THE GEOCHEMISTRY OF BASALTS HOSTING MASSIVE SULPHIDE DEPOSITS, ALEXANDER TERRANE NORTHWEST BRITISH COLUMBIA (114P)

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INTRODUCTION

This paper presents and interprets the results of chemical analyses completed by the British Columbia Ministry of Energy, Mines and Petroleum Resources' Analytical Laboratory on samples previously collected from the Windy-Craggy and Mount Henry Clay areas of the Tatshenshini map sheet (MacIntyre, 1983, 1984; MacIntyre and Schroeter, 1985).

REGIONAL TECTONIC SETTING

The Windy-Craggy deposit and Mount Henry Clay occurrences are located within the Alexander terrane (Fig. 28-1; Berg, 1979; Campbell and Dodds, 1983). This terrane includes a thick succession of Precambrian to Permian basinal and platformal carbonate and clastic rocks with a subordinate volcanic component that is unconformably overlain by Late Triassic calcareous turbidites and a bimodal volcanic suite (Fig. 28-2). Paleomagnetic data indicates that this terrane has migrated northward from low paleolatitudes (Hillhouse and Gromme, 1980). The Paleozoic stratigraphy of the Alexander terrane is strikingly similar to that of the Cordilleran miogeocline; possibly the Alexander terrane is a slice of the continental margin that has been moved northward and stepped westward along major transcurrent faults to its present position. This hypothesis has been proposed by several authors (Jones, *et al.*, 1972; Muller, 1977; Monger and Irving, 1980).

The Alexander terrane is in fault contact with Wrangellia to the west and the Taku terrane to the east (Fig. 28-1). Recently, Davis and Plafker (1985) have presented evidence that the Taku and Wrangellia terranes were coextensive and have been offset by movement on the Denali fault system in Mesozoic and Cenozoic time. If this is true then the Alexander terrane must also have been coextensive with these terranes in Triassic time (Davis and Plafker, 1985).

Both the Wrangellia and Taku terranes are characterized by Middle to Late Paleozoic is and arc rocks, such as the Sicker Group of Vancouver Island and the Skolai Group of Alaska, that are unconformably overlain by a thick Triassic section. The base of this section locally includes a thin or absent clastic sedimentary unit containing Ladinian (late Middle Triassic) fossils that is overlain by the thick Karnian (early Late Triassic) submarine and/or subaerial basalt of the Karmutsen/Nikolai assemblage. The basalts are overlain by Norian-age limestone and calcareous sedimentary rocks such as the Quatsino, Parsons Bay, Kunga, Chitistone, and Whitestripe Formations. Like the Alexander terrane, Wrangellia has moved to its present position from low paleolatitudes (Packer and Stone, 1974; Jones, *et al.*, 1977; Hillhouse, 1977; Irving, *et al.*, 1980; Irving, *et al.*, 1985).

Stratigraphic columns for the Triassic rocks of the Alexander, Wrangellia, and Taku terranes are compared on Figure 28-2. The Triassic succession of the Alexander terrane differs significantly from adjacent terranes in the following ways:

(1) The basalts are of Norian rather than Karnian age.
(2) The basalts are underlain by and interbedded with a thick succession of distal to proximal turbidites and/or limestones.

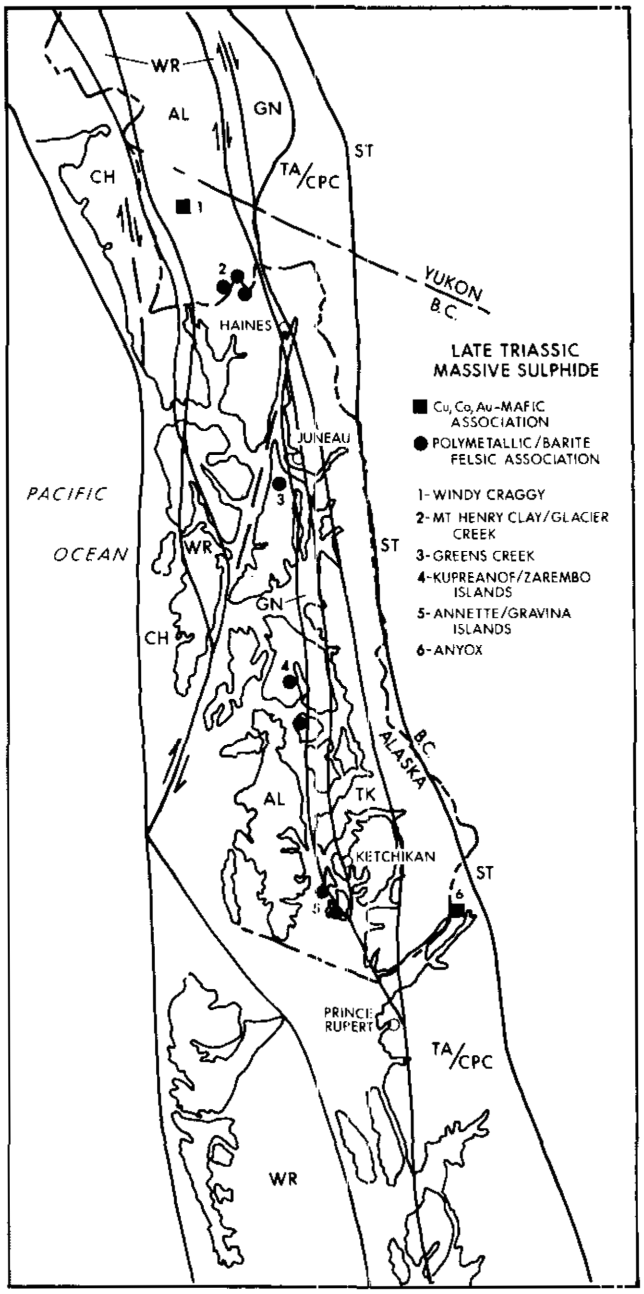

Figure 28-1. Tectonostratigraphic terranes of northwest British Columbia and southeast Alaska, and location of Late Triassic massive sulphide deposits. Terrane abbreviations used are: CH — Chugach; AL — Alexander; WR — Wrangellia; TK — Taku; GN — Gravina/Nutzotin; TA/CPC — Tracy Arm/Coast Plutonic Complex; ST — Stikinia.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

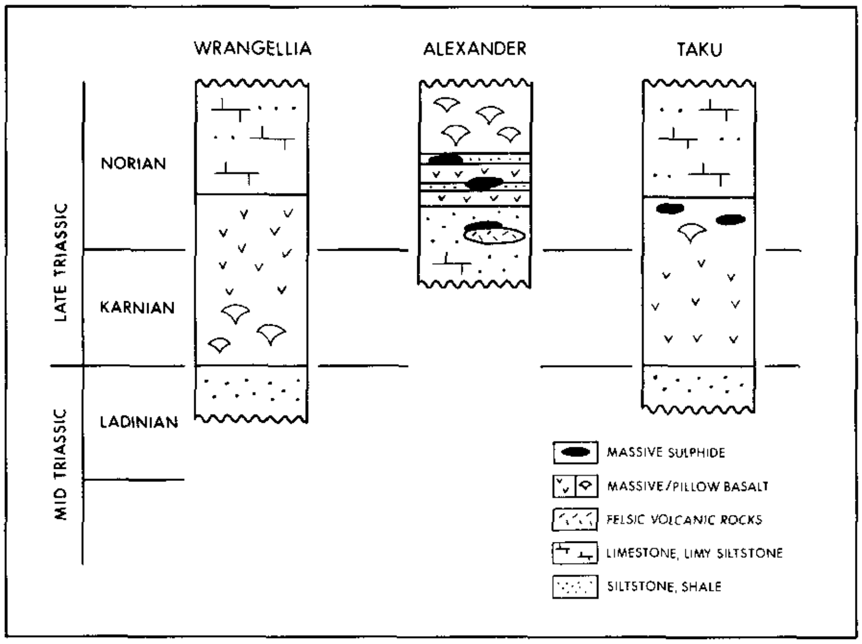

Figure 28-2. Triassic stratigraphic columns for the Wrangellia, Alexander, and Taku terranes.

(3) Sedimentary interbeds are common in the upper volcanic part of the section, which is mainly marine in origin. Karmutsen and Nikolai sections generally lack sedimentary interbeds and are both submarine and subaerial.

(4) Felsic fragmental and flow rocks occur locally in the Triassic section of the Alexander terrane. Felsic volcanic rocks do not occur in the Karmutsen and Nikolai sections.

Another important difference that will be documented in this report is in the composition of the volcanic rocks; those of the Alexander terrane have calc-alkaline characteristics typical of island arcs or back arc basins developed in continental crust; those of the Wrangellia and Taku terranes are mainly low-K tholeiites with oceanic or continental basalt characteristics (Davis and Plafker, 1985).

The timing of suturing of the Alexander and Wrangellia terranes into one superterrane is a matter of considerable debate. As mentioned earlier, Davis and Plafker (1985) have suggested that they were united by Triassic time, a conclusion favoured by this writer. Parts of the superterrane were dislocated by movement along crosscutting transcurrent faults in Mesozoic and Cenozoic time. In general, the current mosaic of terranes that comprise the Insular Tectonic Belt is probably the result of several episodes of oblique subduction and northward translation of slices of oceanic and continental lithosphere in a manner similar to that recently proposed by Bruns (1983) for the Yakutat block. In the Prince Rupert area the Alexander terrane appears to have been thrust eastward under the Coast Plutonic Complex (Woodsworth, *et al.*, 1985).

The Alexander, Wrangellia, and Taku terranes all include Jurassic and Cretaceous calc-alkaline volcanic and plutonic rocks and related back arc successor basin flysch deposits such as the Gravina-Nuzotin assemblage. This implies that these three terranes were together in Early Jurassic time and were probably situated above an eastward-dipping subduction zone. The flysch deposits have also been offset by as much as 300 kilometres of right lateral offset along the Denali fault system in Tertiary time (Eisbacher, 1976). Recently, Irving, *et al.* (1985) suggested that the Wrangellia, Alexander, Taku, Coast Plutonic Complex, and Stikine terranes were all amalgamated by Cretaceous time and travelled north as one superterrane in Late Cretaceous and Early Tertiary time.

Outboard of Wrangellia is the Chugach terrane, a melange-subduction complex which is also of Jurassic-Cretaceous age.

All the terranes of the northern Insular Belt are intruded by granitic rocks of Jurassic, Cretaceous, and Tertiary age again implying amalgamation as a superterrane by no later than Jurassic time.

LATE TRIASSIC STRATIGRAPHY OF THE ALEXANDER TERRANE

The geology, stratigraphy, and mineral deposits of the Windy-Craggy and Mount Henry Clay areas have been described in two previous reports (MacIntyre, 1984; MacIntyre and Scroeter, 1985). Preliminary stratigraphic columns for these two areas are shown on Figure 28-3 together with a typical Triassic section for southeast Alaska. The approximate stratigraphic positions of samples discussed in this report are also shown. The age of the volcanic rocks in the Windy-Craggy area has been established as Early Norian on the basis of conodonts collected from sedimentary interbeds (M. Orchard, pers. comm., 1983). The age of rocks hosting massive sulphide and barite deposits in the Mount Henry Clay-Glacier Creek area is not as well established. One sample collected by Ken Dawson, Geological Survey of Canada, from a sedimentary interbed approximately 50 to 100 metres stratigraphically above the Glacier Creek Main deposit has yielded conodont fragments. These fragments are most likely Triassic in age (M. Orchard, pers. comm., 1985). Elsewhere in the Mount Henry Clay area the age of host rocks is inferred from stratigraphic similarity to other faunally dated Late Triassic sequences in southeast Alaska (Berg, 1981).

The stratigraphic successions observed in the Windy-Craggy and Mount Henry Clay areas are very similar to those observed in other parts of the Alexander terrane, for example, the Glacier Creek area

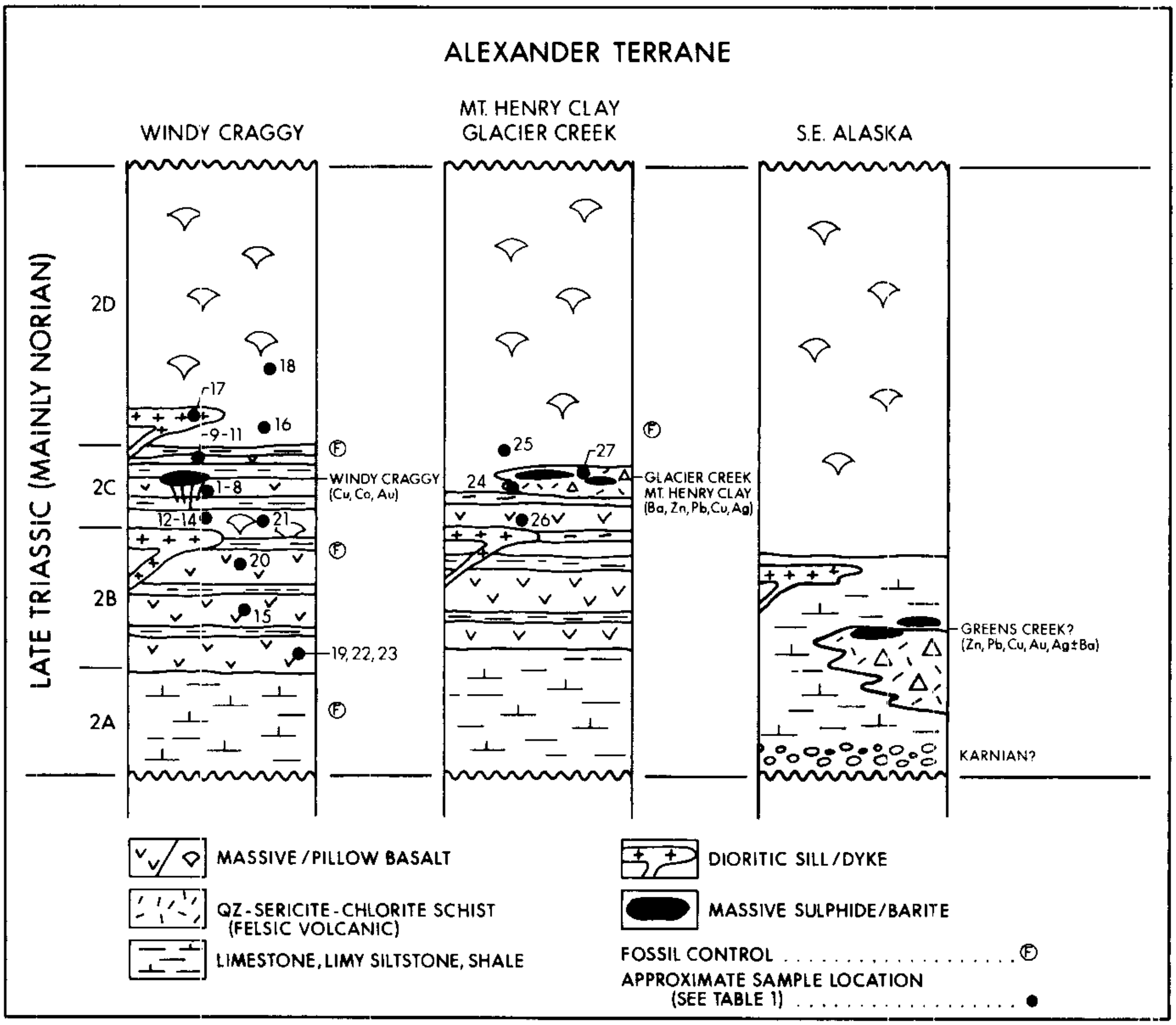

Figure 28-3. Triassic stratigraphic columns for the Windy-Craggy, Mount Henry Clay/Glacier Creek, and southeast Alaska areas of the Alexander terrane.

(Still, 1984) and Gravina Island of southeast Alaska (Berg, 19733; Fig. 28-3). In general, calcareous turbidites and, in southeastern Alaska, erosional conglomerates, occupy the lower part of the sequence. These rocks constitute the Nehenta Formation on Gravina Island (Berg, 1973). The lower sedimentary package grades up section into a thick pillow basalt unit which has been defined as the Chapin Peak Formation on Gravina Island (Berg, 1973). Fossil control is lacking in many parts of southeast Alaska where inferred Triassic rocks occur but, where present, fauna are mainly Norian in age (Berg, 1981); a few Karnian ages have also been reported in southeast Alaska. Karnian age fossils have not yet been found in the Windy-Craggy area.

Unlike other parts of the Alexander terrane, no quartz-sericite schist or phyllite interbeds occur in the Late Triassic mafic volcanic sequence in the Windy-Craggy area. These rocks, which are believed to be sheared rhyolitic fragmental rocks or rhyolite flows, occur in the lower sedimentary or middle mixed sedimentary-basalt parts of the Triassic successions of southeastern Alaska and in the Mount Henry Clay area. Polymetallic massive sulphide and barite deposits (Fig. 28-1), such as Glacier Creek, Low Herbert, Mount Henry Clay, occurrences on Zarembo, Kupreanof, Annette, and Gravina islands and possibly Greens Creek are associated with these felsic rocks (Berg and Grybeck, 1980; McDougall, *et al.*, 1983; Still, 1984; MacIntyre and Schroeter, 1985). The presence of felsic volcanic rocks in these predominantly mafic volcanic sections indicates volcanism in the Alexander terrane was bimodal.

BASALT GEOCHEMISTRY

The chemistry of volcanic rocks that host massive sulphide deposits has been the subject of many previous studies. This data provides important clues (with certain limitations) to the tectonic environment in which the host volcanic rocks were erupted, for example, at a convergent or divergent plate margin or within a plate.

Samples from the Windy-Craggy and Mount Henry Clay areas have been analysed for major and trace elements by the Ministry Laboratory. Results are tabulated in Table 28-1. Whole rock analyses of drill core have also been provided by Falconbridge Nickel Mines Limited for comparative purposes. In addition, Dr. Joe Fox, I.R.E.M./M.E.R.I., Montreal, provided immobile and rare earth

TABLE 28-1

CHEMICAL ANALYSES AND CIPW NORMS

	WINDY-CRAGGY DEPOSIT - FOOTWALL								HANGINGWALL			WINDY-CRAGGY AREA												MOUNT HENRY CLAY AREA			
No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Sample	9-646	9-746	9-1630	12-700	82-3	82-9	82-10	82-11	5-190	82-5A	82-7	83-2	83-3A	83-4	83-16	83-34	83-70	83-80A	84-3	84-7	84-8	84-9	84-10	ST84-1	LH84-2	BC84-3	GL84-4
SiO_2	51.39	48.64	49.17	39.55	41.73	51.84	51.20	40.22	49.49	50.92	46.29	52.77	49.99	48.53	49.73	51.08	47.53	49.49	50.04	52.84	50.87	50.46	52.77	45.84	66.40	57.16	70.70
TiO_2	0.84	0.94	1.13	1.51	0.89	1.14	1.25	1.25	0.90	0.90	1.17	0.75	0.43	0.41	1.34	0.91	1.13	0.97	0.67	0.52	0.84	1.33	0.85	1.24	1.43	1.53	0.63
Al_2O_3 ...	16.00	16 21	14.63	17.59	17.60	15.04	16.55	17.74	17.16	16.65	13.34	15.89	18.18	19.42	16.41	16.79	13.68	13.42	18.01	18.41	13.44	18.46	15.14	13.52	12.27	12.14	15.81
Fe_2O_3 ...	0.98	1.72	2.15	2.32	1.73	8.73	3.70	1.60	2.40	1.29	2.54	1.08	1.64	1.86	1.43	0.93	0.82	0.94	1.32	1.81	0.87	1.88	0.91	4.68	7.41	8.13	1.82
FeO	8.72	15.20	16.60	18.60	12.20	9.73	10.40	16.10	6.35	5.46	5.35	7.27	6.30	5.84	6.42	6.42	7.51	5.29	6.48	5.48	8.15	4.61	0.55	9.66	0.43	6.55	0.36
MnO	0.07	0.06	0.11	0.11	0.06	0.08	0.06	0.18	0.06	0.05	0.11	0.09	0.15	0.13	0.12	0.09	0.14	0.13	0.12	0.15	0.15	0.12	0.15	0.19	0.01	0.16	0.01
MgO	10.61	6.49	7.07	4.91	14.20	1.77	5.33	3.16	4.87	10.08	10.48	6.45	5.68	6.30	5.50	8.04	11.57	4.49	5.97	4.28	9.60	5.81	8.33	7.00	0.48	4.83	0.56
CaO	0.95	1.13	0.58	2.31	0.38	0.03	0.38	5.44	3.70	3.20	7.31	5.82	11.53	11.16	8.44	3.72	7.36	12.51	8.86	8.49	9.71	7.08	4.94	6.06	0.03	0.50	0.06
Na_2O ...	3.96	3.87	2.22	4.24	2.27	3.50	4.67	4.61	4.09	1.63	1.26	5.98	3.53	3.32	4.68	5.09	3.15	5.36	4.19	4.50	2.89	5.70	4.93	4.36	0.21	2.18	1.97
K_2O	0.03	0.03	0.01	0.06	0.01	0.12	0.02	0.35	2.59	2.14	0.86	0.12	0.16	0.32	0.78	1.85	1.08	0.30	0.59	1.17	0.74	0.20	0.10	0.03	3.46	1.33	4.02
P_2O_5	0.41	0.45	0.43	0.88	0.37	0.10	0.44	0.79	0.44	0.49	0.56	0.45	0.06	0.14	0.67	0.55	0.54	0.38	0.13	0.51	0.27	0.97	0.12	0.43	0.10	0.29	0.15
CO_2	0.10	0.48	0.10	0.88	0.10	0.15	0.17	3.68	2.23	1.59	5.18	0.10	0.14	0.04	0.53	0.04	0.06	1.46	0.93	0.21	0.14	0.10	0.24	3.04	0.10	0.10	0.10
H_2O+ ..	4.47	4.80	4.60	5.02	8.68	4.79	4.96	5.34	3.46	4.62	5.68	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
H_2O- ..	0.29	0.27	0.21	0.20	0.41	1.92	1.12	0.22	0.34	0.24	0.21	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LOI	—	—	—	—	—	—	—	—	—	—	—	2.40	2.20	2.60	5.00	3.50	4.10	6.20	2.54	1.50	1.83	2.96	3.32	5.58	6.02	4.28	2.81
TOTAL	98.82	100.29	99.01	98.18	100.63	98.94	100.25	100.68	98.08	99.26	100.34	99.17	99.85	100.03	100.52	98.97	98.61	99.48	98.92	99.66	99.36	99.58	100.11	98.59	98.26	99.08	98.90
CIPW NORM VOLATILE FREE																											
Q	5.57	4.02	14.20	0.00	0.00	26.44	10.25	0.00	0.00	10.05	4.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	55.59	32.24	44.81
C	9.27	9.33	11.63	9.19	15.16	9.94	9.42	1.95	2.13	7.55	0.00	0.00	0.00	0.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.87	7.28	8.56
Or	0.19	0.19	0.06	0.39	0.06	0.77	0.13	2.26	16.63	13.63	5.69	0.73	0.97	1.94	4.83	11.45	6.75	1.90	3.62	7.04	4.48	1.22	0 61	0.19	22.18	8.29	24.72
Ab	35.65	34.55	19.96	38.95	21.00	32.15	42.03	28.97	37.58	14.86	11.94	52.33	30.58	28.11	39.22	44.66	28.19	28.40	36.04	38.78	25.07	48.04	43.08	39.65	1.95	19.45	17.34
An	2.16	2.81	0.07	6.20	0.00	0.00	0.00	23.87	16.82	13.66	31.60	16.73	34.10	38.14	22.49	15.57	21.17	12.53	29.68	27 09	22.07	25.06	19 53	18.54	0.00	0.62	0.00
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.41	0.00	0.00	0.00	0.00	0.00	0.39	1.20	0.24	0.00	10.95	0.40	0 00	0.00	1.01	0.00	0.00	0.00	0.00	0 00
Di	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.91	8.26	19.68	14.42	13.66	0.00	11.05	41.95	12.28	10.18	20.71	3.80	4.07	8.80	0.00	0.00	0.00
Hy	42.96	43.50	47.44	7.60	53.79	14.48	29.10	0.00	14.51	35.20	34.09	0.05	1.57	0.00	0.00	0.00	3.84	0.00	0.00	6.72	14.04	0.00	17.79	6.83	1.30	15.94	1.45
Ol	0.00	0.00	0.00	28.71	4.60	0.00	0.00	28.43	5.61	0.00	0.00	17.75	9.72	13.13	12.16	22.53	24 17	−0.29	14.38	5.33	10.08	13.14	11 62	15.10	0.00	0.00	0.00
Wo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.41	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00
Mt	1.51	2.63	3.32	3.65	2.74	13.74	5.71	2.54	3.78	2.02	4.13	1.62	2.43	2.77	2.17	1.41	1.26	1.46	1.99	2.67	1.29	2.82	1.36	7.30	0.00	12.43	0.00
Il	1.70	1.88	2.28	3.11	1.85	2.35	2.53	2.60	1.86	1.84	2.49	1.47	0.84	0.80	2.66	1.81	2.27	1.97	1.32	1 01	1.64	2.61	1.67	2.53	1.02	3.07	0.80
Hm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.04	0.00	1 89
Ru	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.02	0.00	0.23
Ap	1.02	1.11	1.07	2.23	0.94	0.25	1.09	2.01	1.11	1.23	1.46	1.09	0.14	0.33	1.63	1.34	1.33	0.95	0.31	1.21	0.65	2.34	0.29	1.08	0.25	0.71	0.36
AN=	5.73	7.53	0.36	13.73	0.00	0.00	0.00	45.17	30.91	47.89	72.58	24.23	52.73	57.57	36.44	25.85	42.89	30.61	45.16	41.13	46.82	34.28	31.19	31.86	0.00	3.08	0.00
Ba	12	10	8	28	4	34	11	83	358	860	114	20	20	10	400	760	680	20	220	470	310	120	170	90	3 050	780	2 900
Rb	15	19	6	16	5	9	7	9	33	39	24	15	4	20	20	50	—	13	10	27	9	6	45	10	47	11	75
Sr	51	60	43	77	26	43	34	86	171	128	171	—	—	230	450	630	—	—	371	913	447	674	312	160	39	34	70
Y	13	15	7	12	4	15	15	2	12	13	10	17	6	20	20	10	—	11	6	8	18	22	14	27	24	31	5
Zr	120	130	155	150	68	162	164	164	45	116	118	105	10	20	120	180	—	159	83	93	86	194	60	93	90	211	15
Nb	—	—	—	—	—	—	—	—	—	—	—	—	—	10	50	50	—	—	10	14	8	38	12	11	10	7	3
Cr	241	210	153	155	249	24	25	399	10	170	439	156	130	210	110	150	—	177	100	94	360	83	113	24	13	13	45
Cu	118	43	63	126	81	830	117	74	133	60	49	53	130	125	45	20	59	11	40	72	24	32	100	62	36	16	22
Pb	4	5	5	6	7	5	4	7	5	5	5	4	3	2	2	2	3	3	5	5	5	5	5	5	670	5	35
Zn	20	27	51	40	93	148	30	825	67	68	81	47	60	56	53	58	75	48	70	84	72	71	87	117	0	272	33
Co	28	12	26	23	22	9	9	16	27	19	28	36	44	39	41	29	10	29	47	30	50	26	40	53	50	33	30
Ni	102	45	48	44	76	9	21	115	21	70	250	75	71	76	77	150	320	102	75	42	183	75	64	64	21	21	10

— = not determined.

N.B. Totals do not include CO_2 if L.O.I. determined.

SAMPLE DESCRIPTIONS TO ACCOMPANY TABLE 28-1

1 — Drill core, DDH 9, 197 metres, Windy-Craggy. Medium grey to green chloritic basalt with disseminated pyrrhotite. Near base of massive sulphide.

2 — Drill core, DDH 9, 227 metres, Windy-Craggy. Similar to No. 1.

3 — Drill core, DDH 9, 497 metres, Windy-Craggy. Similar to No. 1.

4 — Drill core, DDH 12, 213 metres, Windy-Craggy. Medium to dark green intensely chloritized and sheared volcanic rock from stratigraphic footwall of massive sulphide deposit.

5 — Surface sample, Windy-Craggy. Sheared, chloritic volcanic rock from stratigraphic footwall of massive sulphide deposit.

6 — Surface sample, Windy-Craggy. Chloritized amygdaloidal flow from outcrop adjacent to DDH 12.

7 — Surface sample, Windy-Craggy. Fine-grained green chloritic pillow lava from outcrop adjacent to DDH 12.

8 — Surface sample, Windy-Craggy. Similar to No. 7.

9 — Drill core, DDH 5B, 58 metres, Windy-Craggy. Massive, fine-grained grey carbonate-altered basalt flow. Sample is interpreted to be from the lower part of the lower volcanic unit of the Tats Group (map unit 2B).

10 — Surface sample, Windy-Craggy. Light grey-weathering, carbonate-altered basalt flow from outcrop up slope from DDH 12. Sample is interpreted to be in stratigraphic hangingwall of the massive sulphide deposit.

11 — Surface sample, Windy-Craggy. Light green-weathering, spotted carbonate-altered, amygdaloidal basalt flow from outcrop located up slope from DDH 12. Sample is interpreted to be in the stratigraphic footwall of the massive sulphide deposit.

12 — Buff-weathering pillow lava, middle volcanic-sedimentary unit, Tats Group.

13 — Buff-weathering amygdaloidal, porphyritic basalt flow, middle volcanic-sedimentary unit, Tats Group.

14 — Buff-weathering pillow lava, middle volcanic-sedimentary unit, Tats Group.

15 — Massive, grey-weathering basalt flow, lower volcanic unit, Tats Group.

16 — Massive, dark grey-weathering pillow basalt, upper volcanic unit, Tats Group.

17 — Massive, grey-weathering microdioritic dyke cutting upper volcanic unit, Tats Group.

18 — Massive, dark grey-weathering pillow basalt with carbonate-filled amygdules, upper volcanic unit, Tats Group.

19 — Medium-grained, chlorite-altered diorite sill, lower volcanic unit, Tats Group.

20 — Fine-grained, dark grey hornblende andesite or basalt, lower volcanic unit, Tats Group.

21 — Fine-grained, dark grey chlorite-altered hornblende andesite or basalt, middle volcanic-sedimentary unit, Tats Group.

22 — Medium-grained, diorite sill, lower sedimentary unit, Tats Group.

23 — Fine-grained, dark grey basalt or andesite, lower volcanic unit, Tats Group.

24 — Amygdaloidal, chlorite-altered pillow basalt overlying Low Herbert mineralized zone, Mount Henry Clay area.

25 — Grey, foliated, quartz-sericite-altered vitric tuff with disseminated pyrite, Low Herbert mineralized zone, Mount Henry Clay area.

26 — Greenish grey, foliated chlorite-altered andesitic tuff or sheared flow, Boulderado occurrence, Mount Henry Clay.

27 — Cream-coloured, foliated quartz-sericite-altered lithic tuff, mineralized zone, Glacier Creek Main deposit, Mount Henry Clay area.

TABLE 28-2

TRACE AND RARE EARTH ANALYSES

Sample	83-16	83-34	N-MORB	
Rb	20	50	1	LIL
Ba	510	1 000	12	LIL
Th	2.9	5.5	0.2	LIL
K	5 810	14 520	830	LIL
Sr	450	630	3	LIL
La	35.5	59.7	10.0	LIL
Ce	70	100	136	LIL
Nb	50.0	50.0	2.5	HFS
Ta	1.70	1.80	0.17	HFS
Nd	31	36	8	HFS
Sm	6.43	6.37	—	HFS
P	2 616	3 139	570	HFS
Hf	3.3	4.1	2.5	HFS
Zr	120	180	88	HFS
Eu	1.80	1.68	1.20	HFS
Ti	10 242	7 008	8 400	HFS
Tb	0.80	0.70	0.71	HFS
Y	20	10	35	HFS
Yb	1.87	1.89	3.50	HFS
Lu	0.29	0.28	—	HFS
Ni	77	150	138	
Cr	110	150	290	

Note: All values in ppm.
N-MORB values from Saunders and Tarney (1984).
Analyses by X-ray Assay Laboratories, Don Mills, Ontario.
Data provided by Dr. J. Fox, I.R.E.M./M.E.R.I., Montreal, Quebec.

analyses for two selected samples (WD83-16, WD83-34) from the Windy-Craggy area (Table 28-2).

The field occupied by basalts from the Wrangellia and Taku terranes is also plotted on Figures 28-7 to 28-16 for comparison purposes. The data used includes 24 analyses of Nikolai greenstone and Chilkat metabasalts (Davis and Plafker, 1985), 12 analyses of Karmutsen basalts (A. Sutherland Brown, pers. comm.) and six analyses of Anyox basalts (Sharp, 1980). All of these basalts are low-K tholeiites or ferrotholeiites in composition.

ALTERATION OF BASALT

Petrographic examination and the analytical data in Table 28-1 indicates most of the samples collected from the Windy-Craggy and Mount Henry Clay areas have been altered to some extent. Analyses 1 to 8 are from drill core and surface samples (Fig. 28-4) that are interpreted to be in the stratigraphic footwall of the Windy-Craggy deposit. These basalts are all pervasively chloritized and contain abundant disseminations and stringers of pyrrhotite. The analytical data suggests strong depletion in calcium, potassium, barium, and strontium relative to normal calc-alkaline basalt compositions. Analyses 4, 5, and 8 are also depleted in silica; iron is moderately to strongly enriched. These altered rocks are typically quartz and corundum normative.

Analyses 10 and 11 are from the stratigraphic hangingwall of the Windy-Craggy deposit and are also altered as indicated by high CO_2 and H_2O values. These rocks contain sericite, clay, and carbonate. Calcium abundances are relatively low compared to normal basaltic rocks; on the other hand K_2O ranges from 0.86 to 2.59 per cent and may be enriched. Corundum and quartz are present in the norm. This data suggests that footwall alteration is mainly chloritic whereas hangingwall alteration is predominantly phyllic to argillic. The phyllic and argillic alteration may be related to fluid boiling near hydrothermal vents.

Analyses 12 to 23 are from various stratigraphic levels in the Triassic section of the Windy-Craggy area (Figs. 28-3 and 28-5). Of these, analyses 13, 14, 15, 19, and 20 have CO_2, H_2O, and CaO concentrations like those of fresh basalt and appear to be the least altered. However, in thin section clay and carbonate alteration is also common in these samples, particularly in No. 14, which is a sample of pale-weathering pillow lava in the middle volcanic-sedimentary unit (2C) of the Tats Group.

Analyses 24 to 27 are from the Mount Henry Clay area and include altered basalt, andesite, and quartz-sericite-schist or phyllite. Sample locations are shown on Figure 28-6. No. 24 is from a pillow basalt flow that overlies the Low Herbert showing (MacIntyre and Schroeter, 1985). High H_2O and CO_2 values reflect the presence of numerous carbonate-filled vesicles in the sample. No. 26 is a foliated, chlorite-rich andesite collected from outcrop near a showing of massive sulphide boulders (Boulderado) on the north face of Mount Henry Clay. Nos. 25 and 27 are samples of quartz-sericite schist or sheared rhyolitic fragmental rocks that host bedded barite-sulphide and disseminated and semi-massive sulphide at the Glacier Creek and Low Herbert showings respectively. These samples are peraluminous (corundum normative), reflecting the presence of abundant sericite.

Basalts from the Windy-Craggy area are characterized by relatively low TiO_2 and high Na_2O, K_2O, and P_2O_5 compositions relative to mid-ocean ridge basalts (MORB). They are also enriched in large ion lithophile (LIL) elements. However, alkali and LIL element enrichment can result from low-grade seawater alteration of basalt (spilitization) and under such circumstances original rock chemistry is difficult to determine. Therefore, caution must be used in interpreting discriminant plots that use mobile elements such as Na, Ca, K, and to some extent SiO_2 and the LIL elements. Consequently, several different discriminant plots using both major oxide and immobile elements have been used in this study; the results from each are discussed and compared in the following sections. In each plot, the samples that plot in the unaltered field on the CaO versus MgO diagram (Fig. 28-7; Nos. 13, 14, 15, 19, and 20 in Table 28-1) of Spence (1985) are indicated by a special symbol so that altered and relatively unaltered samples can be compared.

ALKALINE VERSUS SUBALKALINE BASALTS

Several plots have been devised to identify alkaline and subalkaline series volcanic rocks. The most commonly used is the $Na_2O + K_2O$ versus SiO_2 plot (Kuno, 1966; MacDonald, 1964; Irvine and Baragar, 1971). On this diagram (Fig. 28-8) analysed samples cluster about the alkalic-subalkalic boundary; the least altered samples plot within or close to the subalkalic field. On Irvine and Baragar's (1971) normative olivine-nepheline-quartz ternary diagram (Fig. 28-9) most samples plot in the subalkaline field; the least altered samples plot on or near the alkalic-subalkalic boundary. Floyd and Winchester (1978) used a plot of LOG (Zr/TiO_2) versus SiO_2 to divide and classify alkaline and subalkaline rocks. This plot (Fig. 28-10) is especially useful for altered rocks because Si, Zr, and Ti are relatively immobile at low to moderate alteration levels. Mafic samples from Windy-Craggy and Mount Henry Clay plot in the subalkaline and alkali basalt fields; quartz sericite schists or phyllites from the Mount Henry Clay area plot in the rhyodacite field. A similar conclusion is derived using the Zr/P_2O_5 versus TiO_2 plot (Floyd and Winchester, 1975) although on this diagram (Fig. 28-11) a small group of samples plot in the alkaline field. Floyd and Winchester (1975) also use the ratio of Y/Nb to divide alkaline from subalkaline rocks but Y and Nb concentrations in the samples used in this study are too close to the XRF detection limit for these elements to be reliable.

Major and trace element chemistry of the analysed volcanic rocks from the Windy-Craggy and Mount Henry Clay areas suggest that they are mainly subalkaline in composition, although some samples are chemically similar to alkaline volcanic rocks.

THOLEIITIC VERSUS CALC-ALKALINE BASALTS

Subalkaline rocks include the tholeiitic and calc-alkaline series (Irvine and Baragar, 1971). Pronounced iron enrichment and Al_2O_3 concentrations between 12 and 16 per cent characterize the tholeiitic series; calc-alkaline rocks lack iron enrichment and generally have Al_2O_3 concentrations between 16 and 20 per cent (Irvine and Baragar, 1971). The most commonly used plot to distinguish the two series is the alkalies-total iron-magnesium (AFM) ternary diagram (Fig. 28-12). On this diagram, the least altered samples from the Windy-Craggy and Mount Henry Clay areas plot in the calc-alkaline field (Fig. 28-12); intensely altered samples are enriched in Fe and plot in the tholeiitic field. By comparison, unaltered basalts from the Wrangellia and Taku terranes plot mainly in the tholeiitic field.

TECTONIC SETTING

Major and trace element geochemistry of basalts from different tectonic environments has been examined by many researchers, and a diverse collection of discriminant diagrams has evolved. Most of these are based on relatively immobile trace elements such as Ti, Cr, Zr, Nb, Y, Ta, and Th (Pearce and Cann, 1973; Floyd and Winchester, 1975; Miyashiro and Fumiko, 1975; Garcia, 1978; Pearce and Norry, 1979). On the Ti versus Cr plot of Figure 28-13 the majority of Windy-Craggy samples plot within the island arc basalt (IAB) field, that is, they are mainly calc-alkaline or alkaline in composition; samples from the Wrangellia and Taku terranes plot *in the MORB or tholeiite field*.

Samples from the Windy-Craggy and Mount Henry Clay area have been analysed for zirconium. These samples show considerable scatter on the Ti versus Zr diagram of Figure 28-14 although in general there is a calc-alkaline basalt trend. Samples from the Wrangellia and Taku terranes plot along a well-defined linear trend that falls within the ocean floor basalt field. This plot further illustrates the more alkaline composition of the Windy-Craggy basalts compared to the predominantly tholeiitic Nikolai, Chilkat, Karmutsen, and Anyox basalts.

RARE EARTH ELEMENTS

Chondrite normalized rare earth concentrations for two samples of basalt (Table 28-2) from the Windy-Craggy area are plotted on Figure 28-15. The plot shows that the Windy-Craggy basalts are strongly enriched in the light rare earth elements (LREE) relative to those of the Wrangellia and Taku terranes (Davis and Plafker, 1985)

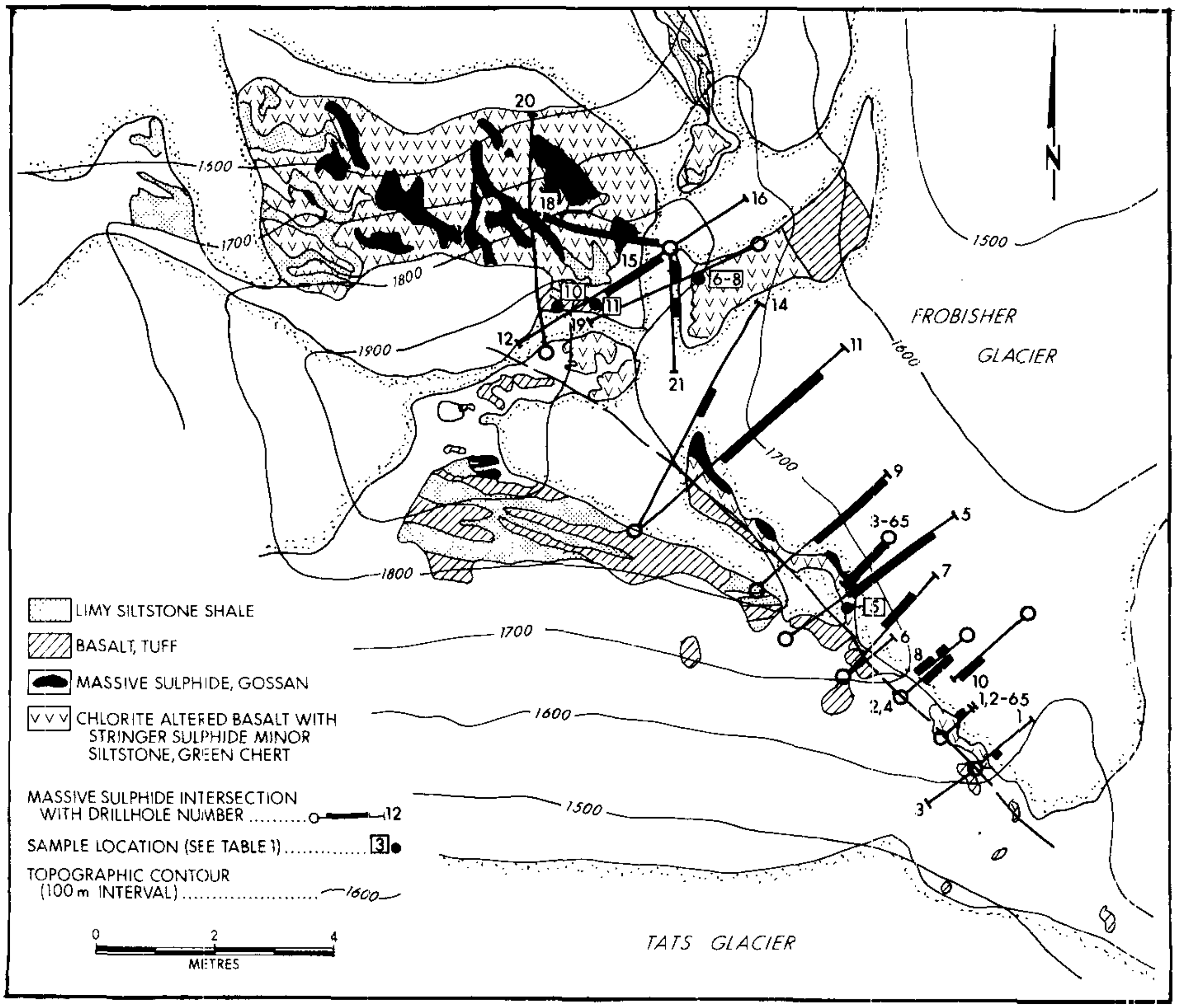

Figure 28-4. Geology, drill hole, and sample locations, Windy-Craggy deposit. Drill hole locations after company plans.

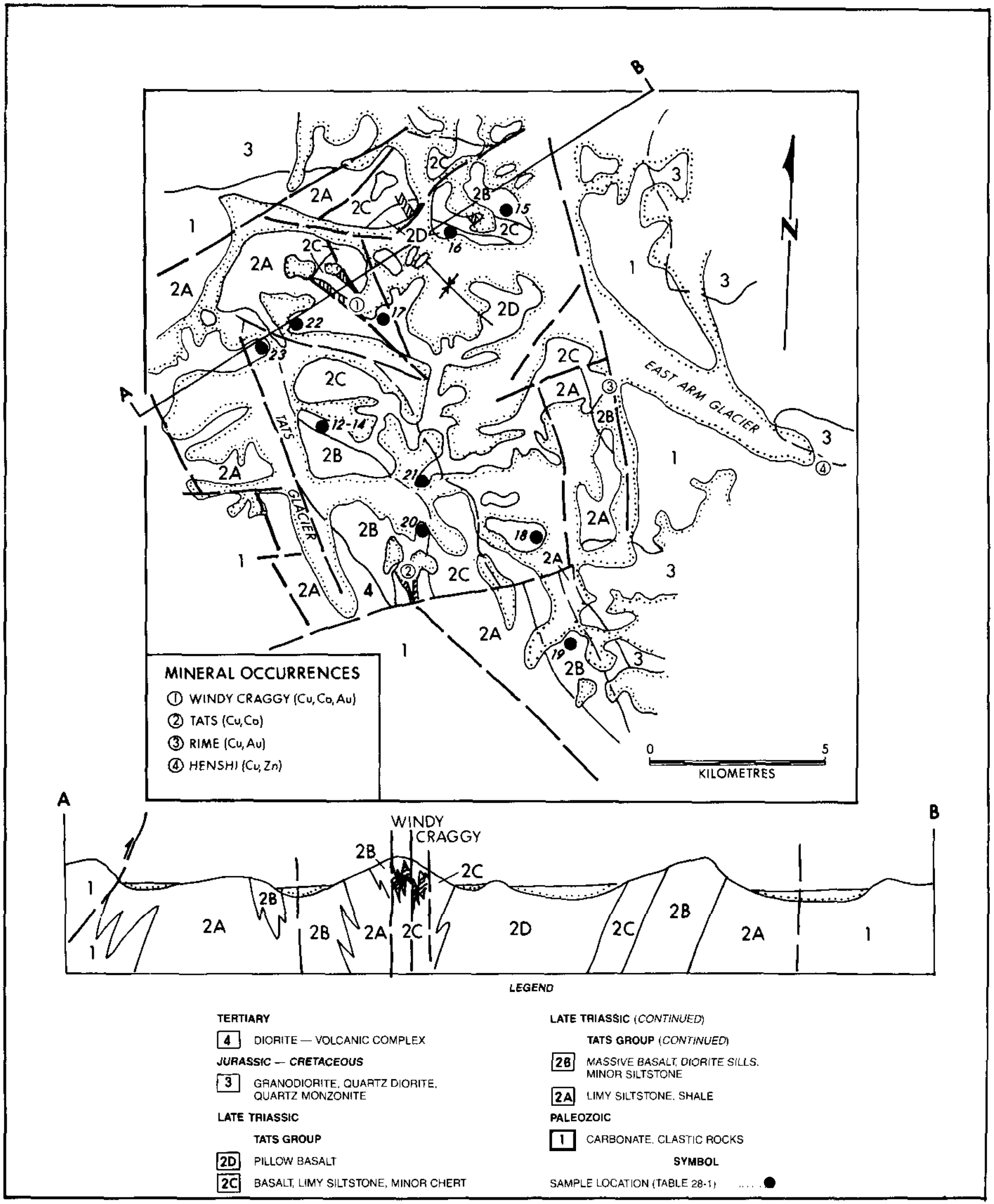

Figure 28-5. Geology and sample locations, Windy-Craggy area. Geology after MacIntyre (1984).

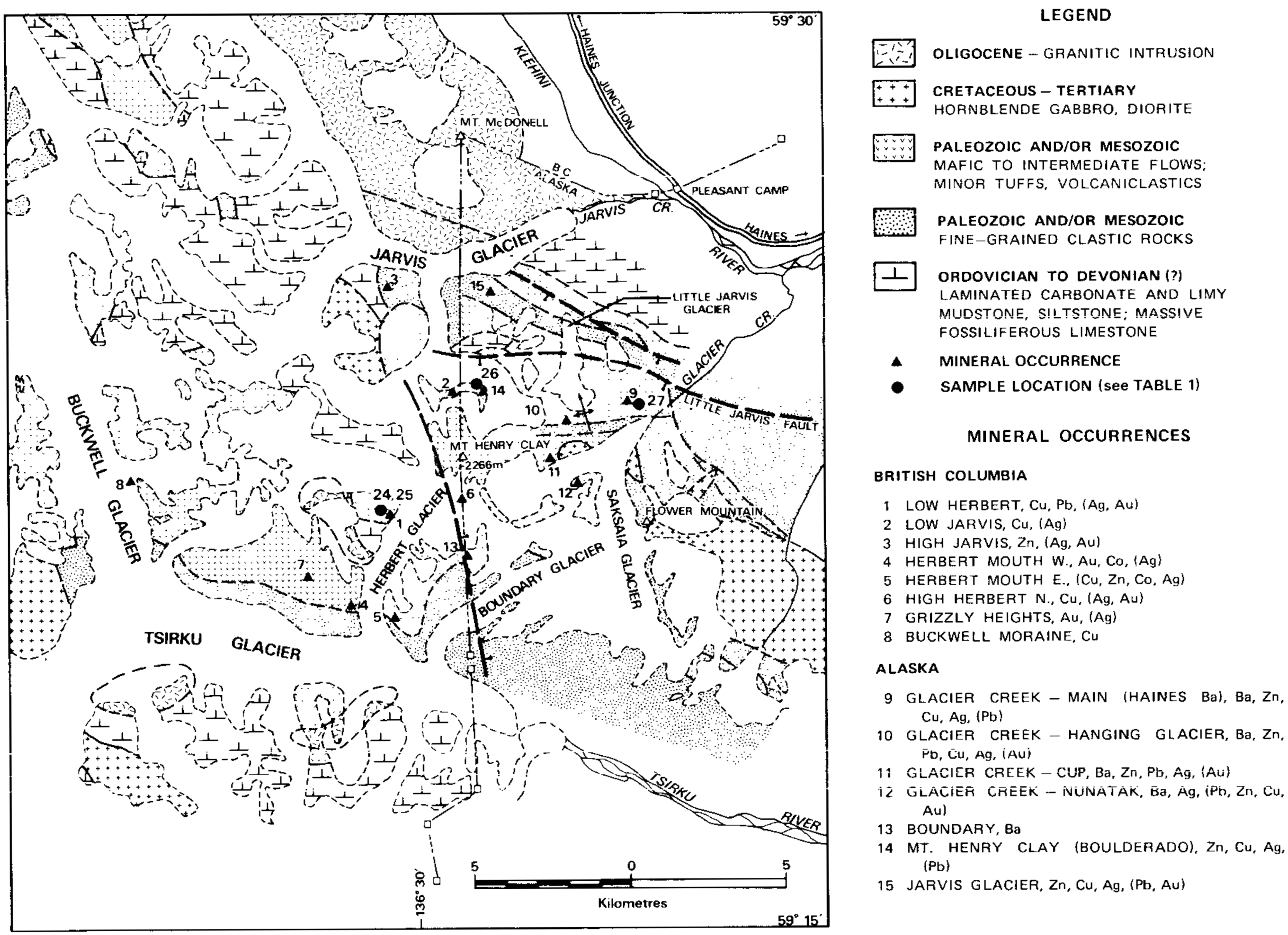

Figure 28-6. Geology and sample locations, Mount Henry Clay area. British Columbia geology after Campbell and Dodds (1983); Alaska geology after Still (1984).

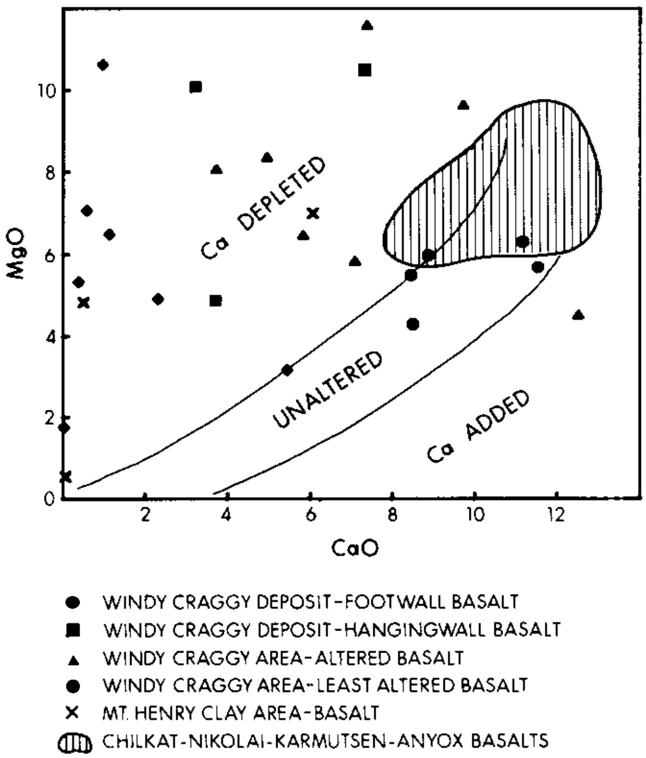

Figure 28-7. MgO versus CaO plot showing unaltered field of Spence (1985).

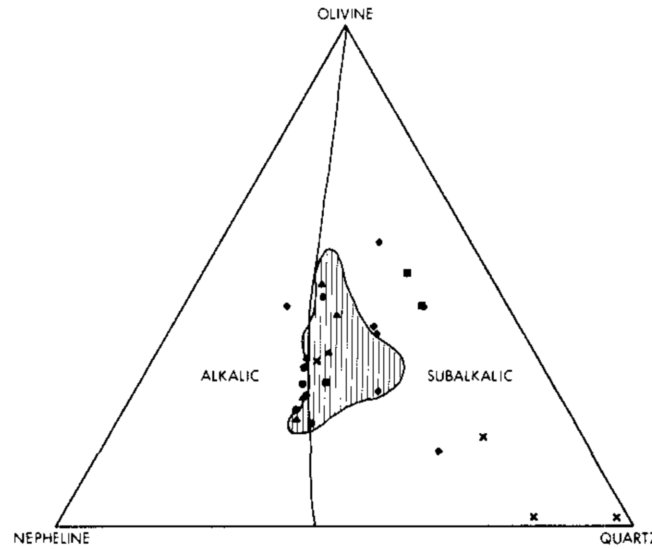

Figure 28-9. Normative olivine-quartz-nepheline ternary plot showing alkalic and subalkalic fields as defined by Irvine and Baragar (1971). *See* Figure 28-7 for explanation of symbols.

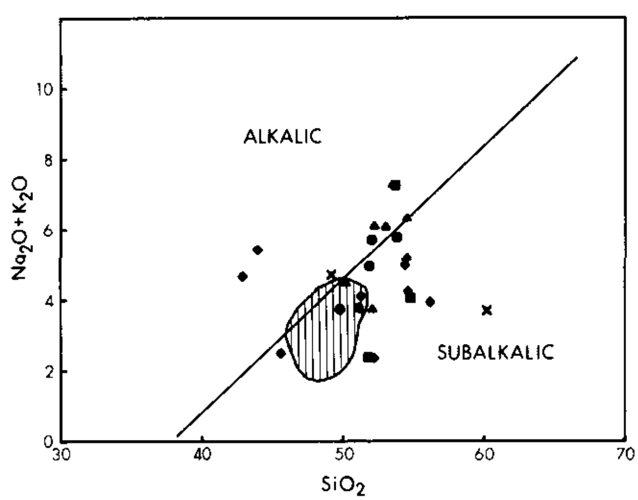

Figure 28-8. Alkalies versus SiO_2 plot showing alkalic and subalkalic fields. Dividing line after MacDonald (1964). *See* Figure 28-7 for explanation of symbols.

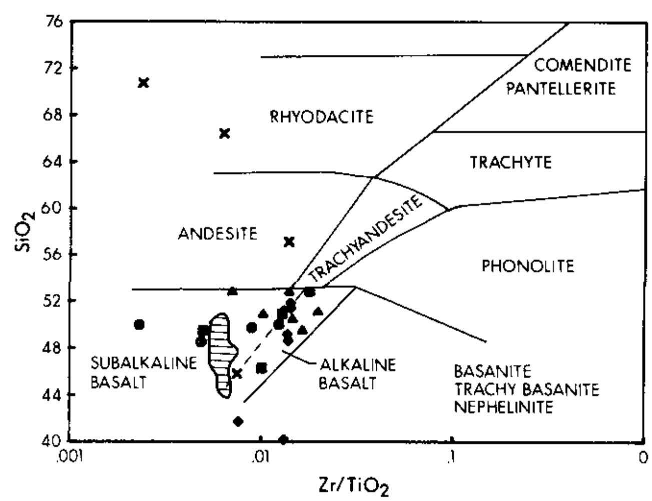

Figure 28-10. SiO_2 versus Zr/TiO_2 plot showing alkalic and subalkalic fields and rock type classification of Floyd and Winchester (1978). *See* Figure 28-7 for explanation of symbols.

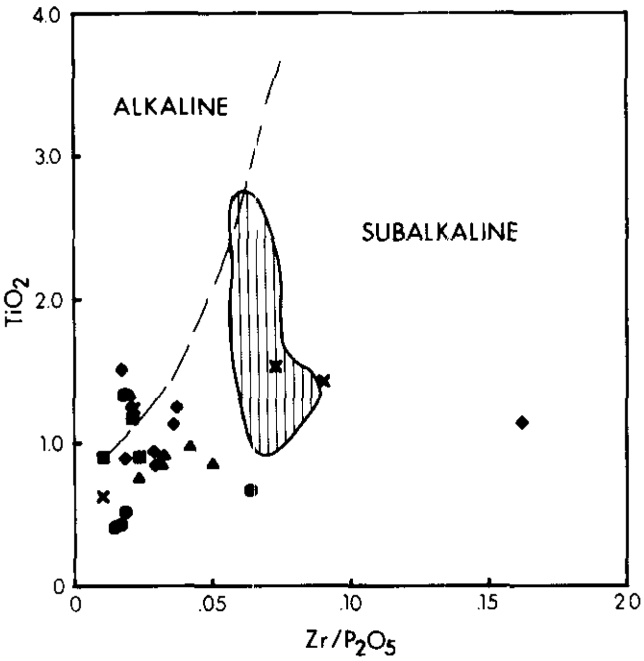

Figure 28-11. TiO_2 versus Zr/P_2O_5 plot showing alkalic and subalkalic fields of Floyd and Winchester (1975). *See* Figure 28-7 for explanation of symbols.

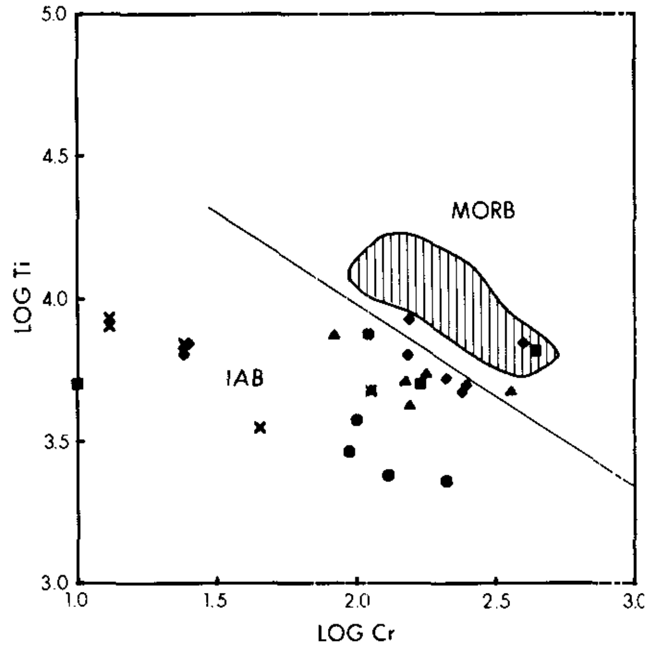

Figure 28-13. Log Ti versus Log Cr showing island arc basalt (IAB) and mid-ocean ridge basalt (MORB) fields of Pearce (1975). *See* Figure 28-7 for explanation of symbols.

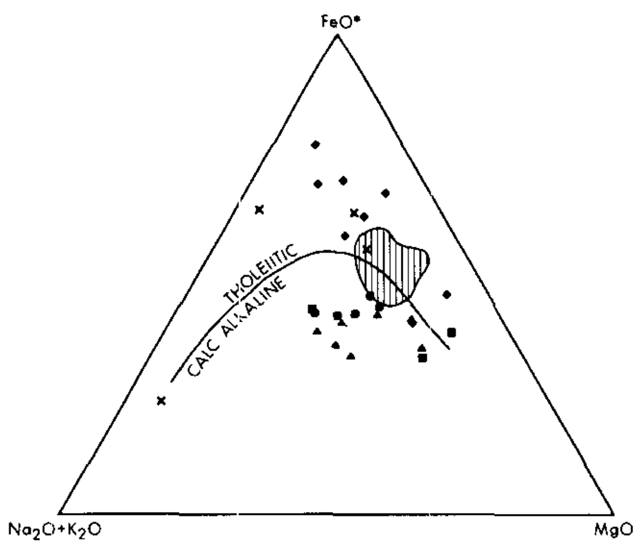

Figure 28-12. Alkalies-total iron as FeO-MgO ternary plot showing calc-alkaline and tholeiitic fields. *See* Figure 28-7 for explanation of symbols.

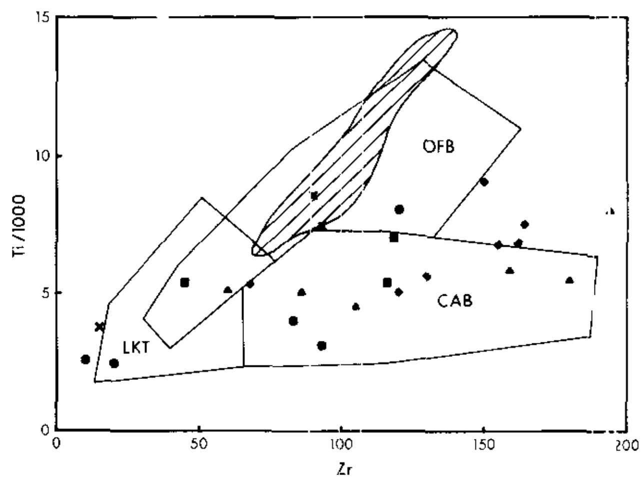

Figure 28-14. Ti/1000 versus Zr plot showing ocean floor basalt (OFB), low-K tholeiite (LKT), and calc-alkaline basalt (CAB) fields of Pearce and Cann (1973). *See* Figure 28-7 for explanation of symbols.

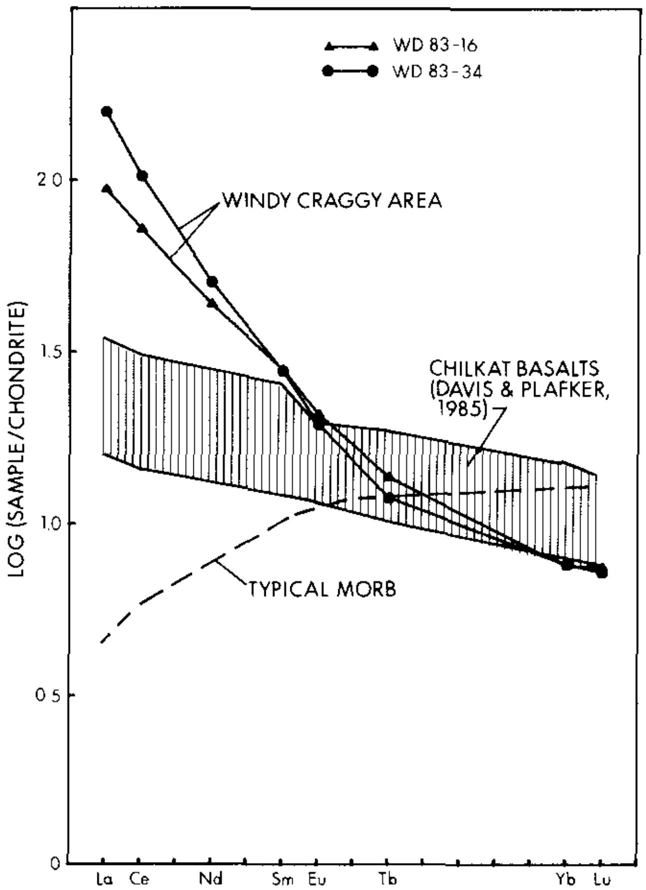

Figure 28-15. Chondrite normalized rare earth plot for two samples from the Windy-Craggy area. Also shown for comparison is the range of values for basalts from the Chilkat Peninsula, Taku terrane (Davis and Plafker, 1985), and a typical sample of MORB.

and to typical MORB. Light rare earth enrichment is characteristic of calc-alkaline and alkaline volcanic rocks (Haskin, *et al.*, 1966; Schilling, 1971; Jakes and White, 1972; Hanson, 1980), therefore the high alkali contents of basalts from the Windy-Craggy area may be a primary feature of these rocks. More rare earth analyses are required, however, to determine if these preliminary observations are applicable to all the basaltic volcanic rocks in the Windy-Craggy and Mount Henry Clay areas.

Tholeiitic basalts such as those from mid-ocean ridges (MORB) are typically depleted in the light rare earths. The Windy-Craggy and Chilkat-Nikolai basalts are enriched in LREE's; clearly they do not belong to this category of basalt.

Saunders and Tarney (1984) used a MORB normalized plot of large ion lithophile (LIL) and high field strength (HFS) elements to examine the chemistry of basalts erupted in back arc basins. Using their plot (Fig. 28-16), samples WD83-16 and WD83-84 show a strong enrichment in LIL elements relative to MORB. The HFS elements and Cr are depleted relative to MORB.

The LIL elements are relatively mobile and can be enriched by low-grade seawater-basalt hydrothermal alteration (Saunders and Tarney, 1984). However, Th is virtually immobile under these conditions and should reflect the primary composition of the basalt. The Th concentrations of the two samples plotted exceeds that of average MORB, suggesting the LIL element enrichment is probably a primary feature and is not due strictly to alteration.

The pattern of LIL element enrichment shown on Figure 28-16 is similar to that observed for calc-alkaline basalts erupted in back arc basins formed in continental crust, such as the Guaymas Basin. Such basins can also contain basalts with MORB-like characteristics. The calc-alkaline basalts are most common in narrow, submarine rift valleys associated with short-lived spreading centres. Such spreading centres are related to transform faulting produced by oblique plate convergence. High LIL element concentrations in basalts of back arc basins may be the result of mantle contamination by LIL element-rich hydrous fluids derived by dehydration of subducted oceanic lithosphere. Alternatively, partial melting of continental crust with concentration of the incompatible LIL elements by magmatic differentiation in shallowly emplaced sills may also be an important process. The latter may be particularly important for Late Triassic volcanic rocks of the Alexander terrane because the magmas apparently rose through a thick section of continental crust that included LIL element-enriched sedimentary rocks, and possibly a Precambrian crystalline basement.

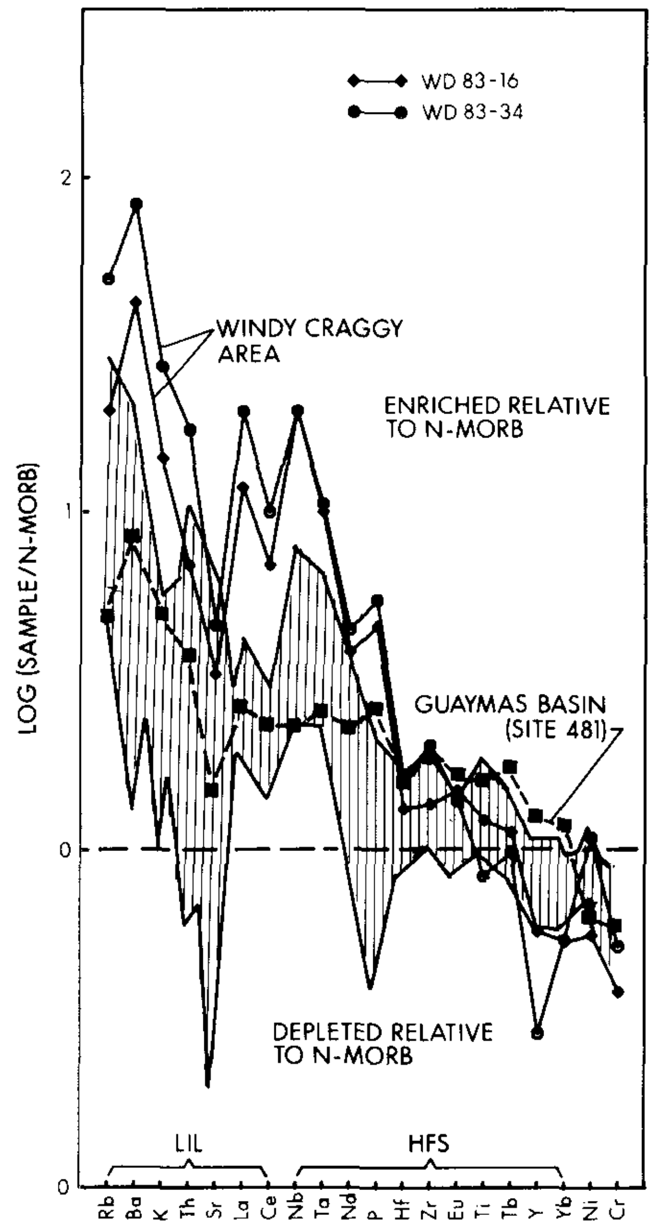

Figure 28-16. Plot showing variation of large ion lithophile (LIL) and high field strength (HFS) elements for samples from the Windy-Craggy area normalized against typical MORB concentrations (*see* Table 28-2). Also shown for comparison is the range of values for samples from the Chilkat Peninsula, Taku terrane (Davis and Plafker, 1985), and a sample of basalt from the Guaymas Basin of the Gulf of California. Plot after Saunders and Tarney (1984).

DISCUSSION

The Wrangellia and Taku basalts are Karnian low K-tholeiites that were extruded in both submarine and subaerial environments with little accompanying sedimentation. The thick and extensive nature of the basalt sequences implies extensive rifting and subsidence accompanied the outpouring of basaltic lava (Carlisle and Susuki, 1974). By contrast, the Alexander terrane was apparently an exposed area during Karnian time, as indicated by erosional conglomerates at the base of the Triassic section in southeast Alaska (Berg, 1973).

In Norian time limestone and calcareous sediments were deposited on the thick basalt sequences of the Wrangellia and Taku terranes, implying a warm, shallow water depositional environment. At the same time, the Alexander terrane was the site of a deep, reducing, sedimentary basin that was characterized by pelagic limestone and turbidite deposition. These turbidites contain abundant carbonate detritus, which may have been derived by erosion of platformal carbonates of adjacent terranes (assuming suturing of these terranes had occurred by this time). Evolution of the basin was accompanied by a progressive increase in volcanic activity, finally culminating in a tremendous outpouring of calc-alkaline to alkaline basalt pillow lavas. This implies the Alexander terrane was the site of subsidence and rifting in Norian time. This rifting may have been restricted to narrow, short-lived spreading centres along a major transform fault system, analogous to the current Gulf of California system.

The abundance of dioritic sills in the Late Triassic section of the Alexander terrane suggests eruption of basalt was accompanied by shallow level injection of basaltic magma into relatively unconsolidated basinal sediments. Slow cooling of these sills probably provided the heat needed to drive the huge hydrothermal system that produced the Windy-Craggy deposit. Positioning of such seafloor hydrothermal vents above subvolcanic sills has been observed in the Guaymas Basin.

Late Triassic felsic fragmental rocks of the Alexander terrane were probably produced by explosive release of LIL element, volatile-rich differentiates from large subvolcanic magma reservoirs. Submarine calderas may have formed in response to this periodic evacuation of the reservoirs; such calderas are common in the Kuroko district of Japan (Ohmoto and Takahashi, 1983). This process was apparently lacking in the Windy-Craggy area and adjacent terranes; there are no felsic fragmental rocks, and no associated polymetallic massive sulphide deposits in these Triassic sections.

If we assume that Wrangellia and the Alexander terrane were sutured by Triassic time, then there is an apparent eastward shift in the location of volcanic eruption centres from Karnian to Norian time. This shift is marked by an eastward compositional change from relatively primitive low-K tholeiites to more highly fractionated calc-alkaline to alkaline volcanic rocks. Similar transitions have been documented in several young island arcs of the southwest Pacific (Kuno, 1966; Garcia, 1978); the implication is that Triassic basalts of Wrangellia and the Alexander terrane represent a similar immature island arc and/or a marginal or back arc basin setting.

SUMMARY

The main conclusions of this paper based on the information available to date are:

(1) Massive sulphide deposits of the Alexander terrane occur in a Late Triassic submarine volcanic sequence that is calc-alkaline to alkaline in composition.

(2) Triassic volcanics of the Wrangellia and Alexander terranes are most likely part of an immature island arc/back arc basin system. Volcanism progressed eastward with time and became progressively more alkaline in composition. Volcanism may have been restricted to narrow rift valleys associated with spreading centres along a transform fault system analogous to that of the present day Gulf of California.

(3) Massive sulphide deposits of the Alexander terrane were formed by hydrothermal systems that developed above subvolcanic sills injected into rift valley sedimentary-volcanic successions. Differentiation of some of these sills resulted in explosive felsic volcanism and formation of polymetallic massive sulphide deposits.

ACKNOWLEDGMENTS

This paper is based on field and laboratory studies completed by the British Columbia Ministry of Energy, Mines and Petroleum Resources (MacIntyre, 1983, 1984; MacIntrye and Schroeter, 1985) in the Tatshenshini (Windy-Craggy) map-area. The author is most grateful to Falconbridge Nickel Mines Limited, Geddes Resources Limited, Stryker-Freeport Resources, and Bear Creek Mining Company for providing logistical support and encouragement for this study. The Geological Survey of Canada generously provided additional geologic data for the Windy-Craggy map-area, plus fossil identifications. Jan Still of the United States Bureau of Mines and Henry Berg of the United States Geological Survey also provided valuable information on southeast Alaska geology and mineral occurrences. Joe Fox (I.R.E.M./M.E.R.I., Montreal) kindly provided immobile and rare earth analyses of rocks collected from the area.

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STRATIGRAPHY AND STRUCTURE IN THE ANYOX AREA (103P/5)

By D. J. Alldrick

INTRODUCTION

This report summarizes preliminary results of a mapping project in sedimentary strata of the Anyox pendant between May 27 and June 6, 1985. The objectives of the program are to:

(1) Study the sedimentary section for marker horizons that may outline present structure and for facies relationships that may indicate paleotopography in the underlying volcanic rocks.
(2) Compare the sulphide-bearing ore horizon chert to strata-bound, sulphide-bearing 'quartz veins' reported within the sedimentary strata.
(3) Sample chert and carbonate sedimentary rocks for fossil studies.

OTHER RESEARCH

The most recent report on the Anyox area is also the most comprehensive. R. J. Sharp completed a Master's thesis at the University of Alberta, Edmonton, in 1980. The research focused on three of the deposits in the area but the thesis also presents a major review of the regional geology and an extensive bibliography.

D. G. MacIntyre (this volume) compared petrochemistry of several Triassic volcanic sequences in the Insular Tectonic Belt. F. V. Kirkham, at the Geological Survey of Canada, is compiling lead isotope data for volcanogenic massive sulphide deposits throughout Canada. Both these studies include data or samples provided from Sharp's work.

STRATIGRAPHY

Schematic stratigraphic columns are illustrated on Figure 29-2, which also shows the stratigraphic position of five major mineral deposits.

VOLCANIC SEQUENCE

Sharp (1980) describes lithologies within the volcanic sequence as predominantly pillowed tholeiitic basaltic flows with subordinate fragmental and tuffaceous layers. The fragmental strata may include tectonic, explosion, pillow, flow top and fault scarp breccias, and volcaniclastic conglomerates. Tuffaceous strata are preserved as chloritic schists. Pelitic rocks are locally interbedded; these form the host rock strata at the Double Ed deposit.

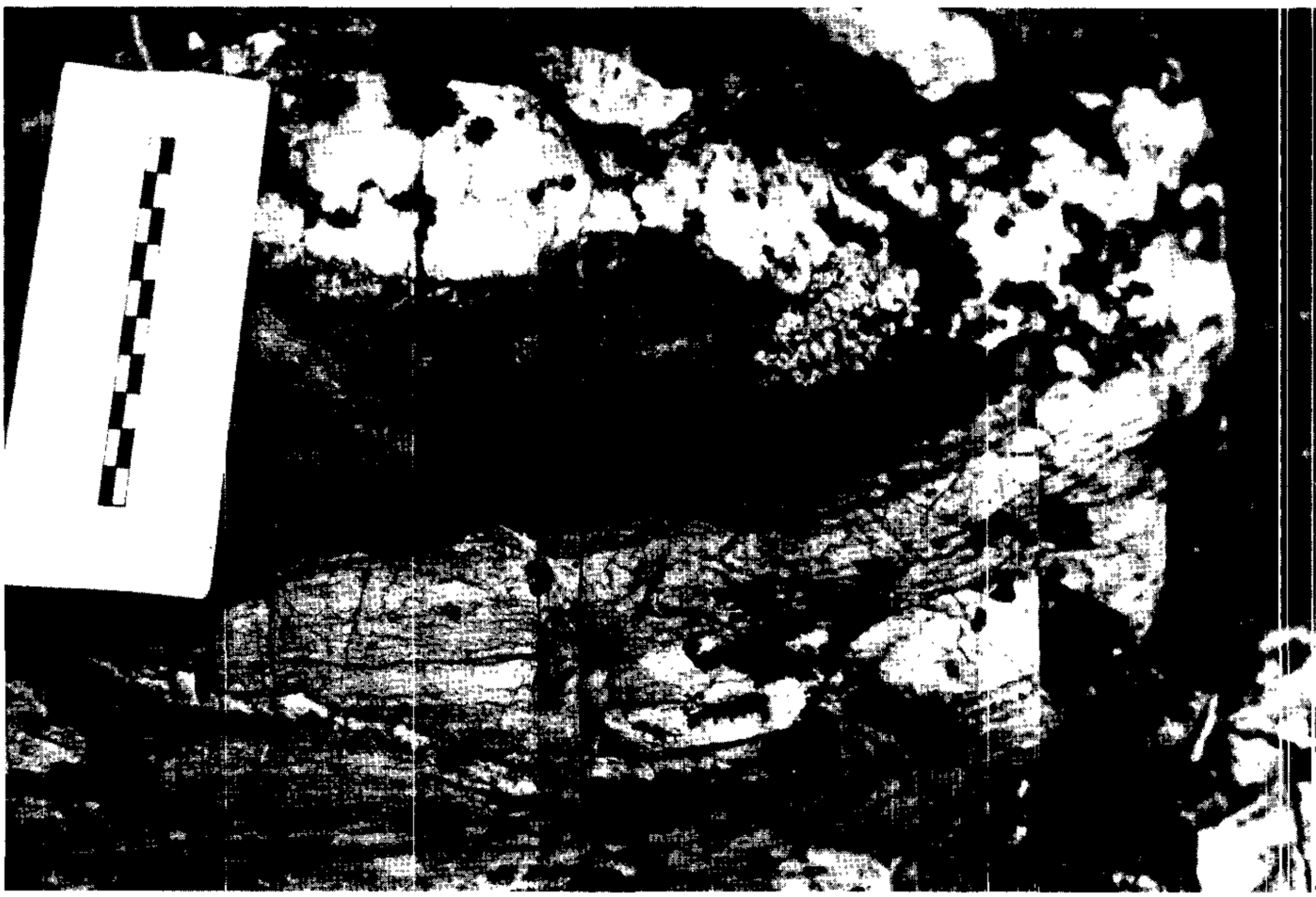

Plate 29-1. Bull quartz vein and foliated chert, 1.5 kilometres southwest of Hidden Creek mine. Scale bar 10 centimetres.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.