanding of the area. Base for inset in lower right is from GeoBase (2019). UTM co-ordinates are in NAD83, Zone 10N.

granodiorite, undifferentiated Gambier Group rocks, and an intrusive porphyry (Figure 2). The type of bedrock along the transect lines appeared significantly more diverse than previously mapped by Journeay and Monger (1998), who suggested the area was underlain solely by mid-Cretaceous granodiorite and undifferentiated Gambier Group rocks. Updated mapping in Figure 2 shows that Sloquet Hot Springs is bound by granodiorite, likely from the mid to Late Cretaceous (Journeay and Monger, 1998), as well as undifferentiated Gambier Group volcanic rocks. However, the main bedrock unit mapped along the northern side of Sloquet Creek included a clast-supported conglomerate that is draped unconformably over an intrusive porphyry (Figure 3). In contrast, the southern side of Sloquet Creek is predominantly intrusive porphyry. Structural measurements collected from the porphyry, granodiorite and undifferentiated Gambier Group rocks show a strong clustering of joints with a northeast to southwest orientation (Figure 4).

Thermal spring discharge is visible along a 420 m stretch of the north and south sides of Sloquet Creek, with discharge from unconsolidated material, conglomerate, intrusive porphyry and undifferentiated Gambier Group rocks. Water

Figure 3. Exposure of the contact between the clast-supported conglomerate (green overlay) and intrusive porphyry (purple overlay). Distinct joint sets are visible within the porphyry and thermal seeps are seen discharging from joints with a northwest orientation.

temperature varied significantly, from 22 to 68.8°C, depending on location and lithology. Figure 5 shows the distribution of water temperature of the springs along the mapped transect lines in relation to flow rate and lithology. Most springs that exceeded 60°C discharged from the intrusive porphyry and had flow rates of less than 5 litres per minute (L/minute). Two high-temperature and high-flow springs were also observed, discharging at 15 m (main spring, herein called HS138, possibly discharging from unconsolidated material) and at 185 m (spring herein called HS100, discharging from conglomerate) along the north side of the creek (Figure 2). All the high-temperature and high-flow springs were observed along the north side of Sloquet Creek. Springs discharging from the conglomerate had the greatest range of temperature and average flow. Overall, most thermal springs appeared to be discharging from the conglomerate and porphyry, with fewer springs discharging from the unconsolidated sediments and undifferentiated Gambier Group volcanic rocks.

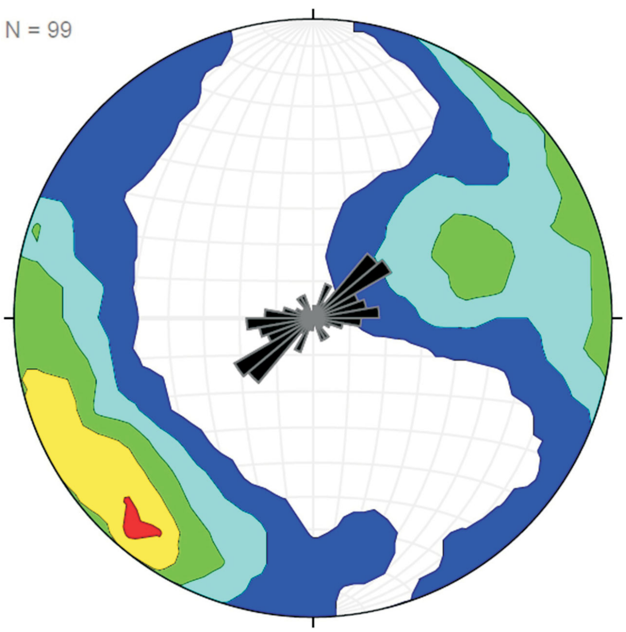

Figure 4. Structural data collected during fieldwork (orientation of joints and fractures measured in bedrock) plotted on an equal-area stereonet. The distribution of the data shows a strong preferred orientation of northeast, and a secondary clustering of west to east orientations. N = number of measurements.

Discussion

Data collected during the 2019 field season show a significant variation in bedrock geology, spring temperature and flow rate at the local scale (hundreds of metres). It is apparent that the hydraulic properties of each lithological unit control the distribution and location of hot and warm springs at Sloquet. These properties have likely been altered by tectonic processes that formed secondary structures within the rocks, and by mineralization from geothermal waters. Typically, unfractured bedrock has low permeability and low hydraulic conductivity, making it an unlikely source for springs or water resources (Freeze and Cherry, 1979), whereas fractured rock is more likely to have higher hydraulic conductivity and permeability along faults, fractures and joints.

The intrusive porphyry appeared to have the most well-developed joints, with a northwest orientation, likely developed during the complex tectonic deformation in the region, which discharge thermal fluids at numerous scattered locations. However, the average flow rate for springs discharging from these joints was relatively low and did not exceed 5 L/minute (Figure 5). The spring with the highest temperature (68.8°C) discharged from the intrusive porphyry along a northwest-trending joint, suggesting these structures may control thermal fluid flow through the rock mass and potentially also at Sloquet. The unit appears to be lithologically distinct from the mid to Late Cretaceous granodiorite, as the mineralogy varies significantly, appearing of intermediate composition, with large, well-developed quartz phenocrysts. The intrusive unit was only observed over a 100 m portion of the creek, suggesting it

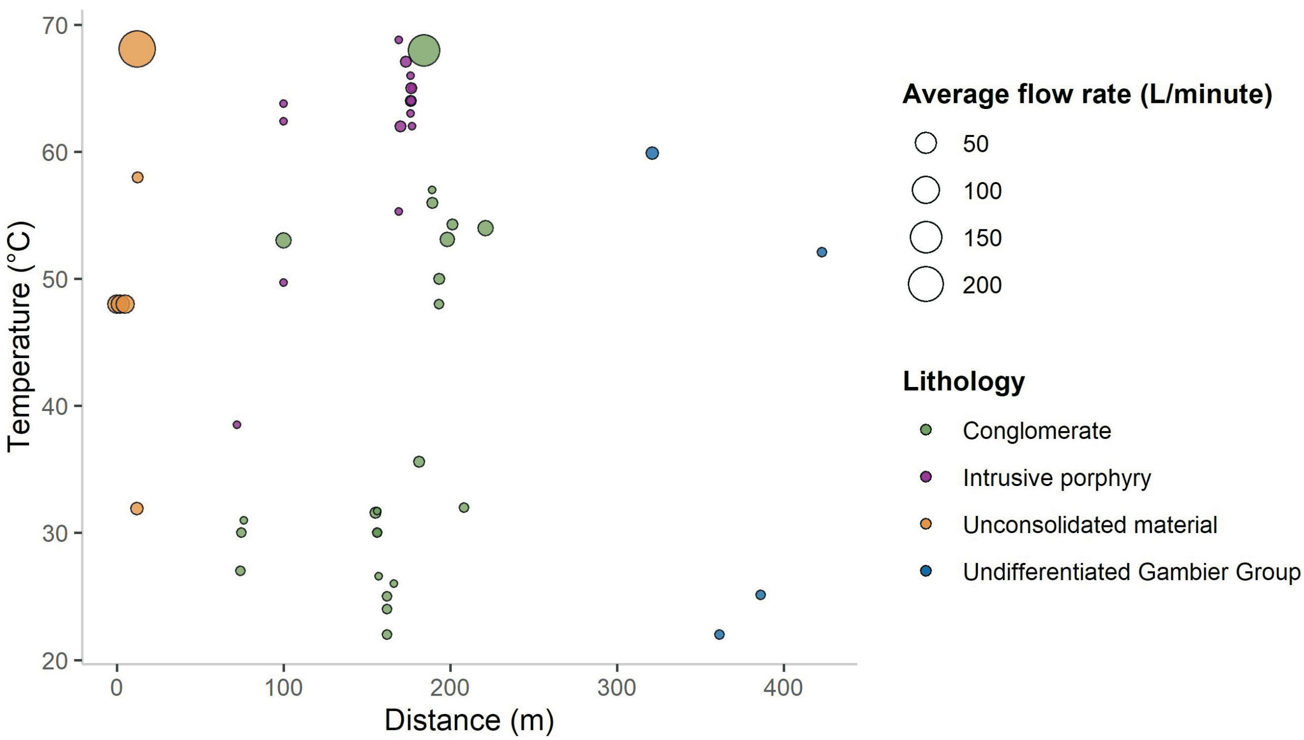

Figure 5. Graph showing the variation in temperature and average flow rate (in litres per minute, L/minute) of springs mapped along the transect lines ('Distance (m)' is distance relative to the start of the transect (see Figure 2), in metres). The size of the circles indicates magnitude of the average flow rate, and the colour represents the lithological unit from which the springs were discharging.

could be a localized, younger intrusion cutting through an existing plutonic body.

The porphyry is overlain by a clast-supported, highly lithified conglomerate that does not appear to be a part of the Peninsula Formation due to the rock types comprising the clasts and the draping nature of the contact with the porphyry (Figure 3), suggesting the sedimentary strata were deposited after emplacement of the intrusion. Clasts within the conglomerate range from pebble to boulder size and are predominantly granodiorite with minor amounts of volcanic clasts, suggesting the unit may be Pleistocene or Holocene in age. If the conglomerate was Cretaceous in age, it would be likely that volcanic clasts would dominate. Springs discharged as pore flow from anastomosing fractures that formed along planes of weakness surrounding clasts within the conglomerate. There was visible hydrothermal alteration of the conglomerate, in contrast to the porphyry, which showed no such alteration.

Overall, the springs with the highest flow rate were observed to be discharging from unconsolidated material at HS138 and the clast-supported conglomerate. The two high-temperature and high-flow springs may originate from the intrusive porphyry, which is at or near the surface where these springs are discharging.

Hydrological data collected from the weir installed at HS138, the main spring source, will not be reviewed within this paper, as it is currently being analyzed to understand trends through the summer season. Further, flow rates and temperature likely fluctuate throughout the year, therefore the data presented herein only represent a snapshot of time.

Next Steps

Research conducted to date represents analysis of the findings from only the first few months of data collection. The findings to date will be further refined to incorporate stereonet interpretations, petrographic analysis of rock samples, as well as analysis of hydrological data from equipment that has been installed at the study site. Mapping to update the geology of the Sloquet area will continue, as there is significantly more lithological variation than was expected along the 500 m stretch of Sloquet Creek and along the forest service road that leads to the site. Further analysis of rock samples will be conducted through examination of thin sections, to understand the mineral composition of the cement within the conglomerate and the hydraulic properties of these constituents. Next steps for analyzing subsurface conditions in the area surrounding Sloquet will include the development of a research well. The location and layout of the well site was established during the 2019 field season, in consultation with TTQ Economic Development Corporation and the University of Victoria. Further, hydrological data collected by equipment installed for this study will be analyzed and interpreted to review changes over time. Water samples will also be collected for geothermometry, to understand the source location of the thermal waters, and to determine if the porphyry is the host unit for the hot springs. Lastly, thermal infrared imaging of the land surface will be conducted during the winter months, to analyze thermal anomalies across the land surface surrounding Sloquet Hot Springs. All data gathered will contribute to development of a conceptual model that integrates the findings from well development, hydrogeology, temperature gradients and system behaviour at local scales (hundreds of metres) to regional scales (tens of kilometres).

Conclusions

During the 2019 summer field season research was focused on identifying an ideal location for well development, while also conducting localized research along the north and south sides of Sloquet Creek, as well as the main recreation area. In total, 49 springs were mapped, and 98 structural features were measured (joints, faults and bedding planes) to provide baseline data on the setting at Sloquet Hot Springs. The main lithological units observed in the area around Sloquet included mid to Late Cretaceous granodiorite, undifferentiated Gambier Group volcanic rocks, intrusive porphyry, conglomerate, and unconsolidated sediments. Overall, spring temperature and flow rate varied significantly depending on location and rock type, suggesting hydraulic properties of the different rocks play a role in the diffuse pattern of the springs in the area. The highest temperature springs discharged from steeply dipping, northwest-trending joints within the porphyry.

All data collected will contribute to the development of conceptual models showing the hydrogeological regime and geothermal conditions at Sloquet. The completed report for this work will be presented to TTQ Economic Development Corporation and disseminated at their discretion.

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References

Freeze, A. and Cherry, J. (1979): Groundwater; Prentice-Hall Inc., Englewood Cliffs, New Jersey, 624 p.

GeoBase (2019): Canadian digital elevation model; Natural Resources Canada, URL <https://maps.canada.ca/czs/index-en.html> [November 2019].

Grasby, S. and Hutcheon, I. (2001): Controls on the distribution of thermal springs of the southern Canadian Cordillera; Canadian Journal of Earth Sciences, v. 38(3), p. 427–440, URL <https://www.nrcresearchpress.com/doi/10.1139/e00-091#.XaZ6I0ZKg2w> [August 2019].

Journeay, J. and Cstontos, L. (1989): Preliminary report on the structural setting of the southern Coast Belt, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 89-1E, p. 177–187, URL <https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=127480> [August 2019].

Journeay, J. and Friedman, R. (1993): The Coast Belt thrust system: Evidence of Late Cretaceous shortening in southwest British Columbia; Tectonics, v. 12, p. 756–775, URL <https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb> [August 2019].

Journeay, J. and Monger, J. (1998): Geology and crustal structure of the southern Coast and Intermontane belts, southern Canadian Cordillera, British Columbia (92G, 92H, 92I, 92J); Geological Survey of Canada, Open File 3276, CD-ROM, URL <https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb> [March 2019].

Lynch, J.V.G. (1990): Geology of the Fire Lake Group, southeast Coast Mountains, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 90-1E, p. 197–204, URL <https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb> [March 2019].

Moore, R.D., Spittlehouse, D.L., Whitfield, P.H. and Stahl, K. (2010): Weather and climate; Chapter 3 *in* Compendium of Forest Hydrology and Geomorphology in British Columbia, R.G. Pike, T.E. Redding, R.D. Moore, R.D. Winkler and K.D. Bladon (ed.), Forests and Range, Research Branch, Land Management Handbook 66, p. 47–81, URL <https://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh66/Lmh66_ch03.pdf> [September 2019].

Roddick, J.A. (1965): Vancouver North, Coquitlam and Pitt Lake map-areas, British Columbia with special emphasis on the evolution of the plutonic rocks; Geological Survey of Canada, Memoir 335, 291 p. (6 sheets), URL <https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb> [August 2019].