A Field Trip Guide to Wrangellia Flood Basalts on Vancouver Island: An Accreted Late Triassic Oceanic Plateau

By
Andrew Greene
Graham Nixon
James Scoates
Nick Massey

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Buttle Lake, Strathcona Provincial Park, Vancouver Island

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Andrew Greene and James Scoates
Pacific Centre for Isotopic and Geochemical Research, Department of Earth and Ocean Sciences,
University of British Columbia, 6339 Stores Road, Vancouver, BC, V6T1Z4, Canada
agreene@eos.ubc.ca, jscoates@eos.ubc.ca

Graham Nixon and Nick Massey
British Columbia Geological Survey, P.O. Box 9320, Stn Prov Govt, Victoria, BC, V8W9N3, Canada
Graham.Nixon@gov.bc.ca, Nick.Massey@gov.bc.ca

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I. Schedule: 3-day itinerary, without field stops listed

<u>July 19</u>	**Saturday** (travel to Port McNeill)
10:00 am	leave UBC, drive to Horseshoe Bay (~35 km, ~1 hr drive)
12:55 pm	ferry from Horseshoe Bay to Departure Bay, Vancouver Island (1.5 hours)
~3:00 pm	drive from Departure Bay to Port McNeill (345 km, ~4 hr drive, Highway 19)
7:00 pm	lodging in Port McNeill (dinner in restaurant at Haida Way Inn)

<u>July 20</u>	**<u>DAY 1-Sunday</u>** (stops in Keogh-Nimpkish Lake area)
7:00-8:30 am	breakfast in Port McNeill (at Haida Way Inn)
8:30 am	meet in the parking lot at the Haida Way Inn
	FIELD STOPS in Keogh-Maynard Lake area
12:00 pm	bag lunch
1:00	FIELD STOPS in Maynard-Nimpkish Lake area
4:30-5:00 pm	leave for Telegraph Cove
~5:30 pm	snacks and drinks at the Old Saltery Pub (drinks, not included)
~7:00 pm	Salmon barbeque at the Killer Whale Café at Telegraph Cove, return to Port McNeill

<u>July 21</u>	**<u>DAY 2-Monday</u>** (stops in Schoen Lake and Strathcona Prov. Parks)
7:00-8:00 am	breakfast in Port McNeill (buffet at Haida Way Inn)
8:00 am	leave for Schoen Lake area
9:15 am	Upper Adam Main turnoff
10:00 am	FIELD STOP in Mount Schoen area
12:00 pm	bag lunch along way
2:00 pm	FIELD STOPS in Buttle Lake area
~4:00 pm	arrive at Strathcona Park Lodge -OPEN TIME -nice place to relax
6:00-8:00 pm	dinner buffet style at Strathcona Park Lodge

<u>July 22</u>	**<u>DAY 3-Tuesday</u>** (stops in Strathcona Prov. Park, return travel)
7:30 am	breakfast at Strathcona Park Lodge
8:30 am	leave for Myra Falls
	FIELD STOPS in the Buttle Lake area of Wrangellia basement
10:30 am	leave for Nanaimo (~195 km, ~2.5 hr drive)
~12:00 pm	bag lunch along the way
3:00 pm	ferry from Departure Bay to Horseshoe Bay
4:45 pm	drive to UBC from Horseshoe Bay (~35 km, ~1 hr drive)
5:45-6:00 pm	arrive at UBC

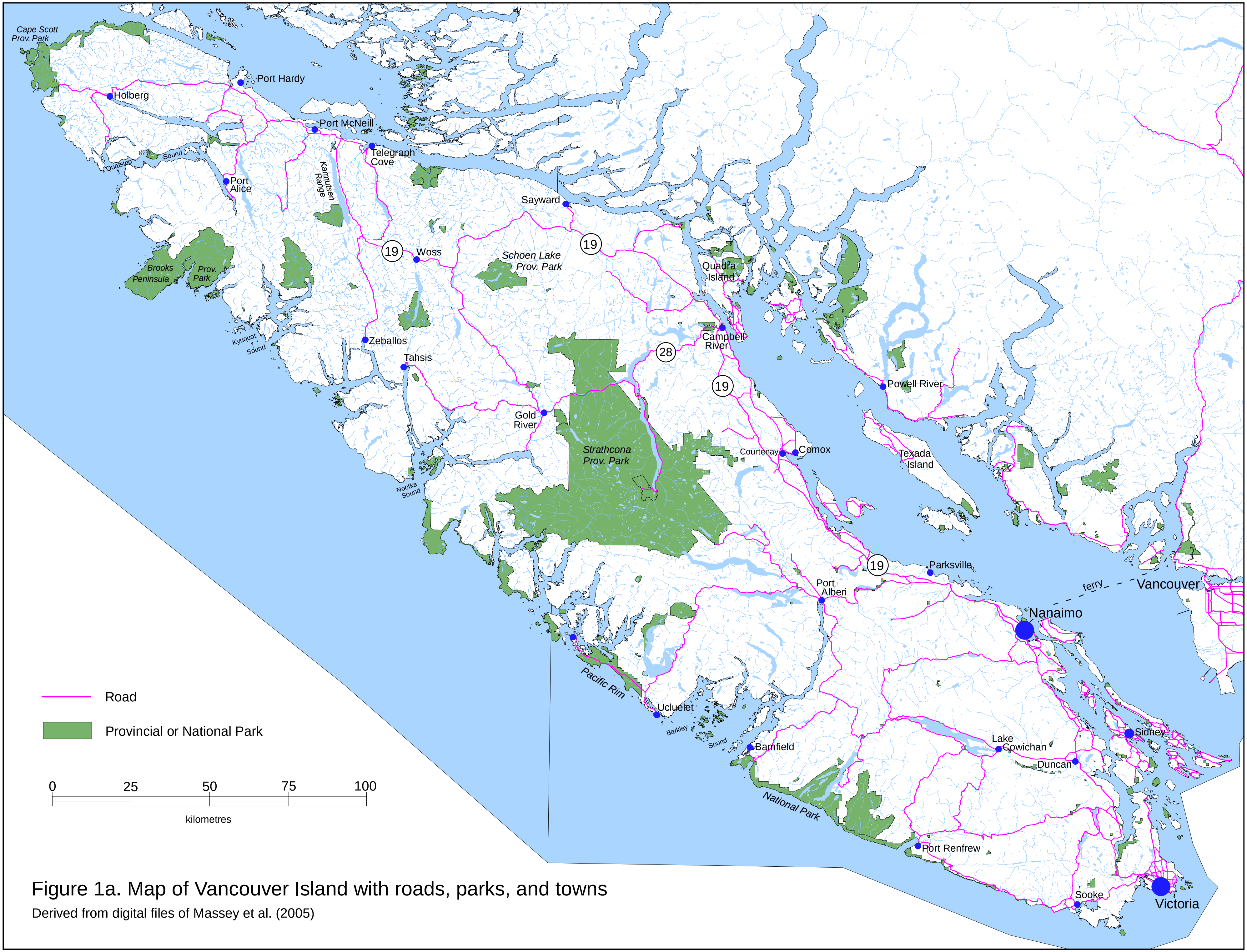


Figure 1a. Map of Vancouver Island with roads, parks, and towns

Derived from digital files of Massey et al. (2005)

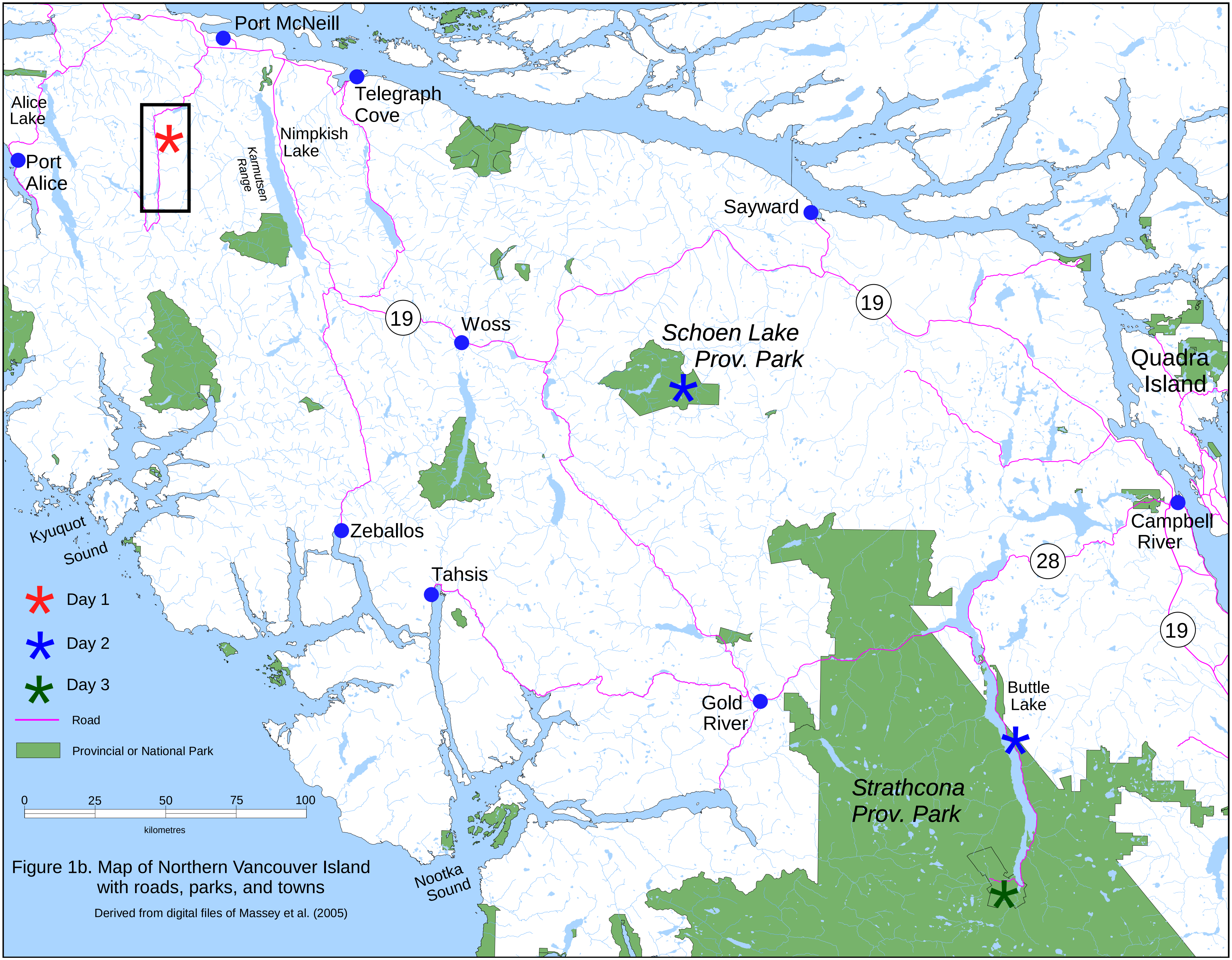


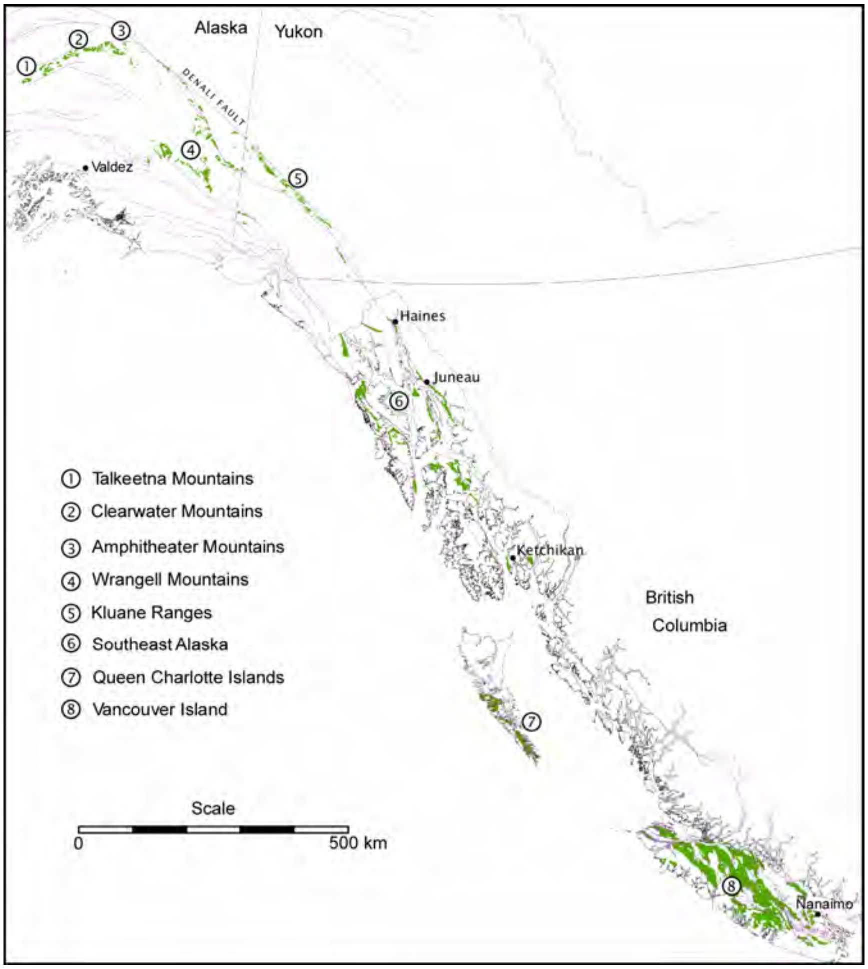
Figure 1b. Map of Northern Vancouver Island with roads, parks, and towns

Derived from digital files of Massey et al. (2005)

II. Geology and field stop itinerary

A. Vancouver Island overview and maps of geology and route

A large part of Vancouver Island is underlain by a Paleozoic and Early Mesozoic terrane called Wrangellia. Wrangellia extends from southern Vancouver Island northwards through the Queen Charlotte Islands (Haida Gwaii) and into southern Alaska. Wrangellia joined the Alexander Terrane in southeast Alaska prior to accretion in the Late Jurassic to Early Cretaceous (Csejtey *et al.*, 1982; Umhoefer & Blakey, 2006; Trop & Ridgway, 2007).

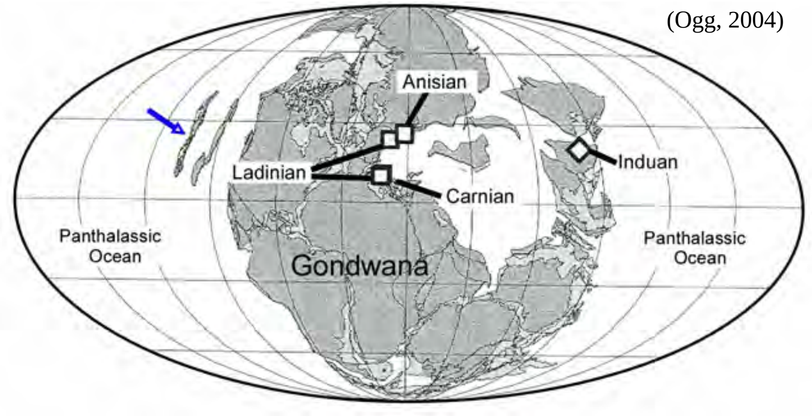


Wrangellia covers approximately 80% of Vancouver Island, which is 460 km long by 130 km wide. Wrangellia is the uppermost sheet of a stack of northeast-dipping thrust sheets that form the upper crust of Vancouver Island and has a cumulative thickness of >10 km (Monger & Journeay, 1994). Wrangellia is in fault contact with the Pacific Rim Terrane and West Coast Crystalline Complex to the west, and is intruded by the Cretaceous Coast Plutonic Complex to the east (Wheeler & McFeely, 1991). The crust beneath Vancouver Island has seismic properties of mafic plutonic rocks extending to depth (~25-30 km thick) that are underlain by a strongly reflective zone of high velocity and density, which has been interpreted as a major shear zone where lower Wrangellia lithosphere was detached (Clowes *et al.*, 1995).

The basement of Wrangellia was originally defined as a Late Paleozoic volcanic arc sequence that may have been deposited on oceanic crust (Jones *et al.*, 1977). The defining units of Wrangellia on Vancouver Island are a succession of flood basalts (the Karmutsen Formation) that includes submarine, volcaniclastic, and subaerial flows, which formed as part of an enormous emergent oceanic plateau. The Karmutsen Formation (ca. 230-225 Ma) is overlain by the shallow-water Quatsino Limestone and deeper-water Parson Bay Formation, which is intercalated with and overlain by Bonanza arc volcanics (169-202 Ma; Nixon *et al.*, 2006). The Karmutsen basalts cover ~20,000 km^2 of Vancouver Island and are ~6 km in total thickness.

Paleogeography of Wrangellia

Paleontological studies indicate that Wrangellia was located in cool-temperate northern paleolatitudes (~25ºN) during the Permian and not far from the North American continent (Katvala & Henderson, 2002). Paleomagnetic studies of Karmutsen basalts indicate eruption in equatorial latitudes (Irving & Yole, 1972) and Upper Triassic bivalves indicate an eastern Panthalassan position in the Late Triassic (Newton, 1983). Paleobiogeographic studies indicate Wrangellia was located in the northeast Pacific Ocean during the Early Jurassic (Smith, 2006).



ca. 226 Ma
(Ogg, 2004)

Wrangellia basement on Vancouver Island

The deepest levels of Wrangellia stratigraphy on Vancouver Island are mostly exposed in two prominent northwest- to southeast-trending anticlinoria (Buttle Lake and Cowichan Anticlinoria) cored by Paleozoic rocks on Central and Southern Vancouver Island (Figs. 2 and 3) (Brandon *et al.*, 1986; Yorath *et al.*, 1999). Wrangellia basement is comprised of the lower to middle Paleozoic Sicker Group and the upper Paleozoic Buttle Lake Group. The Sicker Group is Devonian to Mississippian volcanics, volcaniclastics, and minor chert (Brandon *et al.*, 1986; Massey & Friday, 1988; Yorath *et al.*, 1999). The overlying Buttle Lake Group comprises Mississippian chert, argillite, and limestone, and Pennsylvanian to Permian limestone, argillite, and chert overlain by minor clastics (Yole, 1969; Brandon *et al.*, 1986; Massey & Friday, 1988; Yorath *et al.*, 1999). Conodonts indicate Mississippian to Permian ages in the Buttle Lake Group (Orchard fide Brandon *et al.*, 1986; Henderson & Orchard, 1991; Katvala & Henderson, 2002). The upper parts of the Buttle Lake Group (Mount Mark Formation) are commonly intruded by mafic sills related to the Karmutsen basalts (Massey, 1995; Yorath *et al.*, 1999).

Previous research

In the 1970's, Jones and co-workers (1977) defined the fault-bound blocks of crust that contain diagnostic Triassic flood basalts in BC, Yukon, and Alaska as Wrangellia, named after the type section in the Wrangell Mountains of Alaska. Early paleomagnetic studies indicated long-distance displacement of the basalts from equatorial latitudes (Hillhouse, 1977) and similar *Daonella* bivalves were found in sediments directly beneath the flood basalts on Vancouver Island and in the Wrangell Mountains (Jones *et al.*, 1977). A back-arc setting was initially proposed for the formation of Karmutsen basalts on Vancouver and Queen Charlotte Islands based on major- and trace-element geochemistry of 12 samples (Barker *et al.*, 1989). Richards and co-workers (1991) proposed a plume initiation model for the Wrangellia flood basalts based on evidence of rapid uplift prior to volcanism, lack of evidence of rifting associated with volcanism (few dikes and abundant sills), and the short duration and high eruption rate of volcanism. A geochemical study of 36 samples of Wrangellia flood basalts, 29 samples from Buttle Lake on Vancouver Island and 9 samples from the Wrangell Mountains in Alaska, was undertaken by Lassiter and co-workers (1995) as part of the only modern geochemical and isotopic study of

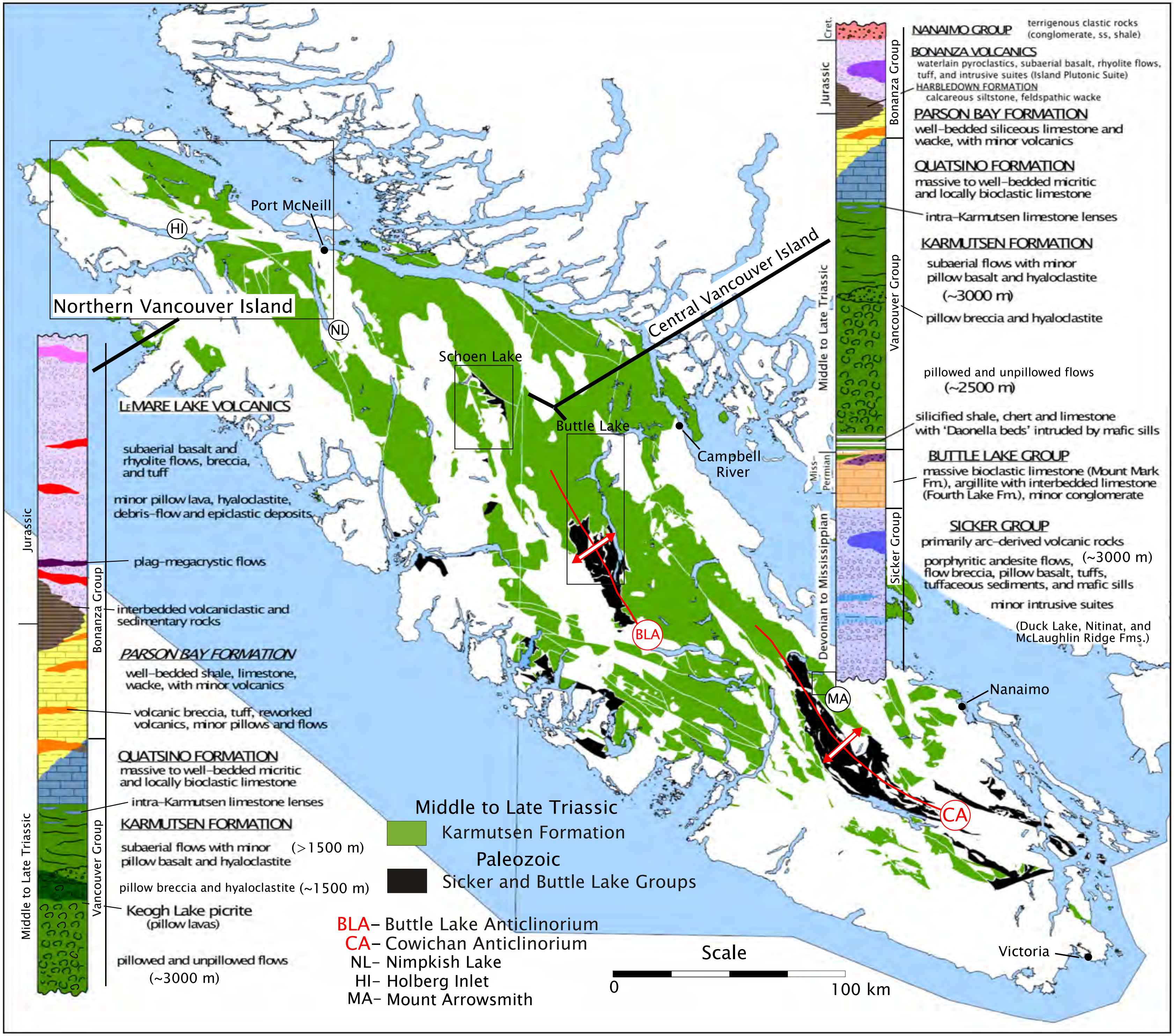


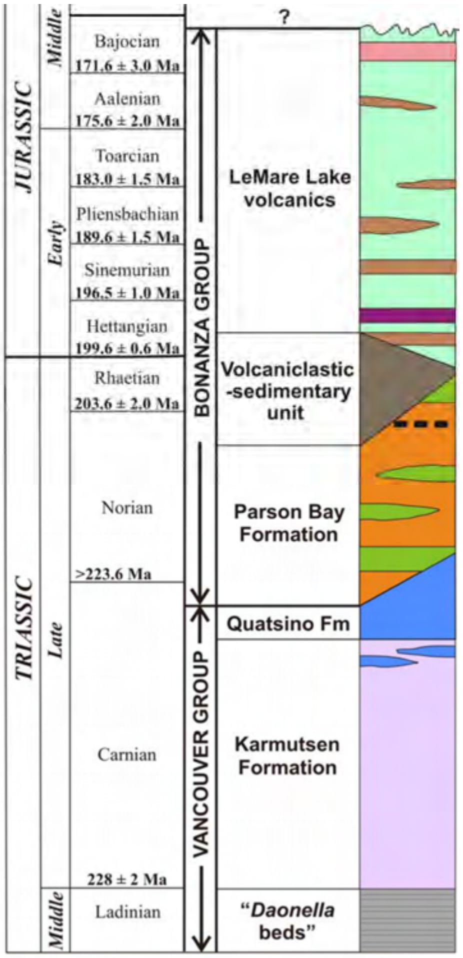
Figure 3. Simplified map of Vancouver Island showing the distribution of the Karmutsen Formation (green) and underlying Paleozoic formations (black; after Massey *et al.*, 2005a, b). Column for northern Vancouver Island adapted from Nixon & Orr (2007). Column for central Vancouver Island is derived from Carlisle (1972), Juras (1987), Massey (1995), and from fieldwork.

Wrangellia flood basalts until the initiation of a research project over the last 4 ½ years on the Wrangellia flood basalts in BC, Yukon, and Alaska at the University of British Columbia (Greene *et al.*, 2006; Greene, 2008; Greene *et al.*, 2008, submitted).

B. Northern Vancouver Island (NVI) overview

There are a limited number of paved roads on Northern Vancouver Island, but the construction of extensive networks of logging roads provide excellent access and exposures. The coastline also has excellent exposures but is mainly accessible by boat. The Karmtusen Range is one of the more rugged areas on Northern Vancouver Island (NVI), with elevations reaching 4,800 ft (1460 m). The first geological explorations of Vancouver Island were made by G. M. Dawson in the late 1870's. Gunning explored parts of NVI and described and named the Karmutsen Formation in the 1930's. Karmutsen is a Kwakwala Indian word for 'waterfall' (Akrigg & Akrigg, 1997). Regional mapping and stratigraphic studies were carried out by Muller and co-workers (1970; 1974) and recently by Nixon and co-workers (e.g. 2006; 2007; 2008).

Most of NVI is underlain by the Vancouver and Bonanza Groups, that are described in detail in Nixon et al. (2006; 2007; 2008) (included). The Vancouver Group contains the Karmusten Formation and overlying Quatsino limestone. The Late Triassic-Middle Jurassic Bonanza Group contains volcanic and sedimentary rocks and coeval granitoid intrusions of the Island Plutonic Suite that represent the main phase of magmatism of the Bonanza island arc (Northcote & Muller, 1972; DeBari *et al.*, 1999). Structures on NVI are mostly northwest-trending and Early Mesozoic strata generally dip to the southwest and west.



Northern VI stratigraphy (Nixon *et al.*, 2008)

1) **Day 1** field stop itinerary

July 20	**DAY 1-Sunday** (Karmutsen stratigraphy in the Keogh-Nimpkish Lake area)
7:00-8:30 am	breakfast in Port McNeill (buffet at Haida Way Inn)
8:30 am	parking lot Haida Way (Graham overview) -drive to Keogh Lake **STOP 1-** Keogh Lake picrite type locality (Keogh Main) **STOP 2-** Maynard Lake picritic pillow locality **STOP 3-** unpillowed flow drapping pillow basalt **STOP 4-** pillow breccia **STOP 5-** massive flows
12:00 pm	lunch
1:00 pm	**STOP 6-** bedded hyaloclastite **STOP 7-** interpillow infilling at Mistaken Quarry (Keogh Main) **STOP 8-** limestone lens at Nimpkish Lake (Highway 19)
~5:00 pm	leave directly for Telegraph Cove
5:30 pm	snacks and drinks at the Old Saltery Pub (drinks, not included)
6:30 pm	Salmon bake at the Killer Whale Café on Telegraph Cove, return to Port McNeill

2) Alice-Nimpkish Lake geology map with Karmutsen stratigraphy **(Fig. 4; Fig. 5, map with field stops)**

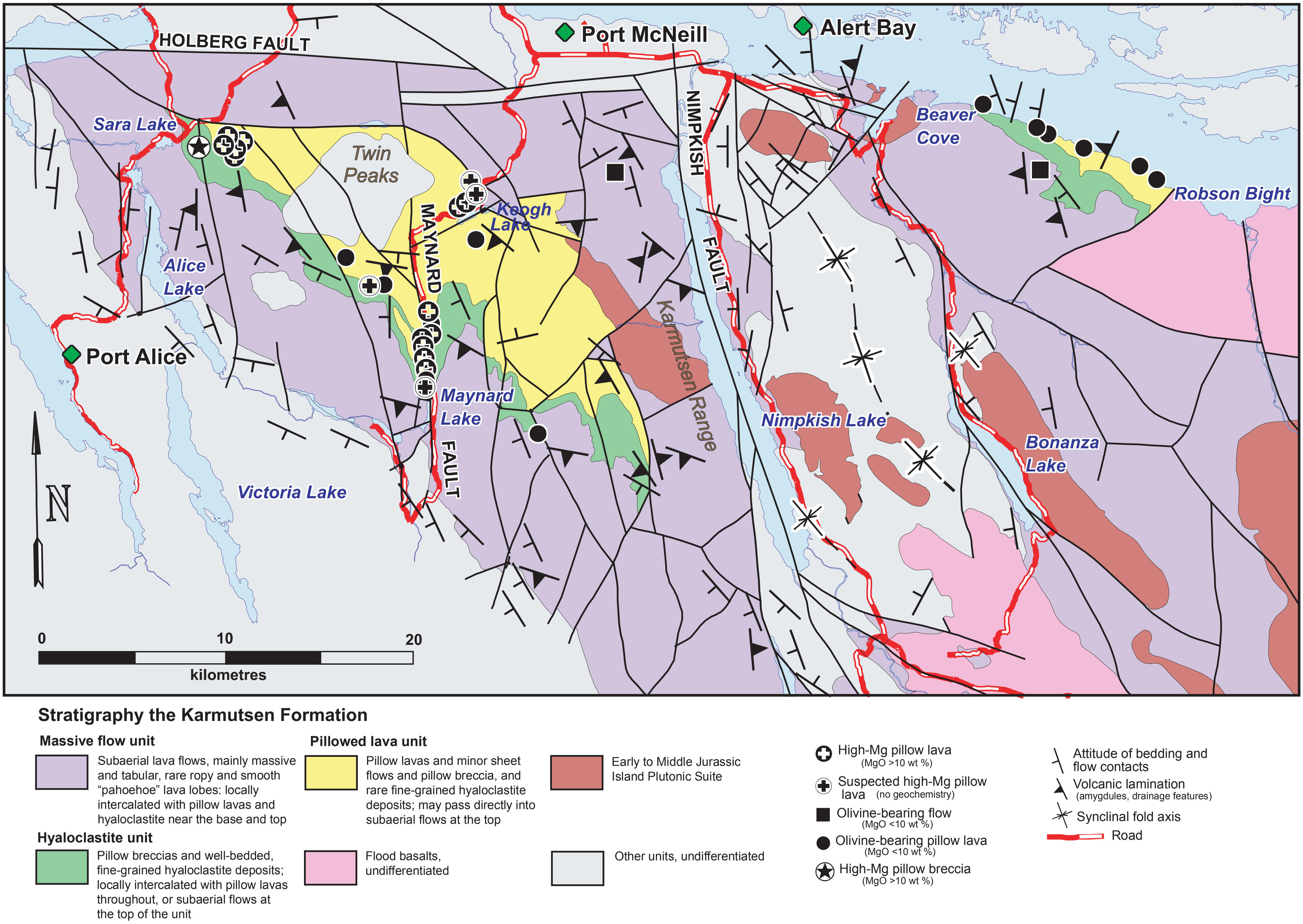


Figure 4. Generalized geology of the Karmutsen Formation in the Port Alice - Port McNeill - Robson Bight area showing the distribution of massive flow, hyaloclastite, and pillow lava sequences (from Nixon et al., 2008).

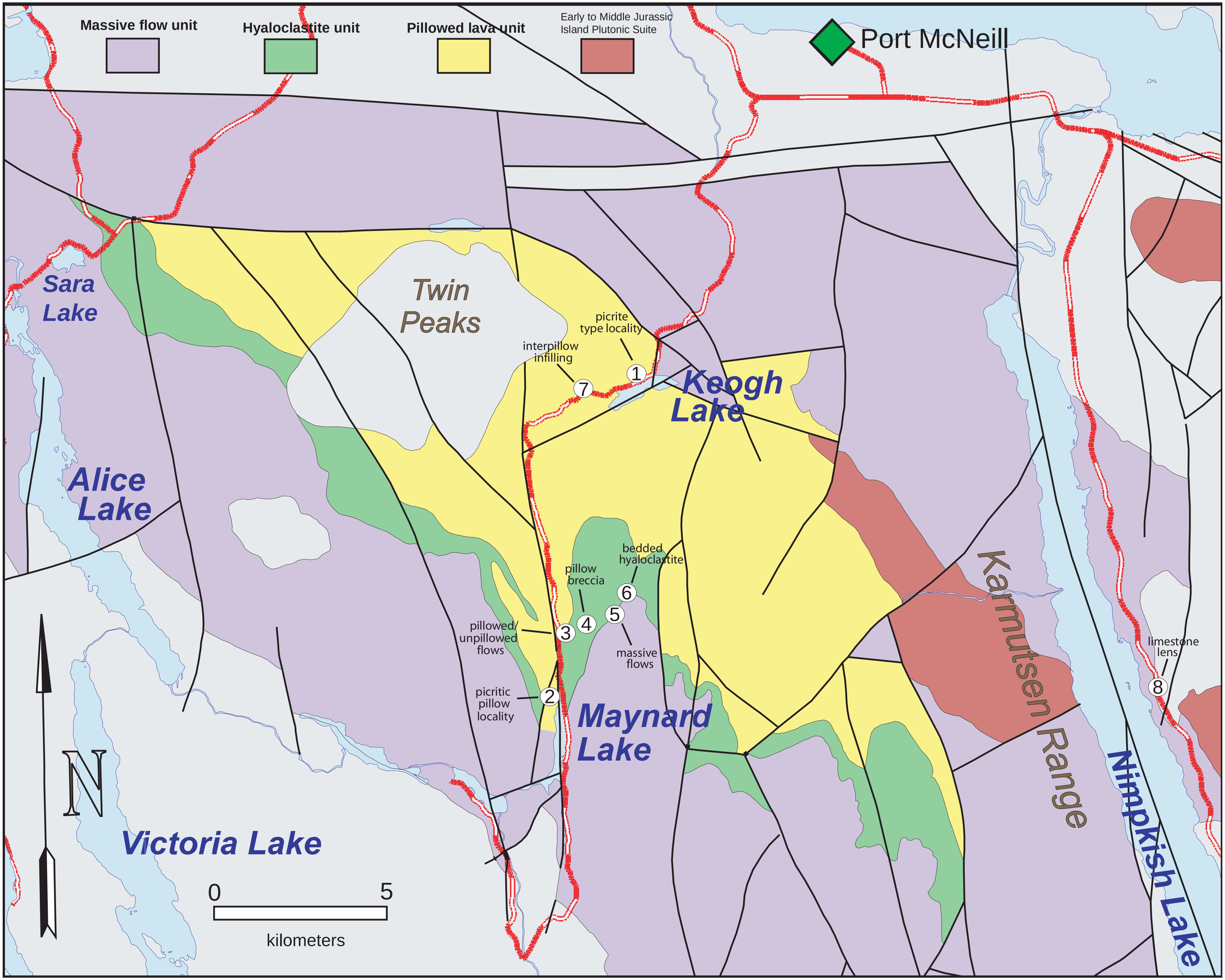
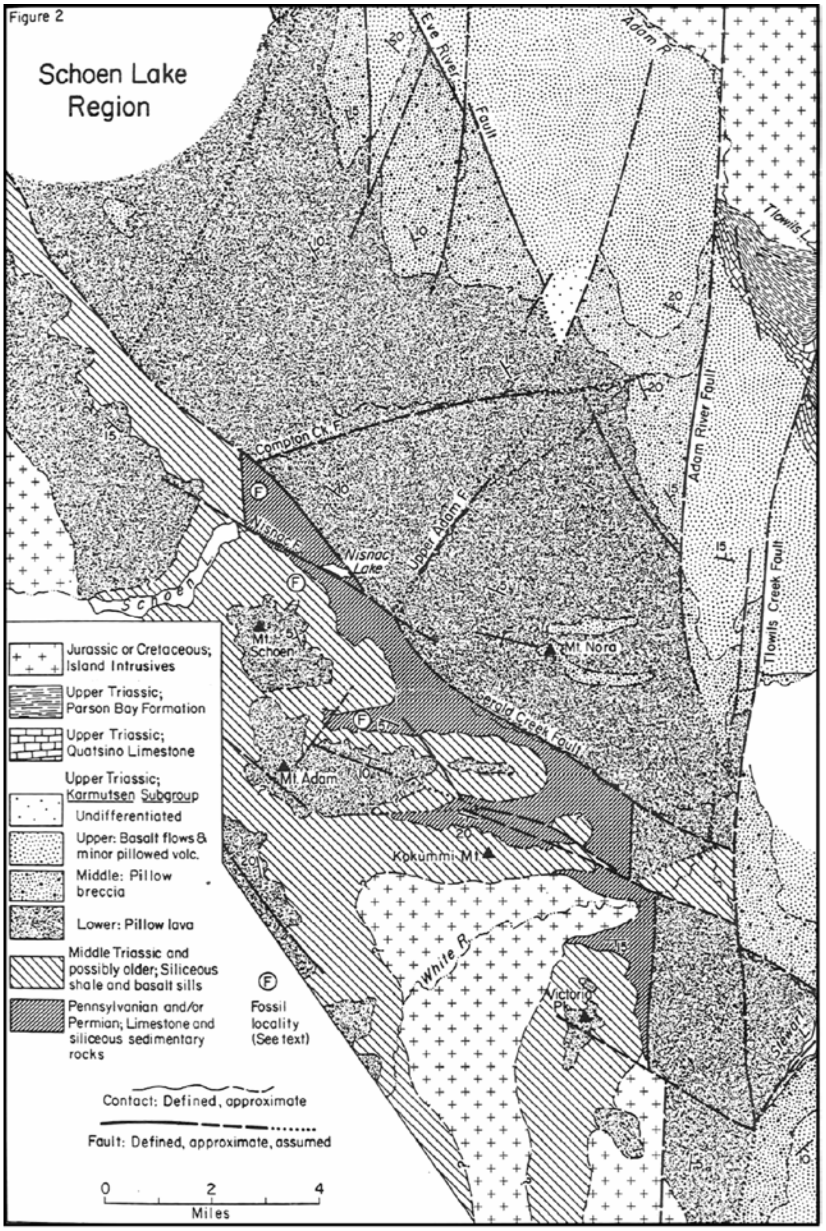


Figure 5. Stratigraphy of the Karmutsen Formation between Alice and Nimpkish Lakes, and the location of field stops.

C. Overview of Schoen Lake and Strathcona Provincial Parks

Many of the high peaks of Schoen Lake and Strathcona Provincial Parks are carved from the basalts of the Karmutsen Formation. Basal sills and large sections of volcanic stratigraphy are exposed in the steep cliffs around Schoen Lake and Strathcona Prov. Park areas (Figs. 6 and 7). Several peaks in the Schoen Lake area are close to 2000 m in elevation, with Victoria Peak (2163 m, 7095 ft) just south of the park being the highest. Schoen Lake Provincial Park (16 x 10 km) was established in 1977 and contains prime range of Roosevelt elk. The sedimentary and volcanic sequences in the Schoen Lake area were mapped and described by D. Carlisle (1972). In the Schoen Lake area, a sediment-sill complex and each of the three subdivisions of the Karmutsen Formation are preserved. Massive mafic sills intrude siltstone, chert, and interbedded limestone with Middle Triassic *Daonella* occurring near the top of the unit on Mount Schoen. The sediment-sill complex is approximately 1000 m thick and sedimentary layers between the sills range from 1 to 60 m thick and sills commonly deform and envelop sediments along contacts (Carlisle, 1972). The sediment-sill complex is overlain by a thick succession (~2000 m) of pillow basalt and some of the lowest pillowed flows contain sediment in interpillow voids, which is absent higher in the volcanic stratigraphy (Carlisle, 1972).

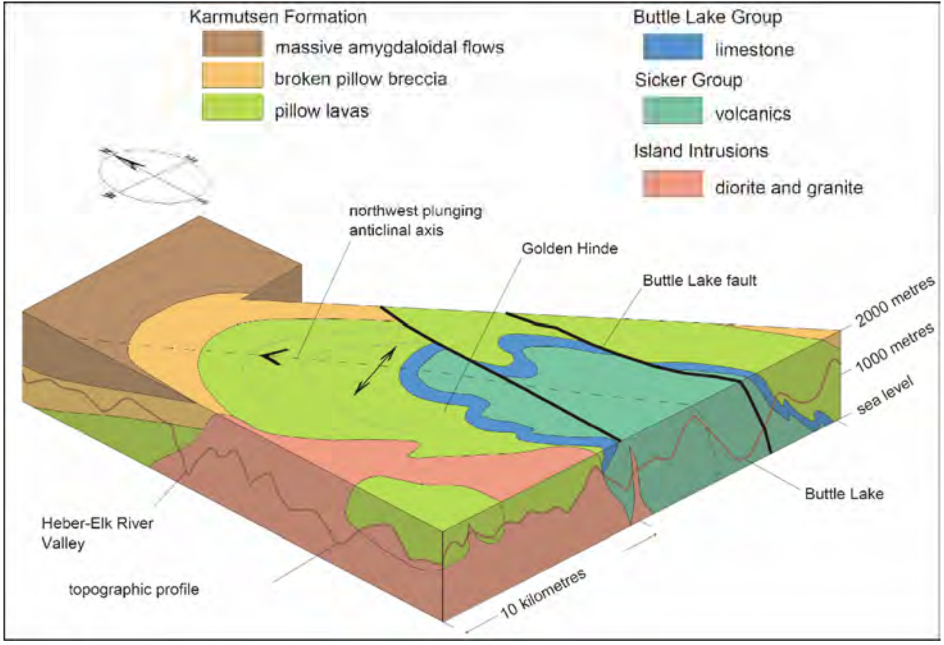


(Carlisle, 1972)

Strathcona Provincial Park was established in 1911 and was British Columbia's first provincial park (Baikie, 1986). Strathcona Park surrounds Buttle Lake, which is now ~725 ft above sea-level and the depth is controlled by hydro-electric power stations on Upper Campbell Lake to the north (Fig. 7). Strathcona Park is 60 x 70 km and contains the highest peaks on Vancouver Island. Golden Horn Peak (7218 ft, 2200 m) to the west of Buttle Lake is the highest peak on Vancouver Island and Elkhorn Mountain (7106 ft, 2166 m) is the second highest. Many of the peaks around Buttle Lake are 6000-7000 ft (1800-2100 m) and are mostly free of trees above ~4000 ft (1200 m).

There has been a considerable amount of geological work conducted in the Buttle Lake area, primarily because of the volcanogenic massive sulfide district with Paleozoic host rocks at the south end of Buttle Lake. This area has been prospected since the early 1900's and mined since the mid-1960's, and has been the focus of two Ph.D. dissertations (Carvalho, 1979; Juras, 1987). The Sicker and Buttle Lake Groups form the core of the Buttle Lake anticlinoria and are overlain by the Karmutsen Formation (Figs. 3 and 7). The first formal stratigraphy for the Sicker Group was proposed by Yole (1965, 1969) and several studies since then have expanded and revised the stratigraphy (e.g. Muller, 1980; Yorath *et al.*, 1985; Juras, 1987).

The Triassic volcanic stratigraphy around Buttle Lake is proposed to be the type section for the Karmutsen Formation because close to a complete stratigraphic section (~6000 m thick) is preserved (Yorath *et al.*, 1999). A Ph.D. dissertation was completed on the low-grade metamorphism of the Karmutsen in the Buttle Lake area by R. Surdam in 1967. On the west side of Buttle Lake, Permian limestone of the Buttle Lake Group (90-120 m thick) is intruded by Karmutsen sills and overlain by pillow lavas. Along the road on the east side of Buttle Lake, basal sills and lower pillowed flows are well-exposed and accessible. The lower part of the submarine stratigraphy at Buttle Lake is intruded by mafic sills 30-40 m thick (Surdam, 1967).



Schematic drawing of the Buttle Lake anticlinorium. MEMPR Information Circular 1995-7

Above the submarine flows at Buttle Lake are <1500 m of pillow breccia and hyaloclastite and over 2000 m of massive subaerial flows (Surdam, 1967). Marine fossils have been found at one locality within the pillow breccia in the lower part of the Karmutsen (Surdam, 1967). The lower part of the subaerial flow member contains thinner flows than the upper part. The upper part of the Karmutsen Formation around Buttle Lake contains discontinuous alternations of pillow basalt, pillow breccia, and hyaloclastite typically <30 m thick, but a single, more widespread subaqueous unit is 1-120 m thick (Surdam, 1967). This subaqueous section overlies limestone and tuff up to 30 m thick (Surdam, 1967).

Myra Falls at the south end of Buttle Lake

The overlying Quatsino limestone at Buttle Lake lies directly on an unweathered

Karmutsen basalt flow (Surdam, 1967), however, occurrences of paleosols between the Karmutsen and Quatsino Formations have been reported elsewhere on central Vancouver Island (Yorath *et al.*, 1999). Evidence of molding of limestone around basalt and disaggregation of the limestone lenses from interaction with basalt flows is described by Surdam (1967). The basal part of the Quatsino Formation west of Buttle Lake is intercalated with pillow basalt in several areas (Surdam, 1967).

Marblerock Canyon, Strathcona Prov. Park

1) **Day 2** field stop itinerary

2) **Day 3** field stop itinerary

<u>July 21</u>	**<u>DAY 2-Monday</u>** (stops in Schoen Lake and Buttle Lake areas)
7:00-8:00 am	breakfast at Haida Way Inn
8:00 am	leave for Schoen Lake area
9:15 am	Upper Adam Main turnoff
10:00 am	**STOP 1**-Upper Adam basal sills (Upper Adam Road)
12:00 pm	lunch
2:00 pm	-drive south to the Strathcona Prov. Park area **STOP 2-** perspective of columnar jointing in subaerial stratigraphy (Westmin Road) **STOP 2-** radial columnar jointing, transition of pillowed and massive flows, and sediments **STOP 4-** view of Wrangellia basement intruded by basalt; maybe more
~4:00 pm	arrive at Strathcona Park Lodge **-**OPEN TIME -nice place to relax
6:00-8:00 pm	dinner buffet style at Strathcona Park Lodge

<u>July 22</u>	**<u>DAY 3-Tuesday</u>** (stops in the Strathcona Prov. Park area, return travel)
7:30 am	breakfast at Strathcona Park Lodge
8:30 am	leave for field stops of basement in southern Buttle Lake area ***Pre-Karmutsen stops*** **STOP 1-** short hike into Myra Falls, Myra Formation **STOP 2-** Thelwood Formation (Westmin Road) **STOP 3-** Buttle Lake Formation
10:30 am	leave for Nanaimo (~195 km, ~2.5 hr drive)
12:00 pm	bag lunch on the way
3:00 pm	ferry from Departure Bay to Horseshoe Bay
4:45 pm	drive to UBC from Horseshoe Bay (~35 km, ~1 hr drive)
~6:00 pm	arrive at UBC

3) Schoen Lake area geology map **(Fig. 6)**

4) Strathcona Prov. Park geology map **(Fig. 7)** (Wilson *et al.*, 1998; Gradstein *et al.*, 2004; Ogg, 2004; Sircombe, 2004; Massey *et al.*, 2005b, a; Wilson *et al.*, 2005; Furin *et al.*, 2006)

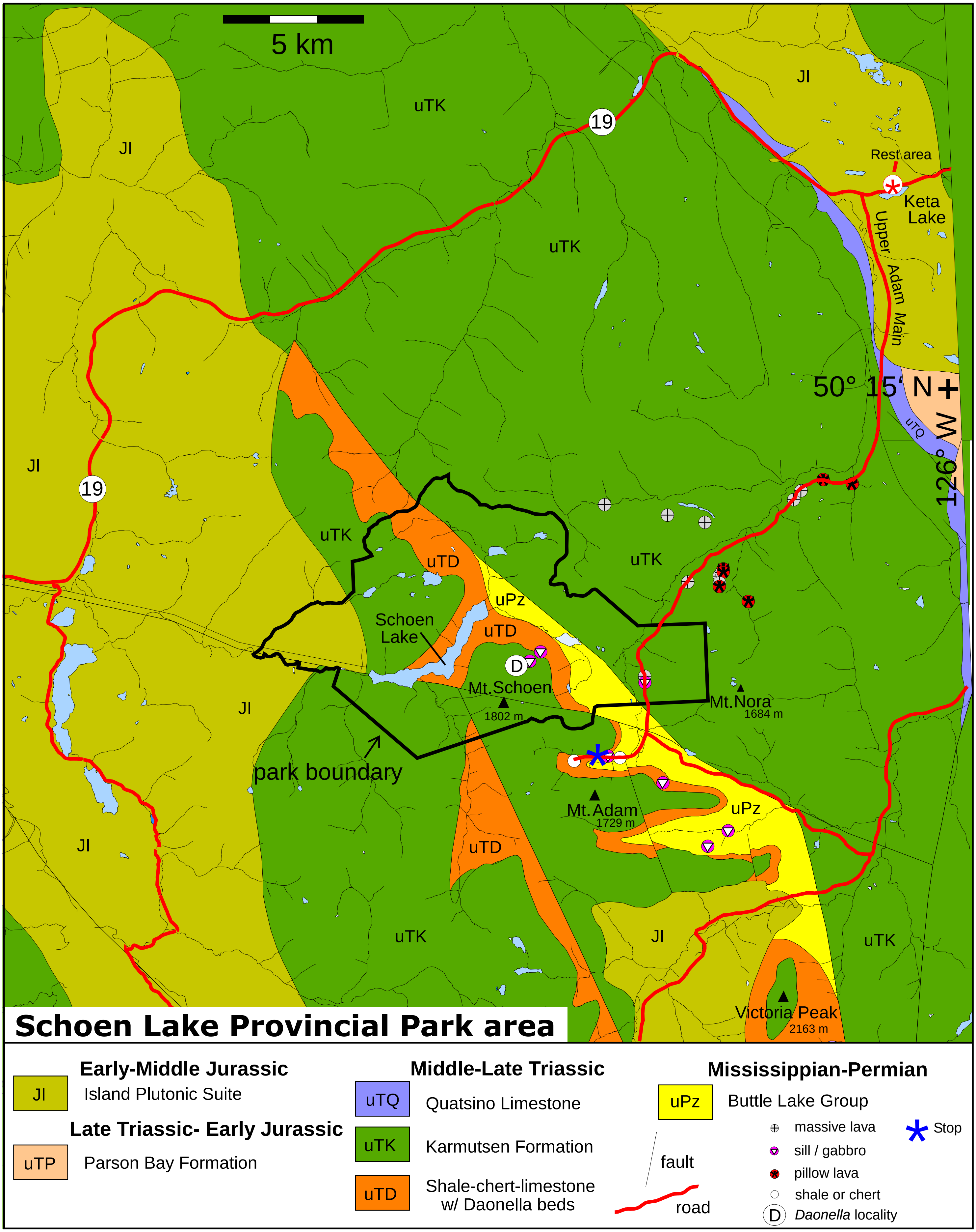

5 km
Schoen Lake Provincial Park area
19
Rest area
Keta Lake
Upper Adam Main
50° 15' N
126° W
uTQ
Jl
uTK
uTD
uPz
Schoen Lake
D
Mt.Schoen
1802 m
Mt.Nora
1684 m
Mt.Adam
1729 m
Victoria Peak
2163 m
park boundary
Early-Middle Jurassic
Jl Island Plutonic Suite
Late Triassic- Early Jurassic
uTP Parson Bay Formation
Middle-Late Triassic
uTQ Quatsino Limestone
uTK Karmutsen Formation
uTD Shale-chert-limestone w/ Daonella beds
Mississippian-Permian
uPz Buttle Lake Group
fault
road
⊕ massive lava
sill / gabbro
pillow lava
○ shale or chert
D Daonella locality
* Stop

Figure 6.

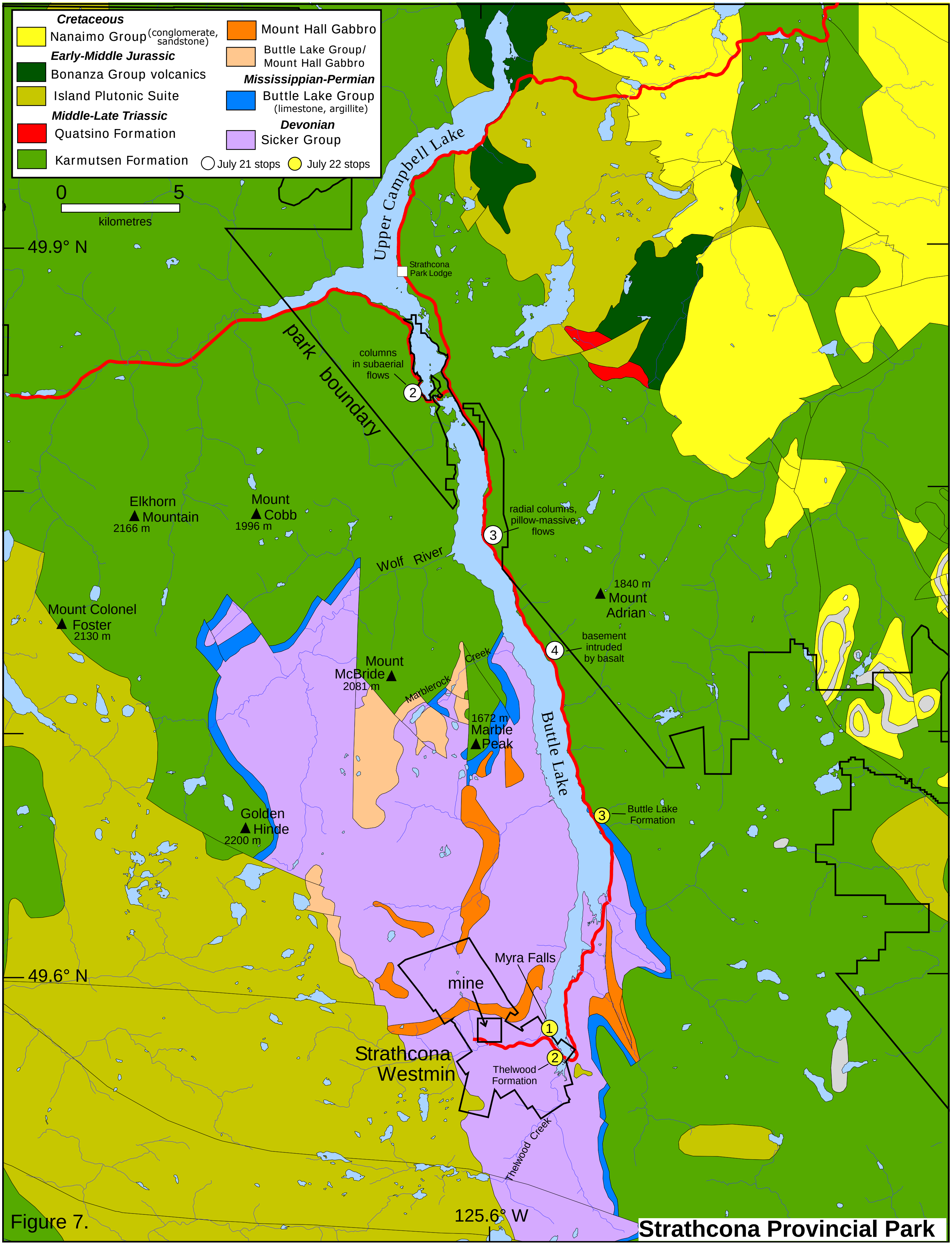
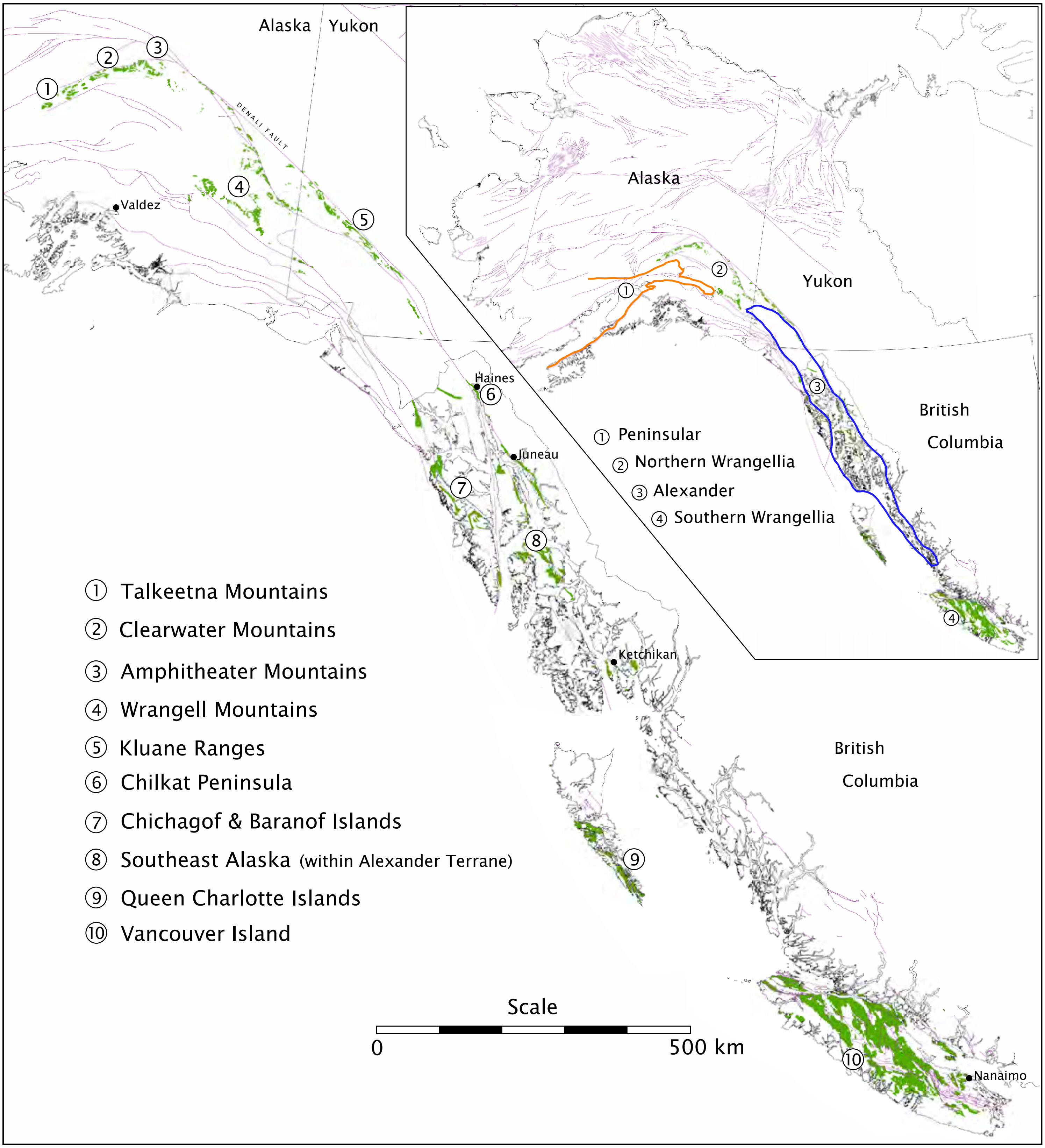
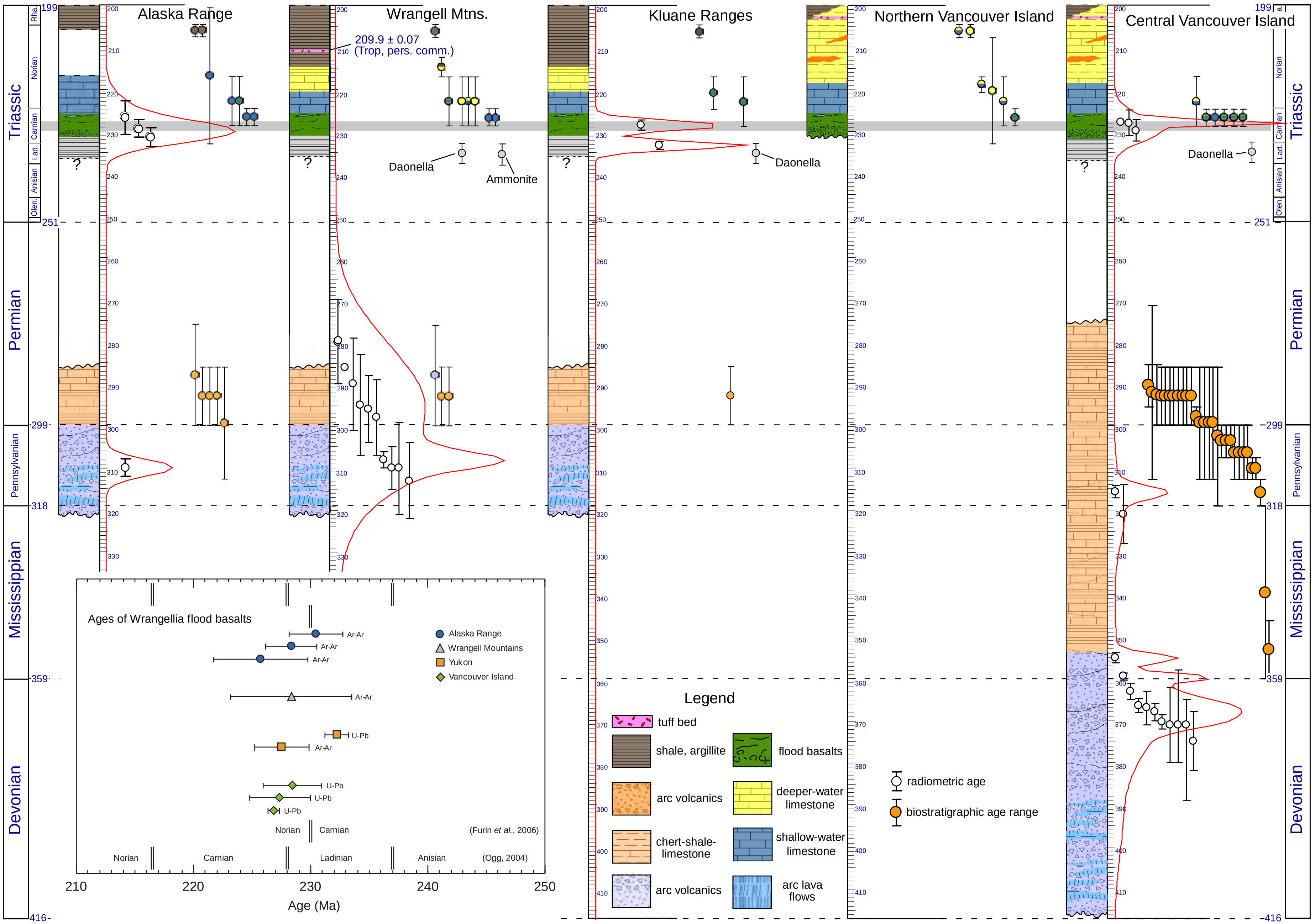


Figure 7.

Strathcona Provincial Park



Appendix 1. Simplified map showing the distribution of Wrangellia flood basalts in Alaska, Yukon, and British Columbia. Map derived from (Wilson *et al.*, 1998; Israel, 2004; Massey *et al.*, 2005a, b; Wilson *et al.*, 2005; Brew, 2007, written comm.). Inset shows northwest North America with Wrangellia flood basalts, and outlines for the Peninsular (orange) and Alexander (blue) Terranes. Purple lines are faults in Alaska and parts of Yukon. Circled numbers are indicated in the legend.



Appendix 2. Summary of ages and biostratigraphy for Wrangellia, divided into 5 areas. Radiometric ages are white circles. Fossil ages are colored according to formation in stratigraphic column, unless colored gray. Age probability density distribution plots for each area are calculated from the plotted ages using AgeDisplay (Sircombe, 2004). The ages for the period boundaries are from Gradstein *et al.* (2004). Ages for epoch boundaries of the Triassic are adjusted using Furin *et al.* (2006). Inset is a summary diagram showing published $^{40}Ar/^{39}Ar$ and U/Pb ages of Wrangellia flood basalts and plutonic rocks with analytical uncertainty <10 Myr. Errors are 2σ.

Appendix 3. Major element (wt% oxide) and trace element (ppm) abundances in whole rock samples of Karmutsen basalts from fieldstops.

Day	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul
Field Stop	1	1	1	1	1	1	1	2	2	2	2
Sample	**4722A4(1)***	**4722A4(2)***	**4722A4(3)***	**5615A7(1)***	**5615A7(2)***	**5615A8**	**5615A10**	**4723A2***	**4723A3***	**4723A4***	**5615A12***
Group	PIC	PIC	PIC	PIC	PIC	THOL	THOL	HI-MG	PIC	PIC	PIC
Area	KR	KR	KR	KR	KR	KR	KR	KR	KR	KR	KR
Flow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow
UTM EW	5595528	5595528	5595528	5595569	5595569	5595513	5595376	5588266	5588274	5586081	5586126
UTM NS	629490	629490	629490	629573	629573	629434	629069	626698	626641	626835	626824
Unnormalized Major Element Oxides (Weight %):											
SiO_2	43.85	43.84	42.94	47.16	45.73	48.31	47.29	46.73	44.41	44.39	45.35
TiO_2	0.425	0.425	0.42	0.466	0.442	1.745	1.807	0.611	0.539	0.663	0.643
Al_2O_3	11.56	11.74	11.26	11.84	11.48	13.45	13.7	15.24	12.75	14.93	14.07
Fe_2O_3*	10.11	9.65	10.82	11.54	11.22	13.48	14.23	10.26	10.33	10.11	10.4
MnO	0.161	0.158	0.161	0.172	0.166	0.196	0.195	0.158	0.148	0.139	0.142
MgO	17.74	17.51	18.28	18.59	18.19	6.78	6.77	10.27	15.42	13.02	12.56
CaO	9.43	9.36	8.98	9.45	9.14	11.77	10.65	9.93	8.73	9.73	9.00
Na_2O	0.53	0.53	0.54	0.42	0.41	1.8	2.58	2.26	0.78	1.56	2.11
K_2O	0.10	0.13	0.02	0.01	0.16	0.03	0.21	0.38	0.07	0.07	0.02
P_2O_5	0.04		0.03	0.03	0.05	0.14	0.14	0.06	0.05	0.06	0.06
LOI	5.45	5.33	5.7		2.86	1.74	1.57	3.70	5.61	4.91	4.68
Total	99.39	98.66	99.16	99.67	99.84	99.43	99.14	99.60	98.83	99.58	99.02
Trace Elements (ppm):											
La	1.06	0.96	1.08	1.09	1.02	7.32	7.34	1.94	1.80	1.78	1.73
Ce	2.6	2.5	2.6	2.7	2.6	18.4	18.5	5.0	4.5	4.5	4.7
Pr	0.41	0.38	0.43	0.44	0.41	2.69	2.84	0.74	0.67	0.71	0.77
Nd	2.6	2.3	2.5	2.5	2.4	12.9	13.2	4.2	3.8	4.1	4.4
Sm	0.92	0.84	0.87	0.88	0.85	3.78	3.92	1.41	1.27	1.48	1.47
Eu	0.38	0.37	0.405	0.381	0.361	1.47	1.48	0.52	0.51	0.63	0.61
Gd	1.40	1.42	1.45	1.42	1.35	4.4	4.65	2.09	1.86	2.16	2.13
Tb	0.30	0.30	0.3	0.3	0.3	0.79	0.81	0.42	0.37	0.42	0.42
Dy	2.16	2.17	2.11	2.16	2.12	4.65	4.79	2.91	2.60	2.79	2.78
Ho	0.49	0.50	0.47	0.49	0.46	0.89	0.91	0.67	0.59	0.60	0.59
Er	1.53	1.54	1.54	1.55	1.46	2.58	2.58	2.10	1.86	1.79	1.78
Tm	0.24	0.23	0.242	0.253	0.236	0.379	0.38	0.32	0.29	0.26	0.27
Yb	1.58	1.52	1.62	1.71	1.58	2.34	2.42	2.06	1.85	1.67	1.75
Lu	0.23	0.23	0.244	0.247	0.245	0.339	0.348	0.31	0.28	0.25	0.27
Sc	38.3	40.1	36.4	39.2	39.5	40.4	39.8	47.2	41.0	38.1	38.3
V	201	189	194	224	222	353	363	261	218	235	215
Cr	1710	1830	1750	1910	1850	173	166	358	1570	725	906
Co	80.3	84.6	80	87.1	89.3	53	52.4	48.8	72.9	60.4	67.2
Ni	755	755	755	729	680	96	94	163	656	339	368
Cu	92	83	83	86	80	175	185	111	110	106	83
Zn	77	55	55	57	54	88	86	61	60	63	50
Ga	10	9	11	10	10	20	20	13	12	13	14
Ge	1.0	0.7	1.2	1.1	0.9	1.4	1.3	1.2	1.1	1.1	1.1
Rb	5	4	6	6	6	2	9	10	2	2	2
Sr	100	97	93	124	120	194	279	271	64	132	189
Y	16	13	15	15	15	28	28	20	17	18	16
Zr	16	19	16	16	15	91	96	33	29	36	35
Nb	0.7	0.9	0.7	0.9	0.7	8.0	8.5	1.5	1.3	1.1	1.4
Cs	2.8	2.7	5.8	4.4	4.5	0.6	1.3	6.5	0.9	0.8	0.6
Ba	19	18	27	27	24	39	61	84	15	20	15
Hf	0.5	0.6	0.6	0.6	0.5	2.7	2.8	1.0	0.9	1.0	1.1
Ta	0.09	0.03				0.6	0.6	0.08	0.06	0.05	
Pb	7	4	22	24	22	91	92		4		34
Th	0.10	0.11	0.09	0.1	0.08	0.59	0.61	0.23	0.20	0.10	0.09
U	0.05	0.03	0.07	0.07	0.07	0.22	0.24	0.10	0.09	0.05	0.07

Abbreviations for group are: THOL, tholeiitic basalt; PIC, picrite; HI-MG, high MgO basalt; CG, coarse-grained (sill or gabbro); MIN SIL, mineralized sill; OUTLIER, anomalous pillowed flow. Abbreviations for area are: SL, Schoen Lake; KR, Karmutsen Range; . Sample locations are given using the Universal Transverse Mercator (UTM) coordinate system (NAD83; zones 9 and 10). Analyses were performed at Activation Laboratory (ActLabs). Fe_2O_3* is total iron expressed as Fe_2O_3. LOI is loss-on-ignition. All major elements, Sr, V, and Y by Fused ICP quadrapole (ICP-OES); Cu, Ni, Pb, and Zn by Total dilution ICP; Cs, Ga, Ge, Hf, Nb, Rb, Ta, Th, U, Zr, and REE by Fused-magnetic-sector ICP; Co, Cr, and Sc by INAA. Blanks are below detection limit. *Ni concentrations for these high-MgO samples by XRF.

Day	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	19-Jul	20-Jul	20-Jul	20-Jul
Field Stop	3	3	4	7	7	7	8	8	1	1	1
Sample	GRAHAM	GRAHAM	**7819A1**	**4722A5(1)***	**4722A5(2)***	**5615A11**	**7819A2**	**7819A3**	**5617A4**	**5617A5(1)***	**5617A5(2)***
Group	HI-MG	HI-MG	THOL	OUTLIER	OUTLIER	OUTLIER	??	??	MIN SIL	CG	CG
Area	KR	KR	KR	KR	KR	KR	KR	KR	SL	SL	SL
Flow	Pillow	Flow	Pillow Brec	Flow	Flow	Pillow	Dike	Flow	Sill	Sill	Sill
UTM EW	5589262	5589258	5589617	5595029	5595029	5595029	5588687	5588687	5557712	5557712	5557712
UTM NS	627205	627212	627566	627605	627605	627605	643967	643967	700905	700905	700905
Unnormalized Major Element Oxides (Weight %):											
SiO_2	46.33	44.89	43.02	48.95	48.45	49.08	46.95	50.31	48.06	49.31	47.4
TiO_2	0.680	0.619	0.737	2.295	2.333	2.304	0.896	0.815	3.505	1.713	1.71
Al_2O_3	15.62	15.26	17.13	13.61	12.51	11.86	17.23	17.91	12.79	13.39	13.33
Fe_2O_3*	9.77	9.69	10.86	12.56	15.24	15.2	10.46	8.07	16.78	12.39	12.71
MnO	0.130	0.141	0.138	0.188	0.191	0.215	0.194	0.173	0.164	0.174	0.174
MgO	10.15	9.76	8.65	6.18	5.99	5.73	5.64	4.57	5.25	7.5	7.46
CaO	11.67	11.93	10.90	9.33	8.99	9.84	6.42	6.81	6.48	12.01	11.93
Na_2O	1.68	2.10	1.93	3.26	3.30	3.25	3.84	4.86	2.31	1.83	1.8
K_2O	0.06	0.03	0.51	0.30	0.30	0.04	2.28	1.5	0.69	0.22	0.17
P_2O_5	0.09	0.07	0.07	0.13	0.19	0.22	0.26	0.28	0.35	0.13	0.14
LOI	3.48	5.04	5.58	2.00	1.95	2.07	5.34	3.19	3.22	1.28	1.38
Total	99.67	99.53	99.52	98.80	99.45	99.81	99.5	98.49	99.6	99.95	98.21
Trace Elements (ppm):											
La			1.59	8.77	9.46	6.41	8.56	10.7	22.3	8.13	7.94
Ce			4.3	23.0	25.2	17.3	21.0	24.8	51.5	19.7	19.2
Pr			0.70	3.37	3.68	2.89	2.99	3.23	7.19	2.89	2.85
Nd			4.0	17.2	17.9	15.6	12.2	12.5	32.7	13.3	13.3
Sm			1.39	5.20	5.21	5.06	2.95	3.05	8.86	3.83	3.77
Eu			0.60	1.74	1.79	1.88	1.1	1.11	3.33	1.45	1.43
Gd			2.09	6.39	6.63	6.19	2.95	3.02	9.84	4.36	4.32
Tb			0.44	1.11	1.20	1.13	0.51	0.51	1.64	0.75	0.75
Dy			3.24	6.59	7.08	6.65	3.15	3.28	9.58	4.35	4.25
Ho			0.72	1.34	1.39	1.24	0.62	0.66	1.78	0.83	0.81
Er			2.19	3.85	3.94	3.67	1.81	1.97	5.06	2.37	2.31
Tm			0.33	0.55	0.57	0.55	0.27	0.29	0.73	0.341	0.342
Yb			2.20	3.31	3.48	3.44	1.73	1.98	4.56	2.13	2.14
Lu			0.35	0.45	0.51	0.49	0.27	0.32	0.637	0.304	0.298
Sc			49.0	38.7	33.1	43.8	26.0	24.0	44.2	40.8	37.7
V			289	481	495	520	251	196	517	342	338
Cr			300	79.7	59.0	107		50	64.4	274	255
Co			50.0	45.6	40.7	53.4	38.0	25.0	38.3	51.8	47.6
Ni			150	59	59	56	20	30	39	98	97
Cu			140	116	114	208	100	50	232	161	160
Zn			160	106	103	94	110	110	160	77	76
Ga			14	17	20	18	18	18	27	19	19
Ge			1	0.7	1.3	0.7	1.6	1.3	2	1.1	0.7
Rb			10	6	6		50	31	21	7	7
Sr			264	225	229	143	565	434	197	255	254
Y			22	39	39	39	19	20	52	24	23
Zr			33	127	126	124	70	95	229	89	86
Nb			1.1	10.0	10.6	9.9	4.4	4.8	19.7	8.9	8.5
Cs			4.4	0.3	0.4	0.1	0.5	0.3	1.2	0.2	0.2
Ba			80	87	88	20	557	393	771	38	37
Hf			1.0	3.7	3.7	3.8	1.8	2.3	6.4	2.6	2.5
Ta			0.04	0.67	0.70	0.70	0.27	0.31	1.4	0.6	0.6
Pb				6	7	113			151	85	83
Th			0.1	1.08	1.08	1.01	0.73	1.50	2.09	0.61	0.57
U			0.06	0.38	0.39	0.41	0.41	0.80	0.88	0.23	0.25

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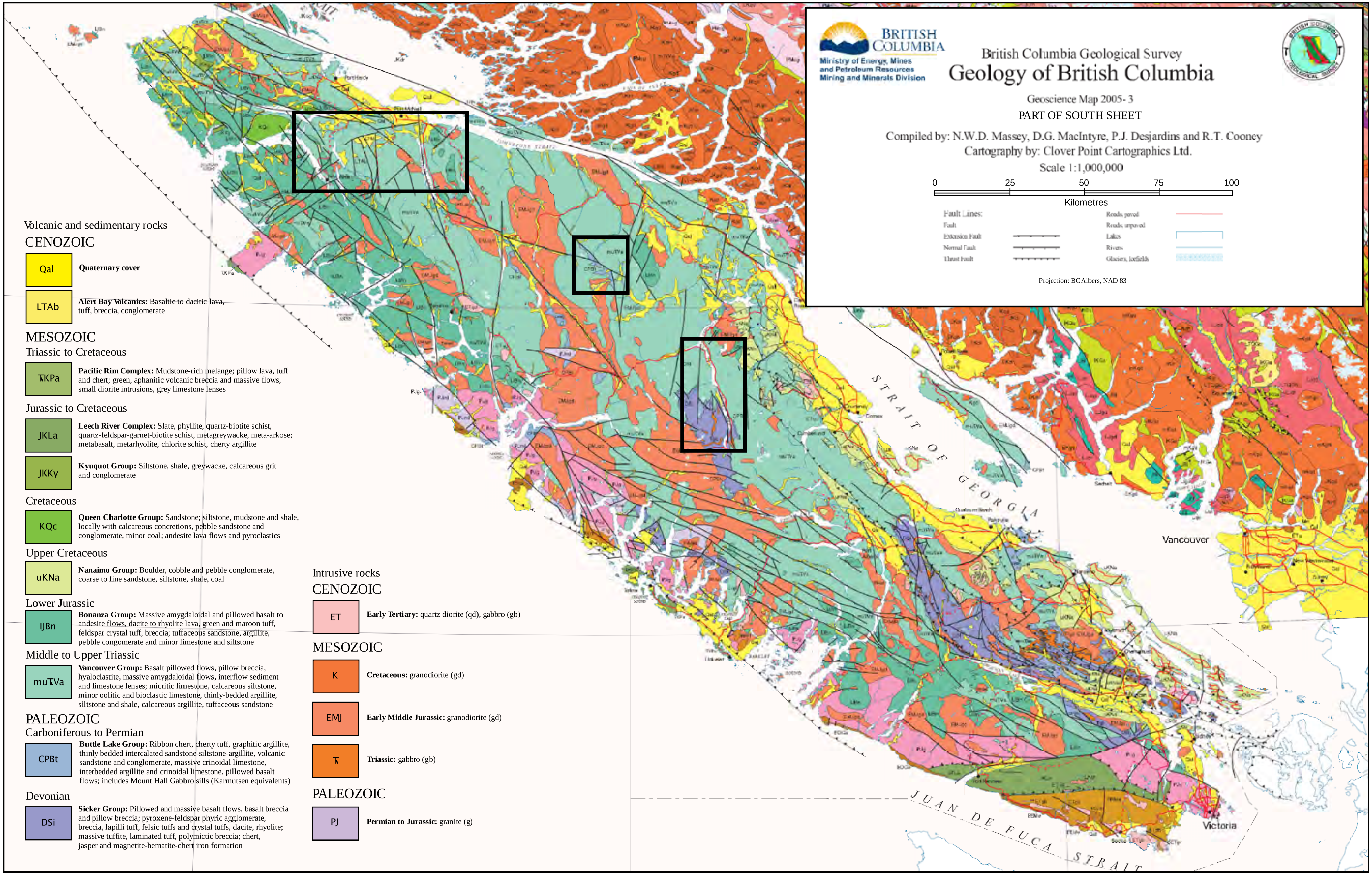

British Columbia
Ministry of Energy, Mines
and Petroleum Resources
Mining and Minerals Division

British Columbia Geological Survey

Geology of British Columbia

Geoscience Map 2005- 3

PART OF SOUTH SHEET

Compiled by: N.W.D. Massey, D.G. MacIntyre, P.J. Desjardins and R.T. Cooney
Cartography by: Clover Point Cartographics Ltd.
Scale 1:1,000,000

Fault Lines:
Fault
Extension Fault
Normal Fault
Thrust Fault

Roads, paved
Roads, unpaved
Lakes
Rivers
Glaciers, Icefields

Projection: BC Albers, NAD 83

Volcanic and sedimentary rocks

CENOZOIC

Qal	**Quaternary cover**
LTAb	**Alert Bay Volcanics:** Basaltic to dacitic lava, tuff, breccia, conglomerate

MESOZOIC

Triassic to Cretaceous

TRKPa	**Pacific Rim Complex:** Mudstone-rich melange; pillow lava, tuff and chert; green, aphanitic volcanic breccia and massive flows, small diorite intrusions, grey limestone lenses

Jurassic to Cretaceous

JKLa	**Leech River Complex:** Slate, phyllite, quartz-biotite schist, quartz-feldspar-garnet-biotite schist, metagreywacke, meta-arkose; metabasalt, metarhyolite, chlorite schist, cherty argillite
JKKy	**Kyuquot Group:** Siltstone, shale, greywacke, calcareous grit and conglomerate

Cretaceous

KQc	**Queen Charlotte Group:** Sandstone; siltstone, mudstone and shale, locally with calcareous concretions, pebble sandstone and conglomerate, minor coal; andesite lava flows and pyroclastics

Upper Cretaceous

uKNa	**Nanaimo Group:** Boulder, cobble and pebble conglomerate, coarse to fine sandstone, siltstone, shale, coal

Lower Jurassic

lJBn	**Bonanza Group:** Massive amygdaloidal and pillowed basalt to andesite flows, dacite to rhyolite lava, green and maroon tuff, feldspar crystal tuff, breccia; tuffaceous sandstone, argillite, pebble congomerate and minor limestone and siltstone

Middle to Upper Triassic

muTRVa	**Vancouver Group:** Basalt pillowed flows, pillow breccia, hyaloclastite, massive amygdaloidal flows, interflow sediment and limestone lenses; micritic limestone, calcareous siltstone, minor oolitic and bioclastic limestone, thinly-bedded argillite, siltstone and shale, calcareous argillite, tuffaceous sandstone

PALEOZOIC

Carboniferous to Permian

CPBt	**Buttle Lake Group:** Ribbon chert, cherty tuff, graphitic argillite, thinly bedded intercalated sandstone-siltstone-argillite, volcanic sandstone and conglomerate, massive crinoidal limestone, interbedded argillite and crinoidal limestone, pillowed basalt flows; includes Mount Hall Gabbro sills (Karmutsen equivalents)

Devonian

DSi	**Sicker Group:** Pillowed and massive basalt flows, basalt breccia and pillow breccia; pyroxene-feldspar phyric agglomerate, breccia, lapilli tuff, felsic tuffs and crystal tuffs, dacite, rhyolite; massive tuffite, laminated tuff, polymictic breccia; chert, jasper and magnetite-hematite-chert iron formation

Intrusive rocks

CENOZOIC

ET	**Early Tertiary:** quartz diorite (qd), gabbro (gb)

MESOZOIC

K	**Cretaceous:** granodiorite (gd)
EMJ	**Early Middle Jurassic:** granodiorite (gd)
TR	**Triassic:** gabbro (gb)

PALEOZOIC

PJ	**Permian to Jurassic:** granite (g)