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Major- and Trace-Element Composition of Greenstones, Greenschists, Amphibolites, and Selected Mica Schists and Gneisses from the North Cascades, Washington

By

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INTRODUCTION

The chemical analyses reported in this paper are for low to medium grade metamorphosed mafic rocks and selected pelitic rocks and gneisses from the North Cascades of Washington. They are from an area extending from about the Manastash Ridge area north to Whitehorse Mountain (see Fig. 1). The rocks were analyzed for an ongoing study of the chemical characteristics of the igneous components of terranes in the North Cascades.

Analytical Methods

The analyses are of hand samples from our office reference collection chosen for their relative lack of alteration, veining, or layering. Most samples were not collected in the field specifically for chemical analysis, but samples were selected to be representative of the local outcrop. The methods of analysis used were wavelength dispersive x-ray fluorescence for the major elements (with an accuracy of 0.4-1%), energy dispersive x-ray fluorescence for Ba, Nb, Rb, Sr, Zr, and Y (accuracy=5-10%), and neutron activation for iron, sodium, and a number of minor and trace elements (accuracy=5-20%). The melange belt rocks were analyzed using Rapid Rock methods. The analyses were performed in the U.S. Geological Survey's laboratories in Denver, Co., and Reston, Va. Table 1 identifies the rock types, locations, and analysts for the samples. Chemical data is given in Table 2.

DESCRIPTION OF ROCK UNITS OR TERRANES

The rocks in this paper are grouped lithologic units, most of which have been referred to as tectonostratigraphic terranes by Tabor and others (1980, in press, b). In the brief description of each unit given below, the ages mentioned refer to protolith ages.

Ingalls Tectonic Complex

The Late Jurassic Ingalls Tectonic Complex (Tabor and others, 1982c, in press, a and b) is an ophiolite complex (Miller, 1980, 1985) or is ophiolitic and island arc material joined during subduction (Southwick, 1974). The unit consists primarily of serpentinite, serpentinized peridotite, and metaperidotite, with lesser amounts of flysch-type sandstone and argillite, radiolarian chert, pillow basalt, diabase and gabbro. Parts of the complex have been metamorphosed to the epidote amphibolite or hornblende hornfels facies (Tabor and others, 1982c; Miller, 1985).

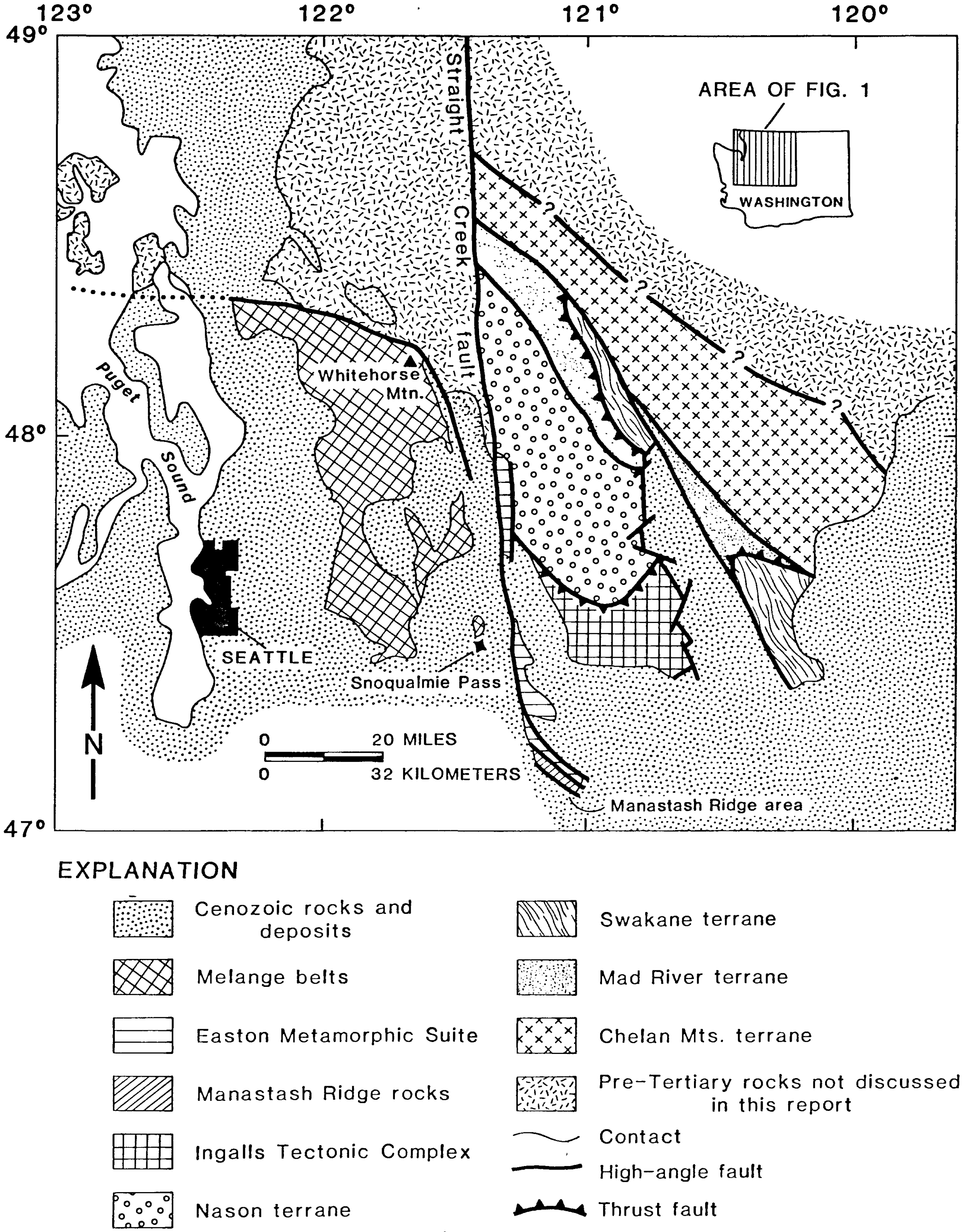

Figure 1. Location of terranes, Easton Metamorphic Suite, melange belts and areas discussed in text. Tertiary batholiths and other plutons not shown. Modified from Tabor and others (in press, b), Frizzell and others (1984), and Vance and others (1980).

Nason Terrane

The Nason terrane, of uncertain age (Tabor and others, 1980, in press, a and b), consists primarily of the Chiwaukum Schist and banded gneiss derived from the schist by igneous and metamorphic processes. The Chiwaukum Schist is predominantly an alumino-silicate-bearing graphitic garnet-biotite-quartz schist, but in its lower part rich in abundant hornblende-biotite schist, hornblende gneiss, amphibolite, calc-silicate schist, and marble.

Swakane Terrane

The Swakane terrane, of probable Precambrian age, is composed entirely of the Swakane Biotite Gneiss, a homogeneous granofelsic gneiss with rare thin layers of hornblende schist, schistose amphibolite, biotite schist, and marble (Waters, 1932; Cater and Crowder, 1967; Tabor and others, in press, a and b).

Mad River Terrane

The Paleozoic (or older) Mad River terrane co~sists mainly of hornblende schist, schistose amphibolite, micaceous quartz schist, and micaceous quartzite, with lesser amounts of biotite gneiss, metaconglomerate, calc-silicate schist, and marble. Its protolith of probable oceanic crustal rocks was mainly mafic lavas and cherts (Tabor and others, in press, b).

Chelan Mountains Terrane

The Chelan Mountains terrane consists of metamorphosed Permian (or younger) marine sedimentary and volcanic rocks, Triassic plutonic and migmatitic rocks, and tonalite plutons of the Late Cretaceous Chelan Complex (Hopson and Mattinson, 1971; Mattinson, 1972; Tabor and others, 1980, and in press, a and b). The metasedimentary and metavolcanic rocks are mostly schistose amphibolite, biotite schist, hornblende-biotite schist, quartzitic schist and rare marble, and have been referred to as the rocks of the Twenty-Five Mile Creek area.

Easton Metamorphic Suite (including the Tonga Formation of Yeats, 1958)

The Easton Metamorphic Suite contains the Shuksan Greenschist and Darrington Phyllite. Analyzed samples of Shuksan Greenschist as used here are mostly from rocks previously referred to the Easton Schist (Smith and Calkins, 1906; Stout, 1964; Yeats, 1958). The Tonga Formation of Yeats (1958) is mostly phyllite and staurolite-biotite schist with intercalations of greenschist and amphibolite, respectively. The Tonga is correlative with the Easton Metamorphic Suite, but because of its geographic isolation and overprint of higher-grade metamorphism than is usually found in the Darrington Phyllite and Shuksan Greenschist, its original name has been retained (Tabor and others, 1982a and b).

Manastash Ridge Rocks

Analyzed samples from Manastash Ridge are from the amphibolite and tonalite gneiss part of the Lookout Mountain Formation of Stout (1964), a unit of unknown age composed predominantly of mica schist, and the tectonic complex of Stout (1964), a zone of cataclastic to blastomylonitic rocks bordering the

Lookout Mountain Formation on the east (Goetsch, 1978; Frizzell and others, 1984). The tectonic complex includes a confusing welter of rocks ranging from unmetamorphosed sandstone and argillite to amphibolite.

Melange Belts

All of the analyzed rocks come from the eastern belt of two roughly parallel melange belts (Tabor and others, 1982a; Frizzell and others, 1985, in press). The eastern melange belt is composed of greenstone, chert, argillite, and graywacke, with megaclasts of migmatitic gneiss, metagabbro, metadiabase, metatonalite, marble and ultramafic rocks. The Whitehorse volcanics of Vance (1957) in the eastern melange belt are a coherent block of mostly greenstone and leuco-greenstone which crop out on the north side of Whitehorse Mountain.

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TABLE 1

Sample Information. Analyst groups are: 1) Major element XRF analysts: A. Bartel, J. E. Taggart, (acting project leader); Minor Element XRF analysts: R. Johnson, D. Burgi, J. R. Lindsay (project leader); INAA Analyst: L. J. Schwarz; 2) XRF analysts: R. Johnson, H. J. Rose (project leader), A. Woodside, B. Scott, B. McCall, G. Sellers, P. Hearn, M. Pickering, J. Lindsay; INAA analyst: L. J. Schwarz; 3) XRF Analysts: L. Espos, V. G. Mossotti (project leader), R. Johnson, H. J. Rose (project leader), B. McCall, G. Sellers, J. Lindsay; INAA analyst: G. A. Wandless; 4) XRF analysts: N. Skinner, F. Brown (project leader); 5) Rapid Rock analysts: K. Coates, H. Smith. Note: Melange Belt rocks were analyzed by Rapid Rock methods. Sample collectors are identified by the letters in the sample number: RWT=Rowland W. Tabor, VF=Virgil A. Frizzell, BG=Bill Gaum, JM=Joe Marquez, JV=Joseph Vance.

Sample Number	Terrane or Unit	Rock type	Location Latitude	Location Longitude	Analysts	Quad. Map	Comments
RWT 40-75	Ingalls	greenstone	47°29.77'	120°03.12'	1	Kachess Lake (15')	
RWT 138-80	Tectonic	greenstone; metadiabase	47°32.00'	121°01.85'	2	The Cradle (7.5')	
RWT 28-76	Complex	amphibolite	47°29.76'	120°41.09'	1	Liberty (15')	
RWT 36-76	do	do	47°27.99'	120°40.22'	1	Liberty (15')	
RWT 41-76	do	do; metagabbro	47°29.10'	120°42.59'	1	Liberty (15')	
RWT 82-76	do	greenstone	47°30.36'	120°40.82'	1	Leavenworth (15')	
RWT 136-76	do	amphibolite	47°30.14'	120°41.52'	2	Leavenworth (15')	
RWT 152-76	do	do	47°27.56'	120°41.50'	2	Liberty (15')	
RWT 165-76	do	do	47°27.05'	120°42.99	1	Liberty (15')	
RWT 231-76	do	do	47°38.70'	120°43.10'	2	Leavenworth (15')	
RWT 368-76	do	do	47°30.12'	120°56.92'	1	Chiwaukum Mts (15')	
RWT 223-79	do	hornblende pyroxene schist	47°34.19'	120°52.10'	2	Chiwaukum Mts (15')	
RWT 136-80	do	amphibolite; metabasalt	47°31.54	121°01.23'	2	The Cradle (7.5')	
RWT 175-80	do	amphibolite	47°31.05'	120°41.01'	2	Leavenworth (15')	
RWT 333-78	Nason	do	47°57.46'	121°04.22'	2	Poe Mtn. (7.5')	
RWT 211-79	do	do	47°53.99'	120°52.16'	2	Wenatchee Lake (15')	
RWT 276-79	do	hornblende pyroxene schist	47°42.37'	120°58.92'	2	Chiwaukum Mts. (15')	
RWT 198-80	do	amphibolite	47°57.57'	121°04.16'	2	Poe Mtn. (7.5')	
RWT 5-82	do	do	47°47.02'	120°53.73'	1	Wenatchee Lake (15')	
RWT 386-78	do	hornblende schist	47°59.34'	121°16.96'	2	Blanca Lake (7.5')	
VF 78-528	do	amphibolite	47°56.04'	121°03.57'	1	Poe Mtn. (7.5')	
VF 78-625	do	do	47°51.84'	120°51.12'	1	Wenatchee Lake (15')	
RWT 345A-79	do	biotite schist	47°40.44'	120°48.80'	1	Chiwaukum Mts. (15')	
RWT 15-80	do	do	47°56.76'	120°57.69'	1	Wenatchee Lake (15')	
RWT 13-81	do	do	47°56.13'	120°57.67'	1	Wenatchee Lake (15')	
RWT 15-82	do	do	47°36.37'	120°53.04'	1	Chiwaukum Mts. (15')	
RWT 40-80	Swakane	biotite gneiss	47°43.30'	120°28.15'	1	Chumstick Mtn. (7.5')	
RWT 1-81	do	biotite amphibolite	47°36.43'	120°14.58'	1	Orondo (7.5')	
RWT 2-81	do	garnet biotite gneiss	47°36.43'	120°14.58'	1	Orondo (7.5')	
RWT 111-77	do	biotite gneiss	47°29.71'	120°19.08'	1	Wenatchee (7.5')	
RWT 112-77	do	do	47°29.71'	120°19.08'	1	Wenatchee (7.5')	
RWT 59-77	Mad River	hornblende schist	47°41.15'	120°20.39'	1	Ardenvoir (7.5')	From the heterogeneous
RWT 148-77	do	do	47°38.77'	120°14.16'	2	Entiat (7.5')	schist and gneiss
RWT 154-77	do	hornblende schist	47°44.03'	120°27.93'	2	Chumstick Mtn. (7.5')	of Tabor and
VF 77-658	do	amphibolite	47°49.64'	120°34.79'	1	Sugarloaf Peak (7.5')	others (1982)
BG 77-105	do	do	47°44.29'	120°23.81'	1	Chumstick Mtn. (15')	do
BG 77-262b	do	do	47°48.72'	120°33.42'	1	Sugarloaf Peak (7.5')	do
RWT 39-80	do	do	47°43.77'	120°29.01'	1	Chumstick Mtn. (7.5')	do
RWT 8-81	do	do	47°44.21'	120°26.84'	1	Chumstick Mtn. (7.5')	do
RWT 9-81	do	do	47°44.07'	120°27.95'	1	Chumstick Mtn. (7.5')	do
RWT 446-79	do	do	47°59.73'	120°54.42'	2	Wenatchee Lake (15')	From rocks of the Napeequa
RWT 156-80	do	do	48°02.52'	120°52.65'	2	Holden (15')	River area of Cater and
RWT 416-79	do	zoisite amphibolite	47°56.71'	120°48.55'	2	Wenatchee Lake (15')	Crowder (1967) and Tabor
RWT 425-79	do	amphibolite gneiss	47°56.44'	120°49.52'	2	Wenatchee Lake (15')	and others (1982)
RWT 427-79	do	do	47°56.01'	120°49.95'	2	Wenatchee Lake (15')	do
RWT 465A-79	do	hornblendite	47°57.50'	120°58.82'	3	Wenatchee Lake (15')	do
RWT 465B-79	do	diorite	47°57.50'	120°58.82'	3	Wenatchee Lake (15')	do
RWT 105-80	do	amphibolite	47°58.40'	120°56.22'	1,2	Wenatchee Lake (15')	do
RWT 46-79	Chelan	do	47°58.73	120°11.22'	2	Manson (7.5')	From the rocks of the Twenty-
RWT 142-79	Mountains	hornblende schist	47°58.50'	120°16.00'	2	Stormy Mtn. (7.5')	Five Mile Creek Unit
RWT 77w-80	do	amphibolite	48°01.23'	120°29.05'	1,2	Big Goat Mtn. (7.5')	(Tabor and others, 1982)
RWT 77m-80	do	do	48°01.23'	120°29.05'	1,2	Big Goat Mtn. (7.5')	do
RWT 72-77	do	garnet amphibolite	47°58.48'	120°13.14'	1	Manson (7.5')	do
RWT 190-75	Easton	greenschist	47°29.96'	121°14.10'	1	Kachess Lake (15')	Shuksan Greenschist
RWT 429-76	Metamorphic	do	47°05.99'	120°57.21'	1	Cle Elum (15')	do
RWT 366-77	Suite	blue amphibole schist	47°20.15'	121°10.92'	2	Kachess Lake (15')	do
RWT 542-77	do	greenschist	47°20.67'	121°14.34'	2	Kachess Lake (15')	do
RWT 552-77	do	do	47°23.69'	121°13.99'	2	Kachess Lake (15')	do
RWT 347-78	do	do	47°48.78'	121°19.79'	2	Evergreen Mtn. (7.5')	Tonga Formation of
JM 122-79	do	blue amphibole schist	47°48.52'	121°20.38'	2	Evergreen Mtn. (7.5')	Yeats (1958)
RWT 235-80	do	greenschist	47°42.60'	121°19.12'	2	Skykomish (7.5')	do
RWT 445-80	do	greenstone	47°48.23'	121°16.98'	2	Evergreen Mtn. (7.5')	do
RWT 446-80	do	greenschist	47°47.67'	121°16.72'	2	Evergreen Mtn. (7.5')	do
RWT 47-81	do	do	47°44.78'	121°19.65'	1	Skykomish (7.5')	do
RWT 49-81	do	banded greenschist	47°44.74'	121°19.51'	1	Skykomish (7.5')	do
RWT 1-82	do	greenschist	47°44.37'	121°19.31'	1	Skykomish (7.5')	do
RWT 2-82	do	greenstone	47°39.67'	121°16.05'	1	Skykomish (7.5')	do
RWT 3-82	do	do	47°40.38'	121°16.34'	1	Skykomish (7.5')	do
RWT 240-77	Manastash	hornblende schist	47°04.08'	121°02.99'	2	Easton (15')	From the tectonic complex
RWT 244-77	ridge rocks	greenstone	47°04.18'	121°03.13'	2	Easton (15')	of Stout (1964)
RWT 260-77	do	hornblende schist	47°04.84'	121°04.09'	2	Easton (15')	From the Lookout Mountain
RWT 286-77	do	leuco-amphibolite	47°02.65'	121°01.58'	2	Easton (15')	Formation of Stout (1964)
JV WH-1	Eastern	greenstone; metabasalt	48°15.6'	121°46.6'	5	Oso (15')	White Horse volcanics
JV WH-8	melange	do; meta-andesite	48°15.1'	121°43.4'	5	Fortson (7.5')	of Vance (1958)
JV WH-9	belt	do; metabasalt	48°15.2'	121°43.7'	5	Fortson (7.5')	do
RWT 240-78	do	do	47°25.58'	121°26.20'	4	Snoqualmie Pass (15')	
RWT 136-78	do	do	47°26.90'	121°24.71'	4	Snoqualmie Pass (15')	

Table 2

Chemical Analyses of greenstones, greenschists, amphibolites, and selected mica schists and gneisses from the North Cascades, Washington. Accuracies are as stated in the text and sample information is contained in Table 1. LOI denotes %gas lost on ignition at 920°C. All major elements were analyzed by wavelength dispersive x-ray fluorescence methods unless otherwise noted, and neutron activation data was not used in the totals. Minor and trace element analyses are from neutron activation methods except where noted. Minor element x-ray fluorescence analyses are energy dispersive.

Ingalls Tectonic Complex														
	RWT 40-75	RWT 138-80	RWT 28-76	RWT 36-76	RWT 41-76	RWT 82-76	RWT 136-76	RWT 152-76	RWT 165-76	RWT 231-76	RWT 368-76	RWT 223-79	RWT 136-80	RWT 175-80
SiO_2	50.3	54.6	41.6	50.9	51.4	51.7	44.2	51.3	51.4	55.6	51.6	47.3	49.0	51.0
Al_2O_3	15.3	16.0	22.0	14.0	17.1	14.2	13.5	14.4	12.8	12.9	14.2	14.9	17.5	14.4
Fe_2O_3	8.56	7.70	8.31	10.2	5.31	10.0	9.95	10.27	11.8	10.96	9.29	13.35	12.22	10.80
Fe_2O_3 INAA	8.31	7.77	8.44	10.79	5.54	10.34	11.14	10.40	12.24	10.89	9.70	13.83	12.51	10.84
MgO	7.59	7.0	9.31	7.98	9.21	8.66	6.6	7.8	7.65	6.0	8.87	8.8	4.4	8.8
CaO	8.90	8.17	13.6	11.6	12.1	9.09	17.52	10.49	9.99	7.07	10.7	9.58	12.70	9.17
Na_2O	3.90	4.9	0.82	2.56	2.94	3.53	2.4	3.1	3.44	5.9	2.99	2.5	3.4	4.4
Na_2O INAA	3.99	4.85	0.81	2.90	3.27	3.72	1.87	3.33	3.76	5.08	3.27	1.99	2.91	3.88
K_2O	0.1	0.27	0.05	0.20	0.11	0.07	0.89	0.14	0.09	0.18	0.32	1.59	0.33	0.23
TiO_2	0.88	0.81	1.04	1.15	0.32	1.32	2.21	1.46	1.48	1.10	0.67	1.89	0.93	1.27
P_2O_5	0.10	0.14	0.18	0.08	<0.05	0.09	0.83	0.16	0.12	0.12	<0.05	0.22	0.16	0.14
MnO	0.19	0.12	0.11	0.19	0.10	0.19	0.16	0.16	0.19	0.16	0.19	0.19	0.35	0.17
LOI	3.56	---	2.83	0.70	0.35	0.44	---	---	0.35	---	0.46	---	---	---
Total	99.4	99.7	99.9	99.6	99.0	99.3	98.3	99.3	99.3	100.0	99.3	100.3	101.0	100.4
Minor and Trace Elements (ppm)														
Ba	<100	240	<100	<100	350	<100	695	<300	<100	195	67	1020	165	<300
Ba XRF	29	90	25	44	343	15	700	22	16	162	84	937	97	50
Co	31.3	30.4	35.8	39.9	33.0	23.9	30.8	36.3	46.2	30.8	40.2	48.5	40.0	40.7
Cr	209	143.0	22.1	221	734	208	34.4	168.0	140	97.3	335	325.0	555.0	290
Cs	0.6	0.3	<0.3	0.6	0.8	<0.4	0.3	<0.9	<0.4	<0.8	0.24	1.7	<0.8	0.7
Hf	1.56	1.6	1.47	1.93	0.39	2.26	5.4	2.4	2.29	1.6	0.60	3.3	1.5	2.0
Nb XRF	5	<5	<5	5	<5	<5	33	<5	6	<5	5	<5	<5	<5
Rb	<20	16	<20	8	<20	<20	26	<40	<20	20	<20	55	<40	16
Rb XRF	<5	6	<5	<5	13	<5	19	3	<5	<2	5	52	4	4
Sb	4.31	---	<0.5	0.47	<0.7	<0.7	---	---	0.3	---	<0.8	---	---	---
Sr XRF	155	177	397	120	724	107	555	145	82	166	189	564	227	176
Ta	0.20	<0.40	<0.2	<0.3	<0.2	0.16	2.22	0.25	0.19	0.39	0.12	0.52	<0.50	<0.50
Th	0.29	0.5	0.57	<0.5	<0.5	<0.5	3.3	<0.8	<0.3	0.5	<0.5	0.6	<0.7	<0.7
U	0.18	<0.9	0.42	<0.5	<0.4	<0.5	1.0	<2.0	<0.5	<2.0	<0.5	<2.0	<1.0	<1.0
Y XRF	22	18	19	28	11	31	28	31	33	21	16	34	28	25
Zn	91	50	54	76	52	115	125	80	67	123	84	122	155	83
Zr	<200	140	<90	<200	<200	73	188	140	84	95	<200	<300	98	84
Zr XRF	72	66	63	71	33	88	213	93	91	60	37	126	65	72
Sc	33.8	30.1	15.7	39.8	37.2	41.5	14.9	38.5	43.1	33.6	43.1	44.9	46.2	40.7
La	3.53	4	5.4	2.10	0.40	2.45	34	3	2.66	5	1.42	7	4	2
Ce	8.7	8	12.5	8.2	2.8	9.4	64	10	9.7	11	4.1	17	6	7
Nd	8.0	8	14	8	<9	7	40	9	9	10	<10	16	13	7
Sm	2.29	1.8	3.04	2.67	0.76	3.16	7.0	2.8	3.42	2.1	1.19	4.0	1.9	2.3
Eu	0.78	0.61	1.69	0.92	0.29	0.95	2.73	1.09	1.09	0.91	0.54	1.39	0.80	0.81
Gd	<6	2.0	<10	<20	<20	<20	6.7	3.9	5.5	3.1	<20	4.0	1.4	3.2
Tb	0.50	0.35	0.47	0.69	0.20	0.84	0.77	0.61	0.87	0.48	0.30	0.73	0.54	0.61
Tm	0.32	0.28	<1	0.7	<1	0.9	0.40	0.48	0.70	0.36	0.7	0.54	0.37	0.42
Yb	2.21	2.0	1.84	3.11	0.91	3.53	2.4	3.8	3.77	2.6	1.52	4.1	3.7	3.3
Lu	0.305	0.32	0.25	0.461	0.19	0.51	0.32	0.52	0.54	0.37	0.233	0.64	0.52	0.52

Table 2 (cont.)

	Nason Terrane											
	Amphibolite								Biotite Schists			
	RWT 333-78	RWT 211-79	RWT 276-79	RWT 198-80	RWT 5-82	VF 78-528	VF 78-625	RWT 386-78	RWT 345A-79	RWT 15-80	RWT 13-81	RWT 15-82
SiO_2	48.7	47.9	48.0	48.8	48.5	46.7	46.6	49.6	70.0	69.1	68.6	61.8
Al_2O_3	15.5	15.7	14.0	16.5	16.2	16.4	15.8	14.5	13.6	13.1	13.2	17.2
Fe_2O_3	14.35	10.84	12.75	16.22	10.2	11.0	12.1	13.56	5.38	5.79	5.96	7.43
Fe_2O_3 INAA	15.00	11.01	10.06	16.57	10.27	11.00	12.46	12.51	5.39	6.00	6.29	7.80
MgO	3.6	8.6	8.6	3.3	7.28	7.04	6.66	5.9	2.34	2.64	2.81	3.95
CaO	7.67	11.09	13.78	7.65	13.2	13.9	12.8	8.89	1.99	2.19	2.26	2.81
Na_2O	5.2	3.2	1.2	3.9	2.03	1.43	2.43	2.7	2.16	1.89	2.33	2.64
Na_2O INAA	4.64	2.82	0.51	4.18	2.18	1.55	2.64	2.76	2.52	2.01	2.45	2.67
K_2O	0.41	0.29	0.11	0.36	0.44	0.32	0.48	0.71	1.82	1.72	1.16	1.81
TiO_2	3.36	1.48	1.65	3.54	1.28	1.62	1.97	2.51	0.70	0.63	0.59	0.81
P_2O_5	0.35	0.19	0.20	0.48	0.12	0.22	0.23	0.36	0.14	0.17	0.17	0.14
MnO	0.20	0.17	0.22	0.20	0.16	0.21	0.20	0.47	0.06	0.07	0.04	0.11
LOI	---	---	---	---	0.36	0.47	0.28	---	1.24	2.15	2.46	1.09
Total	99.3	99.5	100.5	101.0	99.8	99.3	99.6	99.2	99.4	99.5	99.6	99.8
	Minor and Trace Elements (ppm)											
Ba	170	<300	<300	<300	<100	<100	117	86	458	503	313	625
Ba XRF	44	31	58	63	66	30	104	86	473	520	327	650
Co	42.0	45.9	31.6	46.9	39.6	46.7	48.3	46.7	12.9	8.97	10.0	17.3
Cr	173.5	357.0	197.0	141.0	336	521	287	213.0	141	53	103	152
Cs	0.6	<0.9	<0.8	0.6	<0.4	0.19	<0.4	1.4	3.18	3.08	2.13	3.10
Hf	6.6	2.4	2.1	7.1	2.02	2.98	3.22	4.6	3.73	2.05	2.21	3.22
Nb XRF	20	<5	<5	25	5	5	10	6	9	6	6	5
Rb	22	<40	<30	22	<20	<20	<10	18	59	44	41	60
Rb XRF	3	3	<2	6	<5	<5	6	11	55	41	39	54
Sb	---	---	---	---	<0.7	<0.7	<0.7	---	<0.4	<0.5	<0.4	<0.5
Sr XRF	311	162	240	429	195	299	432	409	285	209	241	198
Ta	1.82	<0.50	<0.40	2.02	<0.3	0.24	0.61	0.90	0.53	0.24	0.34	0.42
Th	1.8	<0.8	<0.7	2.3	<0.5	<0.3	0.75	1.0	4.71	2.1	2.56	3.8
U	0.7	<2.0	1.6	0.8	<0.5	<0.5	<0.5	0.5	1.60	0.90	1.06	1.13
Y XRF	35	28	34	47	29	29	33	37	19	20	20	20
Zn	150	98	109	207	91	155	109	134	94	103	89	109
Zr	348	<300	100	285	77	137	109	170	139	50	57	117
Zr XRF	266	90	100	286	80	128	127	167	147	84	89	111
Sc	24.2	37.3	30.4	24.1	37.6	37.1	34.5	25.1	13.8	17.9	16.7	21.8
La	22	4	3	29	2.6	4.9	8.4	10	18.2	9.6	10.8	14.1
Ce	48	11	9	49	8.6	15.4	20.7	24	33.1	19.2	21.6	28.8
Nd	31	10	10	37	9	10	14	19	19	11	13	12
Sm	6.9	3.0	2.6	8.3	2.86	4.06	4.78	5.5	3.56	3.01	2.84	3.63
Eu	2.26	1.29	1.01	2.56	1.02	1.33	1.64	2.17	0.98	0.79	0.77	0.93
Gd	7.4	4.7	4.2	9.5	<20	<20	7	6.9	<10	<10	<10	<10
Tb	0.97	0.64	0.60	1.12	0.67	0.79	1.01	0.97	0.43	0.43	0.39	0.52
Tm	0.59	0.45	0.44	0.61	<1	<1	0.46	0.55	<0.9	<0.9	<0.5	<1
Yb	3.7	3.5	3.3	4.7	2.99	3.51	3.58	4.4	1.76	1.86	1.54	2.33
Lu	0.58	0.51	0.47	0.65	0.447	0.50	0.536	0.64	0.266	0.292	0.278	0.34

Table 2 (cont.)

	Mad River terrane																
sample number	RWT 59-77	RWT 148-77	RWT 154-77	VF 77-658	BG 77-105	BG 77-262B	RWT 39-80	RWT 8-81	RWT 9-81	RWT 446-79	RWT 156-80	RWT 416-79	RWT 425-79	RWT 427-79	RWT 465A-79	RWT 465B-79	RWT 105-80
SiO_2	48.5	54.9	51.1	46.6	50.0	49.5	45.2	47.4	50.2	47.5	49.2	48.4	46.3	48.7	42.42	42.93	54.2
Al_2O_3	15.9	13.6	13.6	16.5	16.7	17.1	15.3	16.0	14.1	17.2	18.3	16.3	16.7	17.5	14.23	19.02	16.3
Fe_2O_3	10.3	9.09	9.83	11.6	10.6	10.3	13.9	10.3	11.1	9.33	6.78	10.45	14.42	10.86	16.20	12.26	9.53
Fe_2O_3 INAA	10.87	9.13	9.96	12.24	10.87	11.0	14.71	11.04	11.63	9.40	7.00	10.40	14.43	11.37	15.86	12.29	10.14
MgO	8.49	7.6	7.6	6.64	6.10	6.47	6.59	9.62	7.51	10.7	10.2	8.5	8.6	7.2	8.85	6.49	5.1
CaO	11.5	8.05	14.10	11.1	10.5	8.35	12.7	11.4	12.4	13.45	12.39	10.38	10.09	11.08	10.93	12.31	7.94
Na_2O	2.66	2.7	1.9	3.24	2.95	4.49	2.00	2.84	2.15	1.5	1.9	2.7	2.3	2.9	2.52	2.84	3.49
Na_2O INAA	2.94	2.84	2.05	3.54	3.26	4.88	2.17	3.13	2.39	1.12	1.95	2.53	2.14	2.82	---	---	3.77
K_2O	0.32	1.35	0.39	0.62	0.72	0.19	0.67	0.31	0.62	0.36	0.14	0.56	0.07	0.09	0.39	0.34	0.83
TiO_2	1.19	0.75	0.86	2.03	0.78	2.12	2.37	1.16	0.92	0.33	0.15	1.58	1.15	0.68	2.11	1.90	1.06
P_2O_5	0.11	0.17	0.12	0.26	0.15	0.28	0.22	0.1	0.06	0.08	0.06	0.43	0.06	0.10	0.27	0.48	0.23
MnO	0.14	0.13	0.18	0.21	0.23	0.16	0.26	0.14	0.15	0.17	0.14	0.16	0.22	0.19	0.20	0.15	0.18
LOI	0.33	---	---	1.01	1.12	0.43	0.69	0.54	0.62	---	---	---	---	---	---	---	0.74
Total	99.4	98.4	99.7	99.8	99.9	99.4	99.9	99.8	99.8	100.6	99.3	99.5	99.9	99.3	98.1	98.7	99.6
	Minor and Trace Elements (ppm)																
Ba	112	351	<300	207	309	85	151	157	<200	<300	<300	367	<400	<400	100	<200	421
Ba XRF	99	321	39	210	298	71	117	114	70	38	18	339	34	38	---	---	427
Co	47.5	29.6	41.8	50.6	33.6	40.7	49.8	49.9	41.3	45.5	35.4	33.5	44.0	32.3	35.1	28.5	20.1
Cr	323	495.0	302.5	390	21.2	118	131	411	320	280.0	215	218.0	43.5	133.0	147	74.1	132
Cs	<0.4	1.5	0.5	0.16	0.27	0.33	0.21	0.5	<0.4	0.3	0.3	1.0	<0.9	<0.9	<2.0	<2.0	1.11
Hf	1.69	2.6	1.3	3.39	1.09	3.47	3.8	1.80	1.50	0.7	<0.7	1.8	0.4	0.4	1.8	1.3	2.26
Nb XRF	10	<5	<5	12	7	25	14	8	5	<5	<5	6	<5	<5	---	---	7
Rb	<10	25	<30	9	18	<10	20	<20	17	<40	<30	<30	<40	<40	<40	<30	21
Rb XRF	<5	32	4	9	17	<5	14	7	10	8	6	13	<2	4	---	---	23
Sb	<0.7	---	---	<0.7	1.35	<0.7	<0.8	<0.7	<0.8	---	---	---	---	---	<2.0	<2.0	<0.6
Sr XRF	260	444	112	347	426	316	311	382	138	260	229	790	194	278	---	---	386
Ta	0.53	0.30	<0.50	0.77	0.28	1.82	0.87	0.31	<0.3	<0.50	<0.50	0.54	<0.50	<0.50	<0.90	<0.60	0.37
Th	0.57	1.3	<0.6	0.98	1.62	2.50	0.98	0.3	<0.5	0.5	<0.7	0.6	<0.8	<0.8	<0.7	<0.6	1.48
U	<0.6	1.0	<2.0	0.29	1.33	0.61	<0.4	<0.5	<0.6	<0.8	<0.9	<0.8	<0.8	<1.0	<0.8	<0.8	0.60
Y XRF	19	9	21	30	20	21	30	18	29	6	4	16	4	10	33	21	24
Zn	91	152	95	124	123	88	130	80	92	84	72	113	120	110	195	127	104
Zr	76	130	110	99	<100	104	156	<100	<200	<300	<300	80	<300	<300	<600	<500	72
Zr XRF	77	64	56	136	46	137	144	75	59	36	20	72	20	28	52	44	90
Sc	34.0	22.4	33.6	34.0	34.1	31.7	39.6	33.1	43.7	42.5	42.9	27.5	42.1	44.0	61.2	37.9	31.3
La	6.4	11	2	10.9	8.9	21.4	12.4	4.5	2.2	1	1	14	1	1	5	7	9.7
Ce	14.6	26	5	27.0	19.8	43.2	29.1	11.6	6.9	3	1	30	2	4	16	18	21.9
Nd	10	20	<5	20	11	24	19	12	<10	6	<8	28	3	4	18	16	15
Sm	2.65	2.9	1.7	5.07	3.29	5.11	5.40	2.65	2.30	0.7	0.3	5.1	0.4	1.0	4.8	4.4	4.01
Eu	0.86	1.14	0.68	1.60	0.93	1.52	1.82	1.00	0.84	0.33	0.17	1.64	0.40	0.59	1.41	1.38	1.11
Gd	<20	3.4	2.4	<20	<20	5	<20	<20	7	<2.0	<2.0	4.1	<2.0	1.5	5.9	5.4	<20
Tb	0.44	0.24	0.40	1.03	0.55	0.58	1.02	0.52	0.61	0.15	0.15	0.59	0.12	0.27	0.98	0.83	0.60
Tm	<1	0.15	0.32	<1	<1	0.30	0.9	<1	<1	0.19	0.17	0.26	0.13	0.20	0.38	0.37	<1
Yb	1.47	1.1	2.7	3.07	2.31	1.82	2.90	1.82	2.77	0.9	0.6	2.1	0.6	1.4	3.2	2.7	2.79
Lu	0.246	0.15	0.42	0.473	0.36	0.263	0.43	0.277	0.42	0.18	0.16	0.28	0.16	0.26	0.48	0.39	0.430

Table 2 (cont.)

	Swakane Terrane					Chelan Mountains terrane				
	RWT 40-80	RWT 2-81	RWT 111-77	RWT 112-77	RWT 1-81	RWT 46-79	RWT 142-79	RWT 77w-80	RWT 77m-80	RWT 72-77
SiO_2	67.7	56.9	71.1	68.0	50.0	56.9	45.9	50.6	48.4	50.1
Al_2O_3	15.3	20.4	14.7	15.2	19.7	16.6	14.3	17.9	19.0	17.4
Fe_2O_3	4.11	6.93	2.79	3.69	10.5	7.52	15.62	11.52	11.6	14.4
Fe_2O_3 INAA	4.44	6.93	2.51	3.53	10.66	7.40	15.43	11.40	11.93	14.43
MgO	1.85	2.39	1.17	1.68	2.41	5.7	10.5	7.5	7.13	5.34
CaO	3.30	6.82	3.31	3.99	7.98	8.99	7.06	8.16	8.39	8.76
Na_2O	3.31	2.17	3.45	3.20	3.53	2.1	2.3	2.8	2.34	2.38
Na_2O INAA	3.67	2.29	3.50	3.27	3.73	1.59	2.74	2.37	2.61	2.53
K_2O	1.97	2.01	2.14	1.99	2.46	1.01	0.16	0.26	0.29	0.18
TiO_2	0.53	0.70	0.35	0.47	1.41	0.42	2.39	0.72	0.73	0.78
P_2O_5	0.16	<0.05	0.09	0.11	0.16	0.11	0.19	0.09	<0.05	0.06
MnO	0.06	0.33	0.04	0.07	0.23	0.09	0.26	0.09	0.07	0.27
LOI	0.90	0.88	0.61	0.99	1.14	---	---	---	1.65	0.43
Total	99.2	99.6	99.8	99.4	99.5	99.4	98.7	99.6	99.7	100.1

Minor and Trace Elements (ppm)

	RWT 40-80	RWT 2-81	RWT 111-77	RWT 112-77	RWT 1-81	RWT 46-79	RWT 142-79	RWT 77w-80	RWT 77m-80	RWT 72-77
Ba	684	385	783	671	526	100	<300	180	76	78
Ba XRF	662	378	813	710	553	79	20	61	74	52
Co	7.01	34.7	5.96	9.72	43.1	27.3	29.1	31.9	32.6	40.2
Cr	60.5	82.3	30.9	60.9	356	33.3	37.8	38.7	39	5.1
Cs	2.45	3.57	1.44	1.99	2.94	2.0	<1.0	1.0	<0.5	<0.2
Hf	3.71	5.0	3.82	3.61	2.42	1.6	3.7	1.1	1.13	0.87
Nb XRF	10	9	11	9	6	<5	<5	<5	<5	<5
Rb	65	65	60	66	58	26	<40	<40	<20	<20
Rb XRF	68	70	66	73	58	21	<2	6	7	6
Sb	<0.3	<0.6	<0.3	<0.3	0.5	---	---	---	<0.9	<0.8
Sr XRF	443	511	452	511	283	109	61	186	214	447
Ta	0.70	0.74	0.68	0.73	0.35	<0.40	<0.60	0.33	<0.3	<0.3
Th	6.60	7.3	7.3	6.91	0.46	0.6	<0.9	<0.8	<0.6	<0.6
U	1.91	1.53	1.96	2.01	<0.7	0.8	<2.0	0.7	<0.4	<0.4
Y XRF	20	35	18	20	28	20	56	14	20	17
Zn	64	91	39	48.4	148	75	342	114	96	119
Zr	138	205	125	159	<200	98	60	260	<200	<200
Zr XRF	132	173	143	136	102	59	121	44	50	44
Sc	11.1	26.7	6.71	10.5	45.7	33.0	49.3	47.3	49.5	48.8
La	26.4	30.1	26.6	26.8	7.8	5	2	1	1.6	1.78
Ce	53.5	57.6	44.3	48.5	12.6	11	12	5	5.4	6.1
Nd	26	31	21	21	11	8	19	5	6	4
Sm	5.18	6.07	3.69	4.43	4.09	2.1	6.4	1.3	1.72	1.63
Eu	1.14	1.45	0.91	1.00	1.36	0.59	3.50	0.56	0.58	0.60
Gd	4.5	7.1	<10	2.5	4.9	2.7	8.9	2.0	<20	<20
Tb	0.49	0.80	0.29	0.48	0.80	0.38	1.24	0.29	0.41	0.40
Tm	0.29	0.68	<0.8	0.12	0.39	0.23	0.86	0.26	<1	<1
Yb	1.87	5.0	1.46	1.92	3.01	2.3	6.9	2.2	2.29	2.16
Lu	0.263	0.790	0.211	0.304	0.45	0.34	1.01	0.32	0.39	0.35

Table 2 (cont.)

	Easton Metamorphic Suite Tonga Formation of Yeats (1958)										Shuksan Greenschist				
	RWT 347-78	JM 122-79	RWT 235-80	RWT 445-80	RWT 446-80	RWT 47-81	RWT 49-81	RWT 1-82	RWT 2-82	RWT 3-82	RWT 190-75	RWT 429-76	RWT 366-77	RWT 542-77	RWT 552-77
SiO_2	46.8	50.6	49.6	51.1	50.3	46.5	48.3	49.5	65.2	43.0	40.7	46.6	51.5	49.0	47.9
Al_2O_3	20.8	15.4	13.5	14.7	15.6	12.1	15.8	13.8	15.2	14.5	15.8	9.06	13.1	15.7	12.8
Fe_2O_3	6.47	11.07	13.86	11.35	11.59	16.4	10.6	11.6	6.79	11.9	16.0	6.69	12.37	14.52	16.13
Fe_2O_3 INAA	6.84	11.26	14.19	11.23	11.91	16.43	10.56	11.86	7.17	12.29	16.57	6.94	12.00	14.01	16.71
MgO	7.5	7.3	7.3	8.7	6.5	6.13	8.83	7.10	3.14	5.98	6.26	12.8	7.0	5.7	7.0
CaO	12.32	10.68	10.21	9.80	10.92	8.80	9.77	10.2	0.27	9.61	14.0	18.4	10.20	6.72	8.60
Na_2O	2.3	4.2	2.3	3.9	3.6	2.72	2.61	3.17	5.68	3.09	1.19	0.37	1.6	4.3	1.7
Na_2O INAA	2.55	3.84	2.47	3.65	3.64	3.03	2.74	3.29	6.39	3.32	1.35	0.36	1.63	4.39	1.56
K_2O	0.10	0.14	0.02	0.10	0.16	0.28	0.47	0.21	0.15	0.04	0.35	<0.02	0.04	0.01	0.54
TiO_2	0.54	1.44	1.91	1.35	1.96	3.13	1.06	1.56	0.53	1.41	2.45	0.15	2.00	1.69	2.84
P_2O_5	0.10	0.14	0.20	0.13	0.26	0.31	0.07	0.11	0.08	0.12	0.25	<0.05	0.22	0.18	0.24
MnO	0.11	0.22	0.20	0.18	0.18	0.35	0.21	0.18	0.18	0.18	0.24	0.16	0.20	0.22	0.21
LOI	---	---	---	---	---	3.04	1.76	2.26	2.14	9.89	2.18	4.98	---	---	---
Total	97.0	101.2	99.1	101.3	101.1	99.8	97.5	99.7	99.4	99.7	99.4	99.3	98.2	98.0	98.0
	Minor and Trace Elements (ppm)														
Ba	<300	<400	<400	<400	<400	108	105	<100	150	62	<200	<200	<300	<300	<300
Ba XRF	28	30	13	37	26	103	79	13	129	40	39	24	16	36	32
Co	36.1	41.0	44.7	44.0	43.4	41.4	49.0	42.4	18.5	42.4	39.6	40.9	36.4	41.2	40.5
Cr	322.0	161.0	70.8	219.0	305.0	69.1	379	103	35	259	158	518	171.0	8.4	86.5
Cs	0.8	<0.9	<0.9	<0.0	<0.8	0.82	1.35	<0.4	0.21	<0.4	0.42	<0.6	<0.8	0.6	<1.0
Hf	0.8	2.4	3.1	2.0	3.5	5.27	1.41	2.31	2.19	1.98	6.2	<1	3.1	2.5	4.8
Nb XRF	<5	<5	<5	<5	6	5	5	<5	6	<5	7	<5	<5	<5	<5
Rb	<30	12	<40	<40	<40	10	12	<20	<20	<20	<20	<20	<40	<40	22
Rb XRF	3	<2	<2	<2	6	<5	11	<5	<5	<5	8	<5	2	2	7
Sb	---	---	---	---	---	3.22	1.43	<0.8	0.47	1.13	<0.04	<1	---	---	---
Sr XRF	61	158	141	170	527	122	157	186	167	420	307	147	100	177	139
Ta	<0.40	0.29	0.46	<0.06	0.74	0.37	0.14	<0.3	0.14	0.24	0.54	<0.3	0.35	0.39	0.44
Th	<0.7	<0.8	<0.8	<0.1	0.8	0.34	<0.3	<0.5	1.80	<0.5	0.58	<0.7	<0.8	0.3	0.5
U	<2.0	<1.0	<2.0	<1.0	<1.0	<0.6	<0.5	<0.5	0.60	<0.5	0.45	<0.7	1.0	<2.0	<2.0
Y XRF	12	28	34	24	28	57	23	31	21	23	58	10	35	30	49
Zn	73	127	123	111	113	145	106	98	118	118	141	64	118	165	133
Zr	<300	70	130	<20	130	217	<200	97	65	<200	266	<300	110	140	180
Zr XRF	35	96	110	72	150	207	64	96	85	80	256	20	118	91	176
Sc	24.0	42.9	42.7	46.4	43.4	43.1	47.7	43.3	21.5	39.3	50.5	74.8	38.6	36.3	45.2
La	1	4	5	3	9	8.5	1.80	2.9	9.7	3.5	10.8	<0.8	5	4	7
Ce	3	12	11	9	19	24.3	5.6	9.1	18.6	9.4	30.8	<4	14	10	19
Nd	<20	9	12	8	15	23	5	8	12	6	23	10	14	10	17
Sm	1.0	3.0	3.4	2.3	4.1	7.51	2.02	3.46	2.93	2.81	7.90	0.32	3.7	3.0	5.1
Eu	0.50	1.18	1.38	0.83	1.51	2.48	0.77	1.28	0.84	1.09	2.44	0.20	1.35	1.10	1.87
Gd	1.3	3.7	4.4	<0.2	5.1	11	<7	<20	<10	<20	<20	<20	2.0	2.5	8.0
Tb	0.25	0.63	0.74	0.53	0.72	1.69	0.52	0.78	0.46	0.68	1.79	<0.3	0.73	0.60	1.05
Tm	0.23	0.42	0.52	0.01	0.30	0.95	0.4	0.9	<1	<1	1.0	<1	0.48	0.46	0.66
Yb	1.6	3.2	4.2	3.0	3.6	7.01	2.50	3.3'	2.31	2.83	7.6	0.29	4.4	3.9	6.1
Lu	0.22	0.51	0.62	0.44	0.55	1.00	0.36	0.51	0.360	0.432	1.09	0.12	0.64	0.59	0.87

Table 2 (cont.)

	Manastash Complex				Eastern Melange Belt				
	RWT 240-77	RWT 244-77	RWT 260-77	RWT 286-77	JV 40-1	JV 2-8	JV 111-9	RWT 112-78	RWT 1-78
SiO_2	58.8	54.5	52.7	54.2	50.0	57.7	50.3	62.4	46.4
Al_2O_3	15.1	16.3	15.6	15.6	13.0	14.2	13.5	15.9	15.8
Fe_2O_3	6.67	8.71	13.64	10.87	11.94	8.09	11.64	6.27	10.55
Fe_2O_3 INAA	6.6	8.80	13.10	10.50	---	---	---	---	---
MgO	5.3	6.6	4.2	5.3	5.8	5.1	5.3	3.6	7.4
CaO	7.93	5.06	8.08	7.76	13.7	6.2	10.6	3.7	16.3
Na_2O	3.1	3.4	2.3	3.0	0.33	4.3	4.4	3.8	0.68
Na_2O INAA	3.22	3.56	2.57	3.07	---	---	---	---	---
K_2O	0.22	1.35	0.36	0.43	0.07	0.43	0.24	1.9	0.49
TiO_2	0.70	0.72	1.02	0.83	1.7	0.78	1.5	1.2	1.4
P_2O_5	0.14	0.16	0.13	0.13	0.19	0.25	0.17	0.23	0.25
MnO	0.09	0.13	0.22	0.19	0.13	0.11	0.20	0.13	0.26
LOI	---	---	---	---	---	---	---	---	---
Total	98.1	96.9	98.3	98.3	98.9	97.2	97.9	99.1	99.5

Minor and Trace Elements (ppm)

Ba	170	255	140	190
Ba XRF	83	200	150	148
Co	23.4	25.8	31.5	35.5
Cr	165.0	138.0	5.2	49.2
Cs	<0.8	0.3	0.5	0.5
Hf	1.8	2.1	1.2	1.4
Nb XRF	<5	<5	<5	<5
Rb	<30	29	<30	<30
Rb XRF	4	28	7	7
Sb	---	---	---	---
Sr XRF	207	175	164	196
Ta	0.19	0.31	<0.50	0.21
Th	0.5	1.5	<0.6	0.6
U	<2.0	1.0	<1.0	<2.0
Y XRF	17	21	14	16
Zn	44	86	121	117
Zr	110	80	<300	<300
Zr XRF	70	91	36	58
Sc	28.6	26.9	39.8	34.1
La	4	11	2	3
Ce	10	22	5	8
Nd	10	12	<20	10
Sm	2.2	2.8	1.2	1.7
Eu	0.78	0.96	0.62	0.68
Gd	2.5	3.4	1.2	2.1
Tb	0.39	0.37	0.34	0.34
Tm	0.31	0.29	0.31	0.17
Yb	2.5	2.3	1.9	2.1
Lu	0.38	0.34	0.32	0.32