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THE GEOCHEMISTRY OF EARLY CRETACEOUS VOLCANIC ROCKS ON THE WEST SIDE OF HARRISON LAKE, SOUTHERN BRITISH COLUMBIA (92H/12)

By G.E. Ray

KEYWORDS: Lithogeochemistry, Brokenback Hill Formation, Gambier assemblage, Fire Lake Group, arc volcanism, volcaniclastics.

INTRODUCTION

This paper presents analytical data on 21 representative samples of volcanic and volcaniclastic rocks collected from the Early Cretaceous Brokenback Hill Formation on the west side of Harrison Lake. The area lies approximately 100 kilometres east-northeast of Vancouver and 45 kilometres north-northeast of Harrison Hot Springs (Figure 1-4-1), close to vein-hosted gold-silver mineralization at Doctors Point and the small, abandoned Providence mine (Ray *et al.*, 1984, 1985).

REGIONAL GEOLOGY

The Harrison Lake fault system is a major dislocation exceeding 100 kilometres in length that passes through Harrison Lake (Figure 1-4-1). It separates rocks of contrasting geological settings (Roddick, 1965; Monger, 1970). To the northeast are highly deformed, largely supracrustal rocks that were originally called the Slollicum series (Crickmay, 1925, 1930) but which are now termed the Slollicum package (Monger, 1986). These schistose rocks are penetratively deformed and regionally metamorphosed to greenschist and lower amphibolite facies (Journeay and Csontos, 1989); they may be metamorphosed equivalents of the Late Triassic Cadwallader Group (Monger, 1986). With the exception of the Chilliwack-Cultus package, which outcrops south of the lake, rocks on the southwest side of the fault are younger, less deformed and of lower metamorphic grade. They include a variety of volcanic, volcaniclastic and sedimentary rocks of largely Jura-Cretaceous age, as well as some plutonic and migmatitic rocks.

The southwest part of the area, west of Harrison Lake, is underlain by the Lower to Middle Jurassic Harrison Lake Formation (Crickmay, 1925; Arthur, 1986). This formation is a sequence of intermediate to acid volcanic flows and pyroclastics that hosts the Seneca copper-zinc massive sulphide deposit (Watanabe, 1974; Urabe *et al.*, 1983). To the north are Middle to Upper Jurassic sediments and tuffs of the Mysterious Creek and Billhook Creek formations which are unconformably overlain by a sequence of Lower Cretaceous rocks. The thin, lowermost portion of this Cretaceous sequence is occupied by sediments of the Peninsula Formation; these pass conformably upward into the Brokenback Hill Formation. Journeay and Csontos (1989) and Lynch (1990) correlate the latter formation as part of the Fire Lake Group (Roddick, 1965), which lies at the north end of Harrison Lake; Wheeler and McFeely (1987) place both these packages within the Gambier assemblage. The Brokenback Hill Formation on the west side of Harrison Lake comprises the volcanic rocks which are the subject of this paper, as well as tuffs and a variety of sediments that range in age from upper Valanginian to middle Albian (Ray *et al.*, 1985; Arthur, 1986). The upper part of this formation to the north is intruded by several high-level, dioritic plutons (Figure 1-4-2) of mid-Tertiary age that are associated with auriferous vein mineralization at Doctors Point. Approximately 5 kilometres south of Doctors Point, on the shoreline of Harrison Lake, the old Providence mine contains both gold-bearing quartz veins and gold-poor, silver-rich quartz-carbonate veins. Minor gold production came from the quartz veins at the turn of the century (B.C. Minister of Mines Annual Reports; 1897, 1901). The steeply dipping silver-rich veins are up to 0.7 metre thick and are hosted by basaltic flows and tuffs of the Brokenback Hill Formation (Ray *et al.*, 1985).

The Harrison Lake fault is associated with a deformation zone 1 to 2 kilometres wide, marked by an intense slaty cleavage and gently plunging linear stretch fabrics (Arthur, 1986). The fault has had a long history of recurrent thrust, strike-slip and normal fault movements that ended prior to development of the Fraser fault system during Eocene time (Monger, 1986; Journeay and Csontos, 1989).

GEOLOGY OF THE BROKENBACK HILL FORMATION, AND SAMPLE LOCATIONS

The locations of samples collected for geochemical analysis are shown on Figure 1-4-2. Between Doctors Point and the Providence mine, the Brokenback Hill Formation dips northeasterly. Bedding and fracture cleavage intersections indicate that this section occupies the northeastern limb of a major northerly trending anticline; there is no evidence of structural repetition and graded bedding shows the sequence is upright. Consequently, rocks between Providence mine and Doctors Point are considered to form part of a continuous, northerly younging sequence. Mafic volcanic flows and tuffs predominate in the lower, more southerly part of the section. Farther north, however, toward Doctors Bay, flows are uncommon, and the abundant tuffs are interbedded with black argillite, volcanic sandstone, siltstone, and rare, thin beds of polymictic conglomerate. Locally, the siltstones contain graded bedding, argillite rip-up clasts, soft-sediment deformation features, load casts and chaotic slump structures.

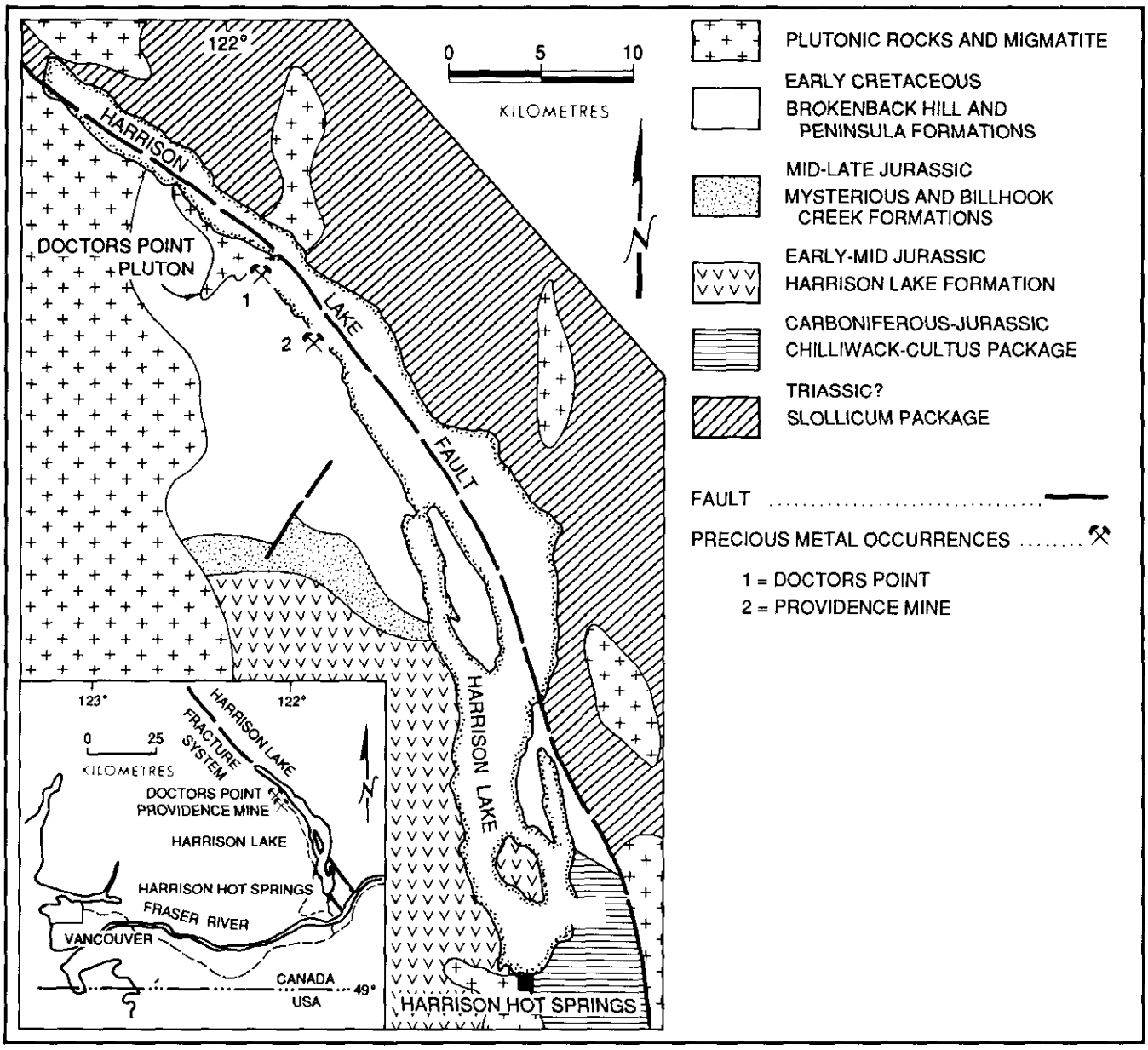

Figure 1-4-1. Regional geology of the Harrison Lake area and location of the Doctors Point and Providence mine mineralization in the sampled area (adapted after Roddick, 1965; Monger, 1970;1986, Arthur, 1986).

The volcaniclastic rocks throughout the section vary from massive to thinly bedded crystal-lithic tuffs and lapilli tuffs, through to chaotic, coarse volcanic breccias and aquagene breccias containing abundant angular to subangular clasts up to 15 centimetres in diameter. Most of the clasts are basalt and andesite, although some fragments in the upper part of the succession are dacitic. The mafic aquagene breccias are characterized by rounded clots of carbonate rimmed with epidote, and most of the tuffs and flows are strongly chloritized.

The varied character of the sedimentary and volcaniclastic rocks in the Brokenback Hill Formation suggests it was deposited during alternating episodes of low and high-energy sedimentation with some periodic explosive volcanic activity.

The volcanic rocks are generally massive; pillowed flows have only been identified in the lower part of the succession, close to the Providence mine. Individual pillows are vesicular and reach 75 centimetres in diameter. The more mafic flows contain altered remnant crystals of augite up to 4 millimetres in length that enclose interlocking laths of andesine-labradorite plagioclase. Alteration products include chlorite, epidote and tremolite-actinolite. Some basaltic rocks with abundant coarse plagioclase phenocrysts up to 0.5 centimetre in diameter may represent subvolcanic intrusions.

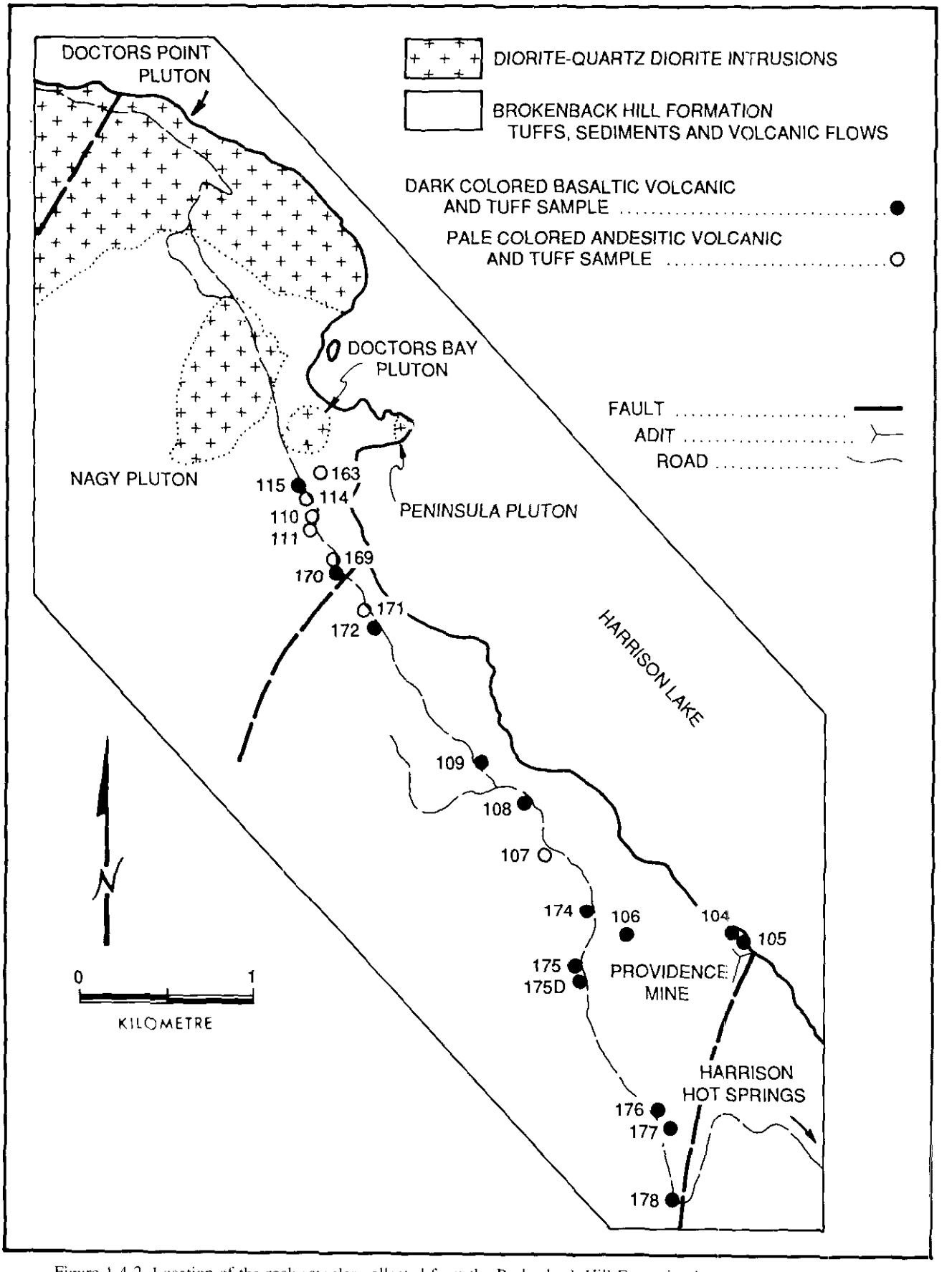

Figure 1-4-2. Location of the rock samples collected from the Brokenback Hill Formation between Doctors Point and Providence mine. (Numbers refer to sample numbers in Table 1-4-1).

TABLE 1-4-1
ANALYTICAL RESULTS OF VOLCANIC AND VOLCANICLASTIC SAMPLES, DOCTORS POINT, BRITISH COLUMBIA

Sample No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3*	MnO	MgO	CaO	Na_2O	K_2O	LOI	TOTAL	Y	Zr
RR 104	47.75	1.04	19.33	9.75	0.35	4.28	7.82	2.48	1.73	4.6	99.13	20	51
RR 105	45.69	0.93	14.95	9.99	1.01	2.39	7.41	0.80	6.65	8.7	98.52	20	45
RR 106	53.44	0.71	17.91	9.05	0.19	3.68	6.49	2.55	0.58	5.1	99.70	18	72
RR 108	46.96	1.07	18.29	10.72	0.26	5.47	11.12	2.02	0.14	3.8	99.85	20	66
RR 109	56.15	0.90	19.34	7.37	0.13	1.85	7.76	3.67	1.53	1.5	100.20	24	84
RR 115	53.40	1.42	16.06	13.19	0.34	4.13	7.35	3.19	0.54	0.9	100.52	24	66
RR 170	53.36	0.95	17.12	7.35	0.12	4.70	6.72	4.01	1.15	5.1	100.58	18	120
RR 172	56.07	0.75	17.13	7.65	0.14	3.84	7.98	2.77	0.68	2.6	99.61	16	63
RR 174	48.58	1.03	19.31	9.95	0.50	5.25	6.12	2.87	0.43	5.7	99.74	18	45
RR 175	50.69	0.81	18.47	10.12	0.17	4.73	6.84	3.38	0.58	4.1	99.89	16	39
RR 176	50.66	0.81	18.57	8.98	0.25	3.00	10.36	2.39	0.62	4.9	100.54	16	42
RR 177	52.38	1.19	19.08	9.12	0.18	3.29	7.11	4.36	0.28	3.6	100.59	20	60
RR 178	48.29	0.94	18.15	11.32	0.20	5.06	9.91	1.18	0.54	5.2	100.79	16	36
RR 175D	51.08	0.80	18.42	10.07	0.18	4.79	6.88	3.39	0.56	4.3	100.47	18	39
RR 107	59.07	0.78	16.82	6.47	0.17	3.47	5.24	2.89	0.94	4.6	100.45	26	90
RR 110	53.11	0.96	18.76	9.15	0.12	4.18	5.52	3.41	0.62	4.4	100.23	22	72
RR 111	61.82	0.79	18.06	7.32	0.13	2.09	4.07	2.79	1.14	2.5	100.71	26	100
RR 114	62.02	0.81	17.61	7.30	0.13	2.08	4.13	2.72	1.13	2.5	100.43	26	90
RR 163	62.12	1.21	17.69	8.70	0.16	1.70	2.01	2.62	1.83	2.3	100.34	42	160
RR 169	61.87	0.80	16.52	6.64	0.04	2.74	0.83	0.08	4.93	3.9	98.35	28	140
RR 171	61.01	0.86	17.16	7.27	0.06	3.67	1.49	1.00	3.25	4.1	99.87	28	130

* Total iron expressed as Fe_2O_3

Y and Zr in ppm; all other values in per cent.
Analytical methods used for data in Table 1-4-1.
Major elements by flame AAS. Precision for major and trace elements averages 5-10% relative error, depending on element concentration.
LOI calculated by heating predried samples to 1050°C for 2 hours.
Y and Zr by XRF.
Y and Zr analyses completed by X-Ray Laboratories Ltd., Don Mills, Ontario.
All other analyses in Table 1-4-1, completed at the B.C. Ministry of Energy, Mines and Petroleum Resources Laboratory, Victoria.

SAMPLE DESCRIPTIONS (for locations see Figure 1-4-2)

Dark colored volcanic and tuff samples, generally of basaltic composition.

RR 104 – Mafic, vesicular, pillowed volcanic.
RR 105 – Mafic, chloritized aquagene breccia.
RR 106 – Chloritized volcanic. Ophitic-textured plagioclase crystals up to 3 millimetres long; original pyroxenes replaced by chlorite.
RR 108 – Mafic volcanic. Ophitic-textured plagioclase (An_{62}) with chloritized amphibole; minor epidote and carbonate.
RR 109 – Coarse feldspar porphyry flow or subvolcanic intrusion. Plagioclase phenocrysts up to 5 millimetres long with minor hornblende.
RR 115 – Mafic, massive volcanic. Ophitic textures; altered amphibole.
RR 170 – Mafic, chloritized volcanic. Minor epidote.
RR 172 – Mafic crystal-lapilli tuff.
RR 174 – Crystal tuff. Abundant plagioclase crystals with minor amphibole.
RR 175 – Fresh crystal tuff. Abundant plagioclase with some augite crystals up to 5 millimetres long.
RR 176 – Chloritized crystal tuff. Abundant altered plagioclase with some augite and remnant amphibole crystals.
RR 177 – Chloritized crystal tuff. Minor epidote and carbonate.
RR 178 – Chloritized crystal tuff. Minor epidote.
RR 175D – Altered crystal tuff containing some augite crystals.

Pale colored volcanic and tuff samples, generally of andesitic compositon.

RR 107 – Altered crystal tuff with minor veinlets of tremolite-actinolite.
RR 110 – Unaltered crystal-lapilli tuff. Fresh volcanic fragments up to 8 millimetres in diameter.
RR 111 – Silicious lapilli tuff. Chloritized volcanic fragments up to 5 millimetres in diameter.
RR 114 – Weakly hornfelsed lapilli tuff with abundant andesitic volcanic clasts and rare dacitic fragments.
RR 163 – Silicious, hornfelsed crystal tuff.
RR 169 – Silicious bedded crystal tuff. Minor pyrite.
RR 171 – Silicious crystal-lapilli tuff. Abundant fresh andesite volcanic fragments.

The appearance of the volcanic and tuffaceous rocks changes from north to south up the Brokenback Hill Formation stratigraphic sequence. In the southern, more basal section the volcanics are mafic, but higher in the sequence, toward Doctors Bay, they are pale grey coloured and generally more silicious (Figure 1-4-2); these pale rocks were originally mapped as dacites by Ray *et al.* (1985), but this work indicates they are andesites.

CHEMISTRY OF THE VOLCANIC ROCKS

Analytical results for the major oxides, ytrium and zirconium are shown in Table 1-4-1. The samples analysed comprise seven from volcanic flows and fourteen from volcaniclastic rocks. Fourteen of the samples represent mafic volcanics and tuffs from the lower part of the succession, and the remaining seven samples are paler coloured

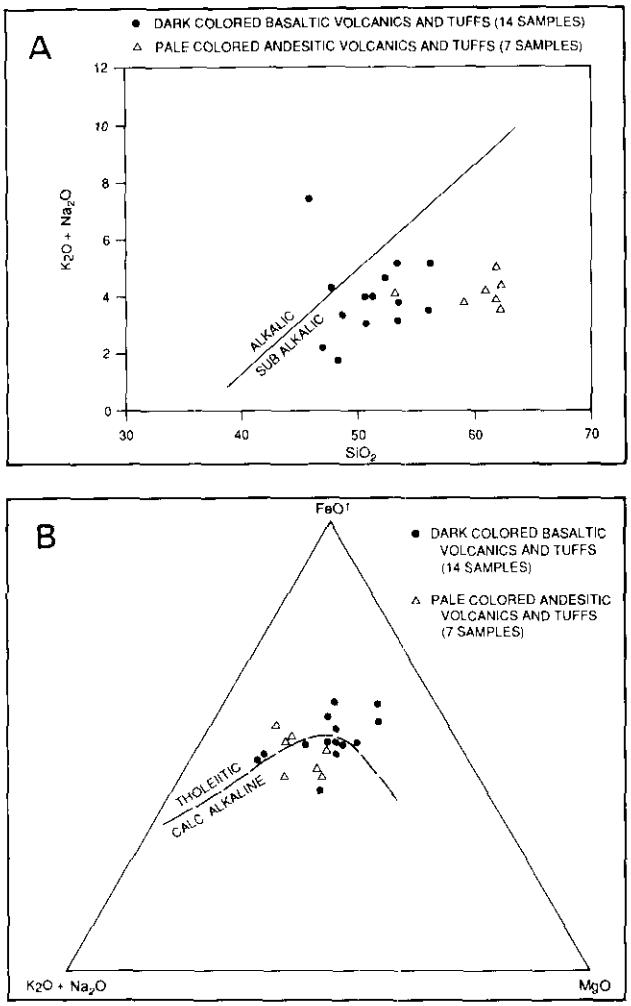

Figure 1-4-3. (A) Alkali versus silica plot (after MacDonald, 1968; Irvine and Barager, 1971) illustrating the subalkalic nature of volcanic and tuffaceous rocks, Brokenback Hill Formation. (B) AFM plot of the volcanic and tuffaceous rocks, Brokenback Hill Formation.

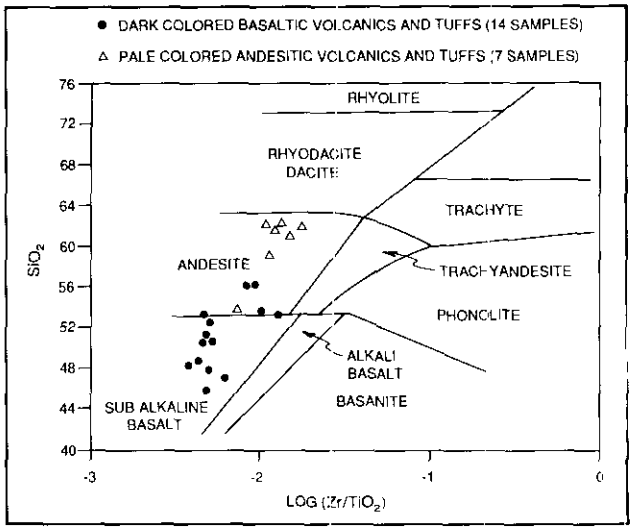

Figure 1-4-4. Plot of SiO_2 versus log(Zr/TiO_2) (after Floyd and Winchester, 1978) illustrating the subalkaline basaltic and andesitic compositions of the volcanic and tuffaceous rocks, Brokenback Hill Formation.

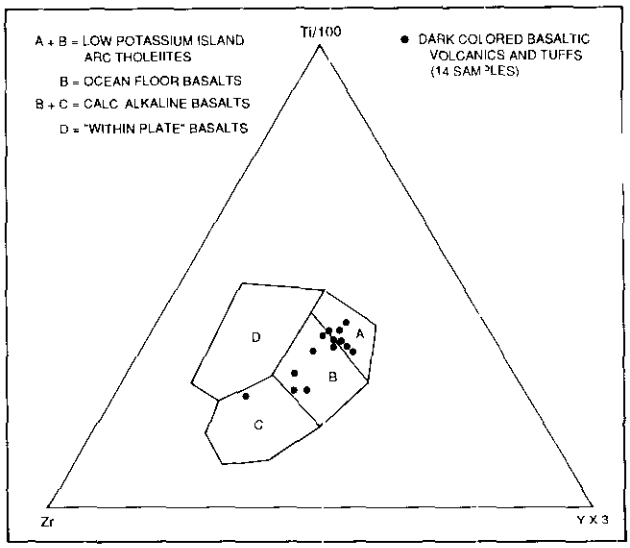

Figure 1-4-5. Zr-Ti-Y plot (after Pearce, 1975) of the volcanic and tuffaceous rocks, Brokenback Hill Formation.

rocks in the upper part of the sequence (Figure 1-4-2; Table 1-4-1).

An alkali/silica plot of the data (Figure 1-4-3A) indicates the majority of the samples are subalkalic while an AFM plot (Figure 1-4-3B) suggests they are of tholeiitic to transitional calcalkaline affinity. Figure 1-4-4 shows that the mafic volcanics in the lower section of the Brokenback Hill Formation are subalkaline basalts while the pale grey rocks originally believed to be dacites (Ray *et al.*, 1985) are subalkalic andesites. The stratigraphic variation in the composition probably marks an original progressive temporal change from basaltic to andesitic volcanism due to differentiation. A discrimination plot (Figure 1-4-5) suggests the basaltic rocks are low-potassium island-arc tholeiites.

CONCLUSIONS

The Early Cretaceous Brokenback Hill Formation on the west side of Harrison Lake contains two compositional suites of volcanic rocks. The lower part of the formation is dominated by mafic, subalkaline basalts; they largely represent low-potassium arc tholeiites that were probably erupted in an island-arc environment. Higher in the formation, volcanic flows are subordinate to tuffs and sediments. These volcanics, which were previously incorrectly described as dacites, are subalkaline andesites of transitional tholeiitic to calcalkaline affinity. The change up the succesion from basalt to andesite probably reflects volcanic differentiation during arc volcanism.

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REFERENCES

Arthur, A.J. (1986): Stratigraphy along the West Side of Harrison Lake, Southwestern British Columbia; *in* Current Research, Part B, *Geological Survey of Canada*, Paper 86-1B, pages. 715-720

Crickmay, C.H. (1925): The Geology and Paleontology of the Harrison Lake District, British Columbia, together with a General Review of the Jurassic Faunas and Stratigraphy of Western North America; unpublished, Ph.D. thesis, *Stanford University, 140* pages.

Crickmay, C.H. (1930): The Structural Connection between the Coast Range of British Columbia and the Cascade Range of Washington; *Geological Magazine*, Volume 67, pages 482-491.

Floyd, P.A. and Winchester, J.A. (1978): Identification and Discrimination of Altered and Metamorphosed Volcanic Rocks Using Immobile Elements; *Chemical Geology*, Volume 21, pages 291-306.

Irvine, T.N. and Baragar, W.R.A. (1971): A Guide to the Chemical Classification of the Common Volcanic Rocks; *Canadian Journal of Earth Sciences*, Volume 8, pages 523-547.

Journeay, J.M. and Csontos, L. (1989): Preliminary Report on the Structural Setting along the Southeast Flank of the Coast Belt, British Columbia; *in* Current Research, Part E, *Geological Survey of Canada*, Paper 89-1E, pages 177-187, 1989.

Lynch, J.V.G. (1990): Geology of the Fire Lake Group, South East British Columbia; *in* Current research, Part E, *Geological Survey of Canada*, Paper 90-1E, pages 197-205.

MacDonald, G.A. (1968): Composition and Origin of Hawaiian Lavas; *Geological Society of America*, Memoir 116, pages 477-522.

Monger, J.W.H. (1970: Hope Map-area, West Half (92H W1/2), British Columbia; *Geological Survey of Canada*, Paper 69-47, 75 pages.

Monger, J.W.H. (1986): Geology between Harrison Lake and Fraser River, Hope Map Area, Southwestern British Columbia; *in* Current Research, Part B, *Geological Survey of Canada*, Paper 86-1B, pages 699-706.

Pearce, J.A. (1975): Basalt Geochemistry Used to Investigate Past Tectonic Environments on Cyprus; *Tectonophysics*, Volume 25, pages 41-67.

Ray, G.E., Coombes, S. and White G. (1984): Harrison Lake Project (92H/5, 12; 92G/9); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1983, Paper 1984-1, pages 42-53.

Ray, G.E., Coombes, S., MacQuarrie, D.R., Niels, R.J.E., Shearer, J.T. and Cardinal, D.G. (1985): Precious Metal Mineralization in Southwestern British Columbia; *Geological Society of America*, Field Trip 9, Guidebook, pages 9-1 to 9-31.

Roddick, J.A. (1965): Vancouver North, Coquitlam and Pitt Lake Map-area, British Columbia; *Geological Survey of Canada*, Memoir 335, 276 pages.

Urabe, T., Scott, S.D. and Hattori, K. (1983): A Comparison of Footwall-rock Alteration and Geothermal Systems beneath some Japanese and Canadian Volcanogenic Massive Sulphide Deposits; *Economic Geology*, Monograph 5, pages 345-364.

Watanabe, R.Y. (1974): Seneca Deposit, an Example of Kuroko Mineralization; *Geological Association of Canada*, Cordilleran Section, Program and Abstracts, page 2.

Wheeler, J.O. and McFeely, P. (1987): Tectonic Assemblage Map of the Canadian Cordillera; *Geological Survey of Canada*, Open File 1565.