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POTENTIAL FOR KUTCHO CREEK VOLCANOGENIC MASSIVE SULPHIDE MINERALIZATION IN THE NORTHERN CACHE CREEK TERRANE: A PROGRESS REPORT

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INTRODUCTION

New geochronologic and geochemical data from the volcanic Kutcho Formation enclosing the Kutcho Creek volcanogenic massive sulphide deposit, call for a reevaluation of the age and tectonic affiliation of these rocks. This dominantly bimodal volcanic succession was previously considered part of a calc-alkaline arc complex of Upper Triassic age (Rb-Sr 210 ±10 Ma; Thorstad and Gabrielse, 1986). More recently, Childe and Thompson (1995) obtained U-Pb zircon age dates from rhyolite at the deposit which are Late Permian (*circa* 249 Ma); approaching the Permian age (275 ±15 Ma) originally reported by Panteleyev and Pearson (1977). Barrett *et al.* (in press) reported major oxide and rare earth element analyses from a select suite of Kutcho Formation rocks showing them to have tholeiitic affinities, indicative of a rifted intra-oceanic setting, probably in a forearc environment.

Potential Kutcho Formation correlatives to the south include the Sitlika Assemblage near Takla Lake (Schiarizza and Payie, 1997), which may originally have formed in a belt contiguous with the Kutcho Formation prior to dextral offset and crustal shortening on major faults (Gabrielse, 1990). Both Kutcho and Sitlika rocks sit within the oceanic Cache Creek Terrane (Wheeler *et al.*, 1991), yet contain felsic volcanic rocks. In fact, coeval and lithologically identical rocks occur within the Cache Creek Terrane far to the south, near Ashcroft (Childe *et al.*, 1997; Figure 1 inset).

Correlations with strata of the Cache Creek terrane north of the Kutcho area had not been made despite the fact that more than half of the area underlain by Cache Creek terrane rocks occurs in the large, pie-shaped, crustal block thatextends northwest from its apex at Kutcho Creek (here called the northern Cache Creek Terrane). Permian volcanic strata are known within northern Cache Creek Terrane, where they have been mapped as the French Range Formation by Monger (1969, 1975) and Gabrielse (1994). Moreover, Monger (1969) notes a quartz-bearing lapilli tuff in the French Range, which, like the silicic Kutcho Formation, is unexpected within the Cache Creek oceanic assemblage. Since silicic volcanic rocks exist in the northern Cache Creek terrane, it is possible that coexisting volcanogenic

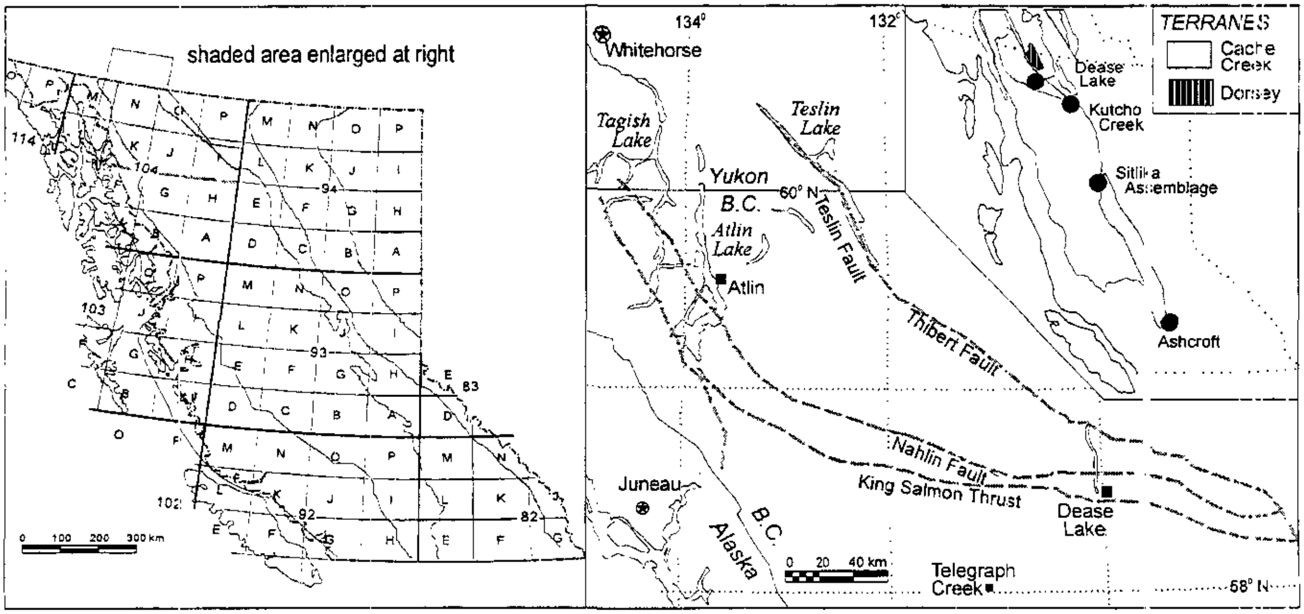

Figure 1. NTS and physiographic location of, and major structural elements bounding, the Northern Cache Creek terrane. The inset shows the distribution Cache Creek Terrane rocks and locations of potentially correlative Late Permian felsic volcanic strata.

massive sulphide (VMS) deposits also occur.

Lack of exploration for Kutcho-style VMS deposits in northern Cache Creek Terrane (especially the eastern belt) results from a combination of factors, not the least of which is the lack of recognition of silicic volcanic rocks in this region. Another factor is relatively subdued topography, and therefore, poor exposure. Poor exposure leads to muted and spatially restricted geochemical responses. In fact, the entire Dease Lake sheet (104J) lacks regional geochemical survey coverage because its subdued topography makes it a less appropriate survey candidate than adjacent, more mountainous areas. Without the benefit of geochemical dispersion, notoriously small (but rich) VMS deposits are difficult targets, especially in the expanse of Northern Cache Creek terrane which, except near Atlin or Dease Lake, is largely inaccessible. As well, prior to 1996, much of northern Cache Creek Terrane was covered by the Kawdy-Level Mountain Protected Area Study area, which was drastically reduced in size in 1996 (Figure 2, inset). Given these factors, a reconnaissance field program was undertaken in 1996. Known as the French Range project, its principal objective is to evaluate the potential for VMS deposits in northern Cache Creek Terrane. During the course of field studies the presence of quartz-bearing tuffs was confirmed, and previously unreported ignimbritic rhyodacite tuff was discovered in the French Range. Preliminary stratigraphic, structural, lithogeochemical and paleontologic data are presented here.

"STRATIGRAPHY"

Current knowledge of French Range Formation and Teslin Formation stratigraphy stems primarily from the work of Monger (1969, 1975) who named them while investigating Paleozoic successions throughout northern Cache Creek Terrane. Monger showed that these rocks, mainly confined to a belt along the terrane's northeastern margin, display a relatively coherent internal stratigraphy, and a restricted age range of Early to Late Permian. They appear to sit structurally and, in some cases, stratigraphically above hemipelagites of the Kedahda Formation, which contains fossils as old as Early Carboniferous. Interpretation and nomenclature is coplicated by depositional interfingering and enclosure of one formation by another, and subsequent. An eloquent discussion of these problems is presented by Monger (1975).

Investigations during the 1996 field season focused briefly on five localities between Dease Lake and the Yukon border (Figure 2). Observations presented here augment those of Monger (1969, 1975) who presents more comprehensive descriptions.

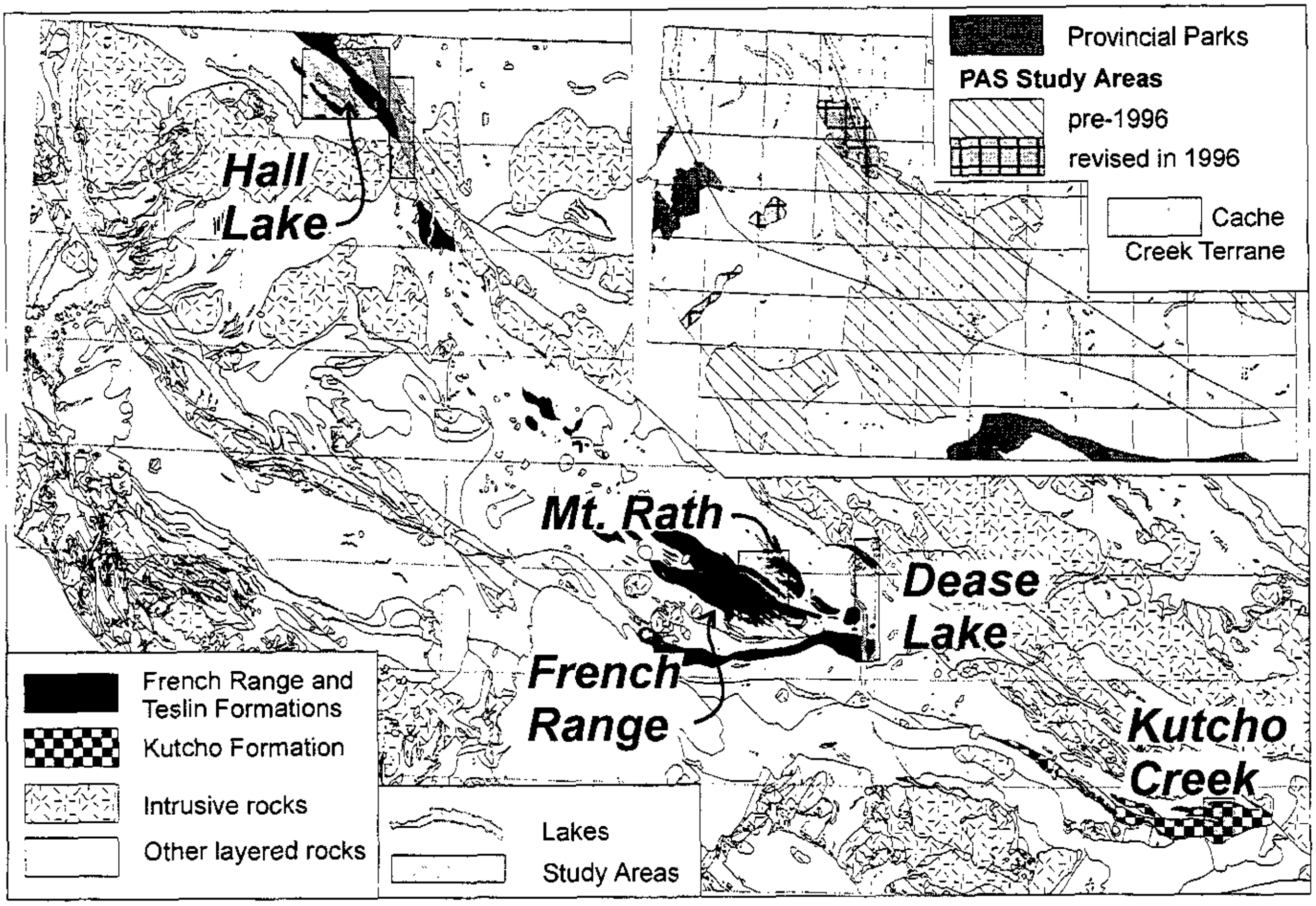

Figure 2. Distribution of the French Range and Kutcho Formations in northern Cache Creek Terrane (modified from Mihalynuk *et al.*, 1996; terrane limits are shown shaded in inset), and study areas visited as part of the French Range Project. Parks and Protected Area Strategy study areas are also shown in the inset.

Teslin Lake

Teslin Lake is occupied by the Teslin Fault (Figure 1) which juxtaposes the Cache Creek and Dorsey terranes (e.g. Wheeler *et al.*, 1991). Cache Creek Terrane rocks, which are well exposed only along the northern stretches of the western shoreline, are dominated by folded and weakly foliated ribbon chert. Argillite partings in the chert may coarsen to fine greywacke, although no coarse greywacke interbeds were observed. Massive greywacke layers 5 m or more thick, and intraformational argillite rip-up clast conglomerate (Photo 1), form cliffs along the lake at, and north of, an irregular bird's foot shaped peninsula. Close examination of the wacke section shows that it is cut by low angle faults, possibly thrusts, in at least two places.

The contact between ribbon chert and the massive wacke sections is not exposed near the lakeshore. Greywacke content rapidly increases eastward in the Teslin Lake section. Perhaps the section is comprised of a series of thrust panels separated by cryptic faults, and represents an originally more gradational facies change that has been subsequently telescoped.

Hall Lake

Stratigraphic successions at Hall Lake are dominated by two major lithologic divisions. The structurally and stratigraphically lower division consists of folded and weakly foliated argillite and chert. The upper, mainly non-foliated division, consists of volcano-sedimentary strata belonging to the French Range and Teslin Formations.

Argillite is typically black and rust weathering. At one locality, tuffaceous fragments are conspicuous. A weak phyllitic texture is common, especially in argillite which occurs as 0.5 to 8 cm thick beds that alternate with 2 to 12 cm thick beds of chert. Chert is tan, grey and black and locally weathers white. It is generally recrystallized and displays a bedding-normal fracture pattern spaced at 2 cm or greater. In zones of high strain, chert layers become rodded and/or transposed.

The French Range Formation at Hall Lake consists of massive basalt, basalt breccia and trachyandesite tuff with interfingering, fossiliferous and massive Teslin Formation limestone. Basalt is typically structureless, aphyric, black to dark green and blocky weathering. Rare bulbous weathering surfaces may be pillows. Distinct pillow breccia occurs at one locality east of northern Hall Lake. Hyaloclastite and layers of varitextured lapilli and ash all appear to be water lain. Nowhere are subaerial pyroclastic deposits clearly evident. Most tuffaceous deposits appear to be basaltic, however, tuff interbedded with limestone on the highest knolls east of Hall Lake, have a trachytic composition (Figure 3, Tables 1 and 2).

Limestone is typically tan to white with angular weathered surfaces resulting from closely-spaced orthogonal fractures. It is invariably recrystallized and, in places, is dolomitized. Less abundant is fossiliferous limestone which is white to dark grey, poorly bedded and commonly fetid. Ripple cross-stratification in crinoidal grainstone occurs rarely. Fossils consist mainly of fusulinids and crinoids. Fusulinid packstone horizons up to 10 cm or more thick, occur at scattered localities.

Contacts between chert and limestone are generally poorly exposed. However, northeast of Hall Lake scoriaceous limestone appears to sit directly on ribbon chert. A fabric is developed at the contact, but it is interpreted to be the result of strain partitioning during post-depositional deformation. At some localities, chert and limestone are interbedded. Such beds tend to be 2-15 cm thick and irregular (Photo 2). At one locality, however, an isolated, 30 cm thick, continuous, parallel-sided chert bed occurs within limestone.

Contacts between limestone and volcanics are clearly gradational. This is especially well displayed with tuffaceous rocks where across one or two metres the lithology changes from coarse ash lapilli tuff to lapilli in a calcareous matrix to carbonate debris in a tuffaceous matrix (Photo 3), to massive carbonate.

Contacts between ribbon chert and volcanic rocks were not observed in the Hall Lake area. The presence of tuffaceous material in cherty argillite, however suggests that chert deposition and volcanism were in part synchronous.

Dease Lake

Strata near Dease Lake are dominated by the same stratigraphic elements as at Hall Lake. Typically, the structurally lowest and most deformed are units are hemipelagites of the Kedahda Formation. At the highest structural levels the French Range Formation volcanic strata and Teslin Formation carbonates are least deformed.

Photo 1. Angular argillite rip-up clasts within coarse, quartzose wacke on west side of Teslin Lake.

TABLE 1. MAJOR OXIDE ANALYSES

Sample Description	Field No.	NTS map	UTM E	UTM N	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	MnO	Cr_2O_3	Ba ppm	LOI	Total
Hall Lake basalt -PP	MMI96-06-09	104N/16	645650	6635350	45.30	3.98	13.45	14.41	5.78	8.83	3.05	0.86	0.43	0.19	0.01	190	2.47	98.78
Hall Lake basalt -PP	MMI96-07-06b	104N/15	636550	6632450	48.47	1.07	15.08	9.51	7.39	8.89	3.15	1.61	0.38	0.16	0.03	1082	2.86	98.71
Hall Lake tuff -PP	MMI96-05-04	104N/16	641600	6639350	53.18	1.39	17.75	9.84	3.02	2.87	3.52	3.12	0.92	0.06	0.01	1390	3.81	99.63
Hall Lake tuff -PP	MMI96-07-04	104N/15	636800	6633750	49.44	2.34	18.74	15.09	2.26	1.53	2.44	2.34	0.31	0.02	0.08	1022	4.58	99.30
French Rg. basalt -PP	MMI96-08-03	104J/16	417700	6514600	50.46	0.91	14.78	9.93	6.80	6.98	3.56	1.27	0.14	0.13	0.04	223	4.02	99.04
French Rg. basalt -PP	MMI96-17-03	104J/09W	418525	6503450	47.45	1.65	14.92	12.51	6.26	5.93	2.45	2.59	0.26	0.13	0.02	154	4.36	98.55
French Rg. tuff -PP	MMI96-09-04	104J/9W	416250	6508400	59.39	1.04	14.18	12.23	0.58	1.33	5.94	1.50	0.31	0.10	0.01	666	0.96	97.66
French Rg. rhyodacite -BS	MMI96-09-02	104J/9W	416950	6508150	64.83	0.97	13.22	7.89	1.16	0.88	4.56	3.23	0.20	0.12	0.01	921	1.56	98.74
Kutcho Ck. basalt -GS	MMI96-15-12	104I/01	534300	6449650	50.43	0.77	15.25	9.92	7.54	7.56	2.62	0.26	0.10	0.18	0.04	88	3.89	98.57
Hall Lake gabbro -PP	MMI96-07-06a	104N/15	636550	6632450	46.94	3.74	17.44	11.98	2.40	5.12	4.60	1.75	1.25	0.15	0.01	556	4.19	99.64
Dease Lk. pyroxenite	MMI96-12-05a	104J/09E	441050	6598900	43.24	2.19	12.67	19.15	8.74	6.29	2.52	0.15	0.23	0.11	0.01	94	4.14	99.45

Samples prepared at BC Geological Survey Branch Laboratory using steel mill grinding; Fe and Cr contamination is known to occur.

Samples anaylzed at Cominco Laboratory by fused disc X-ray fluorescence. Results reported as Wt. % except Ba which is ppm.

Sample abbreviations refer to metamorphic grade: PP = prehnite-pumpellyite, BS = blueschist, GS = greenschist.

Mapsheets with 104N designation are Zone 8; 104I and 104J are Zone 9.

TABLE 2. TRACE ELEMENT ANALYSES BY INDUCTIVELY COUPLED PLASMA MASS SPECTROSCOPY

Field No.	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	^{160}Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Th
MMI96-06-09	32.9	278	46.17	174	31.01	68.2	8.56	36.3	8.39	2.70	8.32	1.15	6.66	1.217	3.27	0.430	2.5	0.385	6.3	1.75	3.18
MMI96-07-06b	18.0	116	7.47	1051	28.40	60.2	7.43	30.1	5.69	1.64	4.75	0.63	3.54	0.691	1.91	0.258	1.7	0.235	2.5	0.18	6.50
MMI96-05-04	24.2	640	127.60	1307	90.16	191.0	21.20	78.7	13.53	3.73	9.69	1.25	5.99	0.951	2.24	0.265	1.4	0.195	13.0	6.42	10.09
MMI96-07-04	8.6	242	58.49	932	25.12	42.5	4.67	16.7	3.35	1.56	2.84	0.42	2.42	0.417	1.16	0.166	1.2	0.163	4.8	1.81	3.92
MMI96-08-03	27.3	118	9.14	183	7.28	16.7	2.27	10.3	3.10	1.09	4.21	0.69	4.97	1.043	3.28	0.457	3.2	0.461	2.8	0.24	0.84
MMI96-08-03R	27.1	112	9.16	178	7.34	16.7	2.25	10.1	3.15	1.15	4.16	0.74	4.82	1.050	3.21	0.471	3.2	0.461	2.7	0.41	0.85
MMI96-17-03	26.8	113	8.13	116	7.87	19.4	2.82	13.6	4.08	1.47	4.88	0.77	4.96	1.014	2.91	0.429	2.7	0.393	2.6	0.32	0.55
MMI96-09-04	49.9	447	72.62	545	55.77	119.3	14.51	59.7	12.85	5.22	11.54	1.75	10.09	1.926	5.49	0.763	4.9	0.738	9.4	3.66	6.29
MMI96-09-02	87.0	845	111.63	765	76.78	165.5	20.22	80.0	18.66	4.76	17.78	2.76	16.85	3.356	9.55	1.363	8.5	1.262	17.5	5.71	9.57
MMI96-09-06	95.5	957	144.27	954	105.20	218.3	25.52	96.1	19.82	4.17	18.56	2.86	17.69	3.648	10.13	1.443	9.5	1.409	20.2	7.37	15.43
MMI96-15-12	15.2	42	0.63	51	1.81	5.6	0.95	5.1	1.84	0.60	2.14	0.37	2.56	0.560	1.76	0.256	1.6	0.252	1.1	0.04	0.16
MMI96-12-05a	45.7	156	9.18	62	11.26	31.2	4.48	21.7	6.77	2.11	9.06	1.40	8.47	1.777	5.00	0.687	4.2	0.701	3.9	0.31	0.68
MMI96-07-06a	51.3	384	90.06	498	59.02	129.6	16.44	67.5	14.05	4.42	13.38	1.89	10.86	2.021	5.33	0.717	4.0	0.636	8.6	3.45	5.53
detection limit:	0.9	3	0.09	4	0.03	0.3	0.01	0.1	0.09	0.02	0.05	0.02	0.05	0.005	0.03	0.008	0.1	0.006	0.3	0.03	0.07

Analyses performed at Memorial University of Newfoundland. Analytical method is peroxide fusion-ICPMS. Detection limit method is mean blank + 3σ blank.

Sample MMI96-08-03R is a duplicate analysis.

Sample MMI96-09-06 is a "rhyodacite" from the French Range; oxide values are not reported because of a low total (91.19). For other sample description information refer to Table 1.

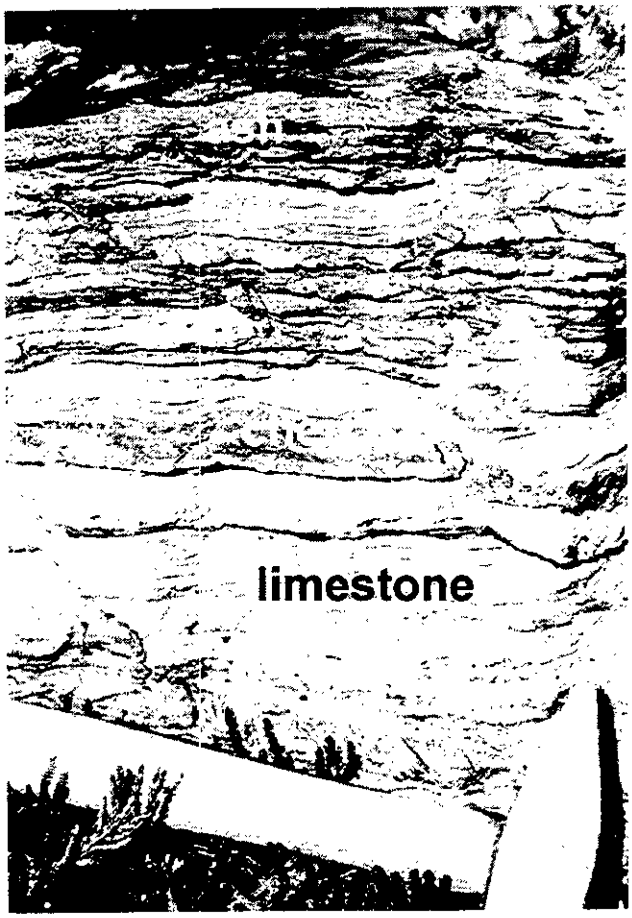

Photo 2. Parallel chert and ash beds in limestone on west flank of Mount Rath, French Range.

Photo 3. Carbonate debris deposit with tuffaceous matrix.

Kedahda Formation rocks along the shores of Dease Lake are strongly foliated phyllites and, in places, weakly developed schists. Protoliths were dominantly graphitic and silty argillite. Kedahda Formation in the French Range is more chert-rich and, locally, is not foliated. For example, ribbon chert on the north flank of Mount Rath is highly folded, but is neither foliated nor strongly recrystallized and thus preserves a good radiolarian fauna (Table 3).

Volcanic strata are dominated by basalt tuff, massive fine-grained flows and pillowed flows. Most units are between 1 and 15m thick; although some basalt accumulations probably reach a few hundred metres in thickness. Basalt flow rocks contain sparse amygdales of calcite, chlorite, and locally, stilpnomelane Some pillow basalt flows display interpillow sediments which weather recessively (Photo 4). Flows are interlayered with green to maroon, basalt to trachyandesite lapilli tuff. The basalt

TABLE 3. RADIOLARIANS FROM NORTHERN CACHE CREEK TERRANE

Sample No.	UTM E	UTM N	Radiolarian Genus/Species	Age
96FC-5-1			Latentifistula sp.	
			Quadriremis sp.	
			?Entactinia sp.	
				Paleozoic, probably Permian
96FC-15-2			Follicucullus scholasticus Ormiston and Babcock morphotype I Ishiga	
			Follicucullus scholasticus Ormiston and Babcock morphotype II Ishiga	
			Follicucullus sp. cf. ventricosus Ormiston and Babcock	
			Pseudoalbaillella sp.	
				Guadalupian

tuff is mint green, locally with up to 20% coarse bladed feldspar and highly vesicular clasts (Photo 5). It may envelope sparse, but conspicuous ferrugenous chert layers. Rare red ribbon chert layers (some contain radiolarians) occur within the mafic successions. Weakly crenulated argillaceous partings in the chert may be blue as a result of abundant fine-grained, blue amphibole, such as occurs on the ridge west of Slate Creek. Trachyandesite tuffs generally display a weak to moderate foliation and commonly grade into limestone or comprise the matrix of carbonate debris flow deposits. Some tuff appears reworked and displays vague ripple cross stratification, and therefore, is tuffite.

Silicic tuffs in the headwaters of western Slate Creek contain embayed quartz phenocrysts and display an eutaxitic texture (Photo 6). Unfortunately, alteration and blueschist metamorphism have destroyed any relict pumice outlines that may once have been present. Therefore it is not possible to demonstrate that the banded and flattened nature of volcanic clasts is due to welding and not due to compaction alone. Major and trace earth

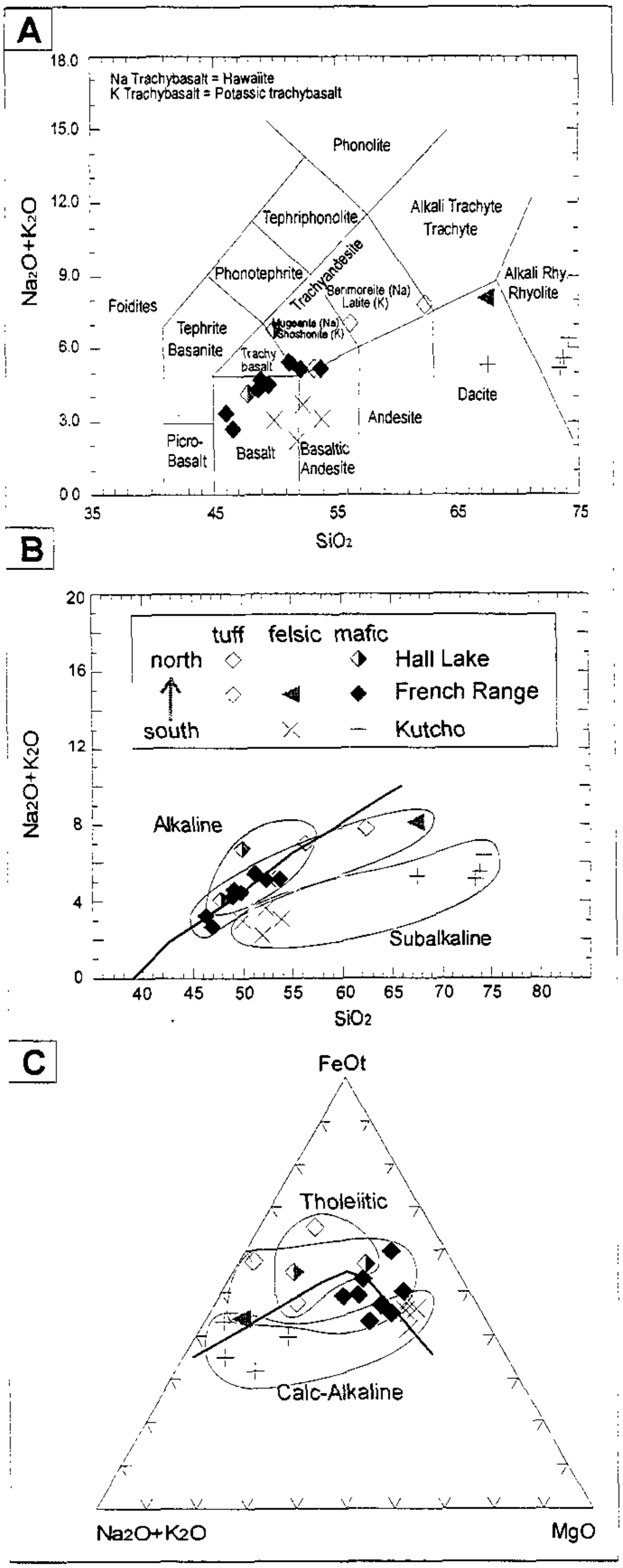

Figure 3. (a) Samples collected and analyzed as part of this study are classified by the method of LeMaitre (1984). Kutcho Formation: felsic crosses and mafic x's, Hall Lake volcanics: basalt = half filled diamond and tuff = open diamond, and French Range volcanics basalt = solid diamonds and rhyodacite = left-pointing triangles. Felsic volcanic samples from the French Range fall within the dacite field, near the rhyolite boundary and are herein classed as rhyodacite (see text for discussion). Major oxide volcanic classification diagrams (following the method of Irvine and Barager, 1971) show distribution of (b) Alkalis versus silica separating alkaline from subalkaline rocks, and (c) alkalis - FeOt and MgO to resolve subalkaline rocks into tholeiitic and calc-alkaline series. See text for a discussion on possible sources of error.

Photo 4. Pillow basalt in the French Range. Interpillow sediments have weathered recessively.

Photo 5. Monomict, coarsely bladed feldspar porphyry lapilli tuff and breccia.

element analyses of two samples indicate that they are of rhyodacitic composition (see "Lithogeochem-istry" below).

Teslin Formation limestone varies from white, buff or pink and generally poorly-bedded, to black and well-bedded. The bed thickness is variable, but is generally 3 to 15 cm in well-bedded varieties. Limestone may be interbedded with black or red chert and green or maroon ash tuff.

Contacts between many units are undoubtedly modified by faults; however, there is clear evidence for gradational contacts between the three major lithologic divisions (Kedahda Formation chert, French Range Formation basalt and tuff and Teslin Formation limestone). The contact between the combined French Range and Teslin Formations and Kedahdah Formation may in part be a regionally significant, low to moderate-angle fault. Evidence for this is based on the high strain zones observed at the top of the Kedahda Formation at several localities south of Mount Rath and at one locality along Highway 37, east of Dease Lake (see "Deformation and Metamorphism" below).

BIOGEOCHRONOLOGY

At the time of writing only 2 of 30 samples containing radiolarians, radiolarian ghosts or radiolarian-like artifacts have been processed to yield preliminary age data. One of these samples is from near Hall Lake, the other is from the French Range.

A small isolated outcrop of light green-weathering chert southwest of Hall Lake was collected for radiolarian extraction. Preliminary identification of radiolarians etched from the sample indicate a probable Permian age (96FC-5-1, Table 1). This poorly bedded chert occurs within a section of interbedded limestone and volcaniclastic debris. The age is consistent with Permian fusulinid identifications from the adjacent limestone reported by Monger (1975).

A sample of well-bedded, strongly folded grey ribbon chert on the north flank of Mount Rath contains abundant radiolaria readily visible in hand sample. Chert and argillite form beds 2-20 cm thick (mainly 5-15 cm). Folds are generally open with gently dipping axial surfaces and hinge lines that plunge shallowly southeast and northwest. Contacts were not observed, but outcrops both down slope and up slope are limestone. Limestone of the upper outcrop grades upwards into tuff. Well preserved radiolaria, identifiable to morphotype level, indicate a Guadalupian age (lower Late Permian). Limestone in a homotaxial section 5 km southwest of Mount Rath contains Permian (probably earliest Guadalupian) Fusilinids and is in contact with underlying

Photo 6. Eutaxitic texture is displayed by rhyodacite in the French Range.

chert and overlying agglomerate of the basal French Range Formation (Monger, 1969). These basal French Range Formation strata grade upwards into tuffs, including rhyodacite (see "Discussion").

DEFORMATION AND METAMORPHISM

Deformation is generally less intense in the Hall Lake than in the Dease Lake area. Regional metamorphic grade is prehnite-pumpellyite facies at Hall Lake, but varies from prehnite-pumpellyite to lower greenschist and blueschist near Dease Lake.

Photo 7. (a) south verging folds in Kedahda Formation east of Dease Lake. (b) photomicrograph showing crenulations common in Kedahda Formation phyllite. (c) transposed bedding in a more highly strained phyllitic schist east of northern Dease Lake. Long dimensions of photomicrographs is approximately 4 mm.

Folds at Hall Lake are upright with steep limbs and nearly vertical axial surfaces. A foliation fabric is developed in tuffaceous units and the argillaceous partings of ribbon chert locally become phyllitic. Basalt flows and massive to thick-bedded limestone display little or no fabric.

Hemipelagic sediments along Dease Lake are strongly deformed by mainly south-verging, inclined folds with wavelengths of metres to hundreds of metres. Parasitic folds are ubiquitous at scales ranging from millimetres to decimetres (Photos 7a, b, c). In good road and canyon exposures, macroscopic folds alone have resulted in shortening of this rock package to less than a third of its original length. The same fold styles are visible in the French Range although phyllitic partings are not so common and shortening is probably much less. On the northwest flank of Mount Rath a series of south-verging folds cascade down the dip slope (Photo 8).

Contractional faults are difficult to identify. One candidate is a strongly foliated zone exposed along Highway 87 between Kedahda Formation and overlying French Range Formation. It contains lenses of limestone and basalt in a sheared cherty argillite matrix with a moderately north-dipping fabric. Similar relationships are displayed south of Mount Rath in the French Range. A strong mylonitic flaser fabric is developed in chert just below the contact with French Range Formation volcanics. These high strain zones might be part of regional, low angle faults that place panels of French Range and Teslin Formation rocks atop Kedahda Formation and are later folded and faulted. Alternatively, they could be due strain partitioning around the relatively competent French Range volcanic succession. The possibility of a regional reverse fault that places blueschist grade rocks atop the Kedahda Formation is intriguing and warrants further investigation.

Everywhere the primary foliation (including blueschist minerals) has been subjected to one or more successive phases of folding. However, in no case did we

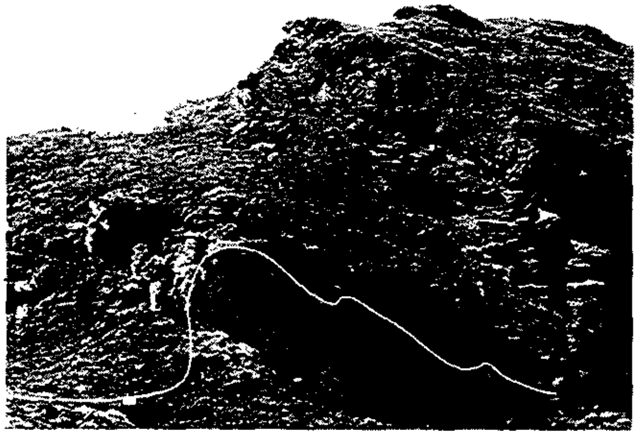

Photo 8. South verging cascading folds on the northwest flank of Mount Rath.

identify a pervasive metamorphic fabric developed during the later fold event(s). Late folding is probably related to emplacement of the Cache Creek Terrane during Aalenian-Bajocian times (early Middle Jurassic; Mihalynuk *et al.*, 1995). Blueschist metamorphism may be Late Triassic as elsewhere in the Cache Creek Terrane (e.g. Paterson and Harakel, 1974). Efforts to date the metamorphic mineralogy using ^{40}Ar/^{39}Ar techniques are currently underway.

LITHOGEOCHEMISTRY

Volcanic rocks displaying no obvious evidence of alteration, secondary veins or amygdales are rare within the northern Cache Creek Terrane. Nevertheless, five apparently fresh, very fine-grained basalt units without veins or inclusions were selected for chemical analysis; the analytical data are shown in Tables 1 and 2. Tuffaceous rocks are by nature more heterolithic and may be affected by eruptive or depositional processes that modify their chemistry. Despite this, five of the least altered tuffaceous samples were also selected for analysis. Analytical results from a gabbro near Hall Lake (MMI96-07-06a) and a pyroxenite along northern Dease Lake (MMI96-12-05a) are also tabulated (Tables 1 and 2), but are not discussed here.

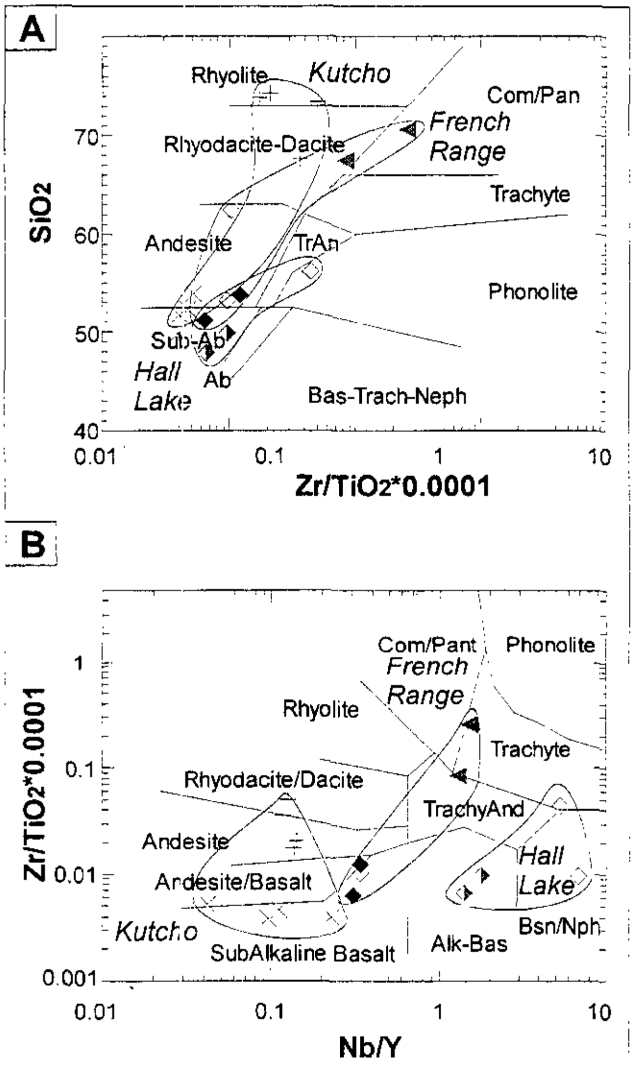

Figure 4. Volcanic rock classification diagram of Winchester and Floyd (1977) based upon the abundances of relatively immobile elements. A clear separation of Hall Lake (alkaline basalt) and French Range (subalkaline basalt) samples is evident. See Figure 3 for symbols. Abbreviations: Com = comendite, Pan = pantellerite, Bsn = basanite, Nph = nephelinite

The five basalt samples include two of blueschist grade basaltic andesite/mugearite pillows from the French Range and two of massive, prehnite-pumpellyite grade basalt/mugearite from near Hall Lake (Figure 3a, b). For comparison, one sample of lower greenschist grade foliated, basaltic andesite of the Kutcho Formation was analyzed. The Kutcho sample is from an outcrop that displays possible relict pillows.

Three of the tuff samples are trachyandesite. One is from the French Range and two are from near Hall Lake. They all contain plagioclase phenocrysts, and are maroon or green and moderately foliated. The other two silicic tuffs are from the French Range. They are dacite or rhyolite depending on the scheme used to classify them (i.e. Le Maitre (Figure 3a) versus, Cox *et al.*, 1979 -not shown), and are herein refered to as rhyodacite. No volcanic rocks this silicic are known from the Hall Lake area.

Rhyodacite analyzed during this study is compared with published data from Kutcho Formation rhyolite of Barrett *et al.* (in press). Basalts analyzed as part of this study are compared with previously published major oxide data for basalts near Hall Lake and the French Ranges (Monger, 1975) and with data for rocks near the Kutcho deposit (Barrett *et al.*, in press).

Late Permian volcanic strata at Kutcho Creek, and Hall Lake mark the south to north spatial limits of the samples studied. French Range samples are not only geographically located between those at Kutcho Creek and Hall Lake, they also display geochemical characters that consistently plot between those of the other two sample suites.

Major and Trace Elements

Rock classifications based upon the abundance of major oxides, especially mobile alkali and alkali earth species in old, altered volcanic terrains, are error prone due to the susceptibility of alkalis to alteration and metamorphism (cf. Smith and Smith, 1976). Normalized major oxide data from French Range Formation basalts and tuffs are plotted on alkalis-silica (Figure 3b) and alkalis-FeOt-MgO (AFM, Figure 3c) diagrams following the method of Irvine and Barager (1971). Figure 3b shows that Hall Lake and Kutcho Formation fall separately into dominantly alkaline and subalkaline fields. French Range samples tend to be subalkaline, but plot between and overlap the other suites.

On the AFM diagram (Figure 3c) French Range compositions straddle the boundary between the tholeiitic and calc-alkaline fields. This could be due to shifting of the basalt analyses towards the alkalis axis as a result of sodium metasomatism, common in a submarine environment. However, there is no correlation between alkali depletion and hydration. Indeed, the analysis with the lowest H_2O (0.6%, MV66-159; Monger, 1975) plots closer to the alkalis axis than other samples with nearly equivalent SiO_2. The uniformly subalkaline Kutcho Formation volcanics also straddle the field boundary. In this case the basalts are tholeiitic and felsic rocks tend toward calc-alkaline. As in Figure 3a, geochemical character changes consistently from Kutcho volcanics in the south to Hall Lake volcanics (plotted in Figure 3c for reference) in the north, in this case Fe increases northward.

To mitigate the effects of alteration, some classification schemes consider only elements that are relatively immobile, especially high field strength trace elements. Figure 4 shows two such plots: Zr/TiO_2 versus Nb/Y or SiO_2 (Winchester and Floyd, 1977). Sample suite classifications based on these plots confirm volcanic classifications based on major oxides. Again, the sample suites display a geochemical variation that is consistent with their geographic distribution. Nb/Y ratios are particularly useful in distinguishing between the alkaline Hall Lake, subalkaline Kutcho and intervening French Range Formation suites, which are completely separated on Figure 4b.

In some instances, trace element distribution can be used to provide clues as to the tectonic setting in which the sample was formed. Ti, Zr, Ta, Th, Nb and Y are especially powerful descriminants in this regard. Figure 5a shows tectonic descrimination of basalts based upon the Ti-Zr-Y ternary plot (Pearce and Cann, 1973). Hall Lake samples fall in the within-plate basalt field while Kutcho Creek basalts are clearly low potassium tholeiites. French Range samples plot in an intermediary position displaying calc-alkaline and within plate characteristics. A clearer picture is presented by Figure 5b which shows the logarithmic distribution of Zr/Y versus Zr (Pearce and Norry, 1979) for the most common basalt-forming environments. Kutcho Creek samples clearly display island arc basalt characteristics while Hall Lake samples display a strong within-plate signature. French Range samples plot between with a slight within-plate signature.

Ti-Zr fractionation trends can aid in establishing magma parentage of evolving melt compositions from various lava settings (Figure 5c). A rigorous application of this technique is not only beyond the scope of the paper, it is probably not possible due to the fragmental preservation and structural complexity of the Kutcho Formation as well as widespread alteration of phenocryst phases. Nevertheless, useful comparisons can be made

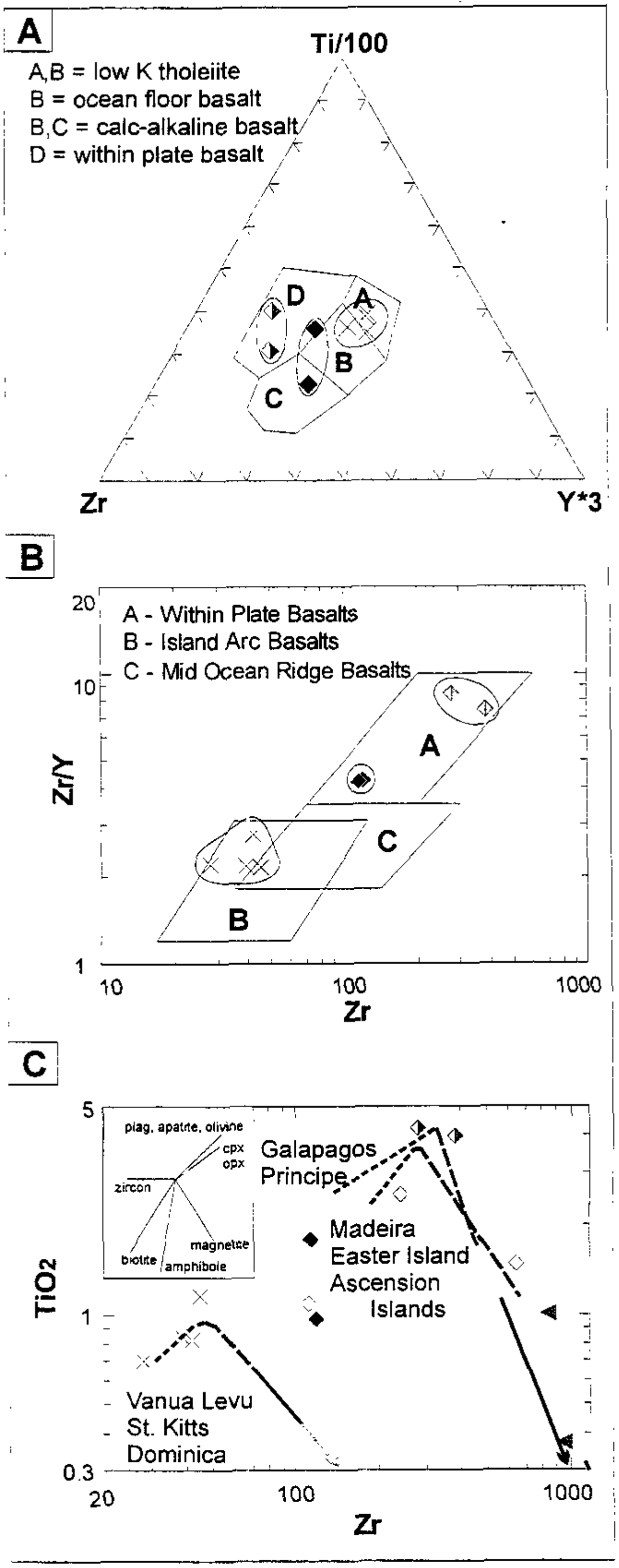

Figure 5. (a) Discrimination diagram showing low-K tholeiitic character of Kutcho basalt, within-plate character Hall Lake basalt and mixed character of Dease Lake basalts (method of Pearce and Cann, 1973). (b) Descrimination diagram showing island arc affiliation of Kutcho basalts, strong within plate affiliation of Hall Lake basalt, and transitional character of Dease Lake basalt (method of Pearce and Norry, 1979). (c) TiO_2 and Zr content of Kutcho Formation samples are consistent with model fractionation curves for volcanic series in arc settings while those of the French Range Formation are follow trends from lava series in within plate settings (model fractionation curves from Pearce, 1982). See Figure 3 for symbols.

with fractionation trends of unaltered rocks in known plate settings (e.g. Pearce, 1982). Kutcho Formation lavas mimic the fractionation trend of volcanic arc lava series like those of Vanua Levu, St. Kitts and Dominica. Hall Lake and French Range samples plot near within-plate volcanic series fractionation trends like those of Galapagos-Principe (upper curve) or Easter Island-Madeira-Ascention Islands (lower curve). The difference in arc versus within-plate fractionation trends is due mainly to early fractionation of magnetite in arc settings. Negative slopes on the felsic ends of all the fractionation trend lines is consistent with the lack of reported biotite or hornblende in both Kutcho Creek and French Range volcanics.

Rare Earth Elements and Spidergrams

Interpretations drawn from rare earth element (REE) data echo those of the trace elements. REEs from a single sample of Kutcho basalt (x's, Figure 6a) display a Mid-ocean ridge basalt (MORB) signature, with overall depletion relative to N-MORB (Sun and McDonough, 1989 normalizing factors) and slight overall negative slope. In contrast, Hall Lake basalts (half solid diamonds) show a strong negative slope; a within-plate setting is suggested. French Range samples (solid diamonds) appear transitional with respect to the other two suites, possibly representing a hybrid source area. A weak negative Eu anomaly in the lower French Range curve may indicate minor plagioclase fractionation.

A comparison of felsic volcanics from Kutcho Creek (crosses) and the French Range (sideways triangle) is shown in Figure 6b. Plagioclase fractionation is indicated by a negative Eu anomaly in both suites. Otherwise Kutcho rhyolite shows weak enrichment. French Range samples show very strong LREE enrichment and an

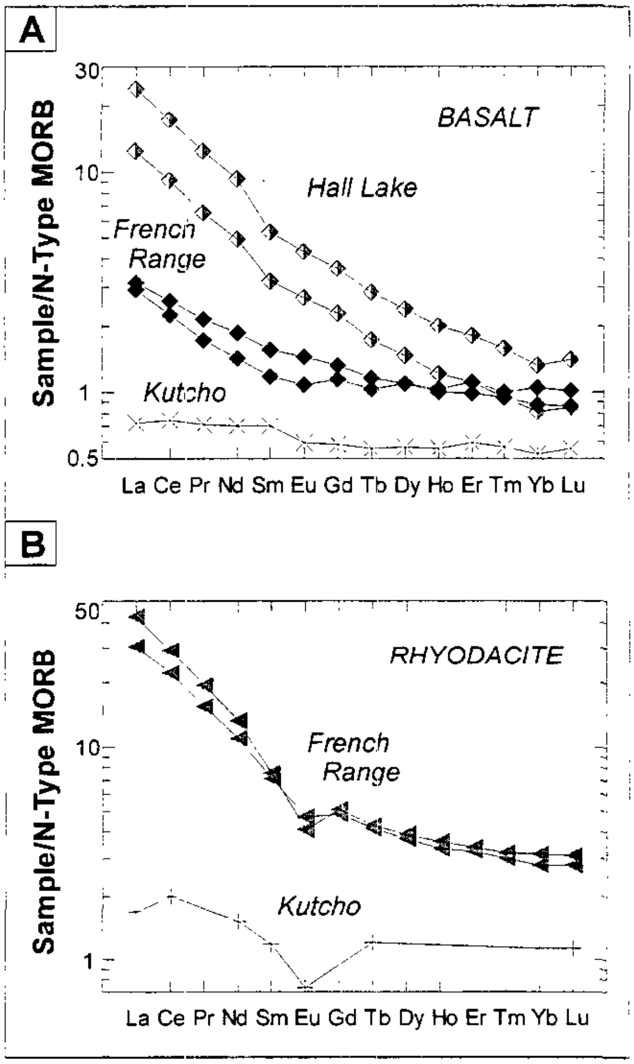

Figure 6. Rare earth element plots comparing (a) basalts from Kutcho Creek (x's), French Range (closed diamonds) and Hall Lake (half closed diamonds), and (b) rhyolite from Kutcho Creek (crosses; T. Barrett sample number 95-298) and the French Range (sideways triangles). Normalizing factors are those of Sun and McDonough (1989).

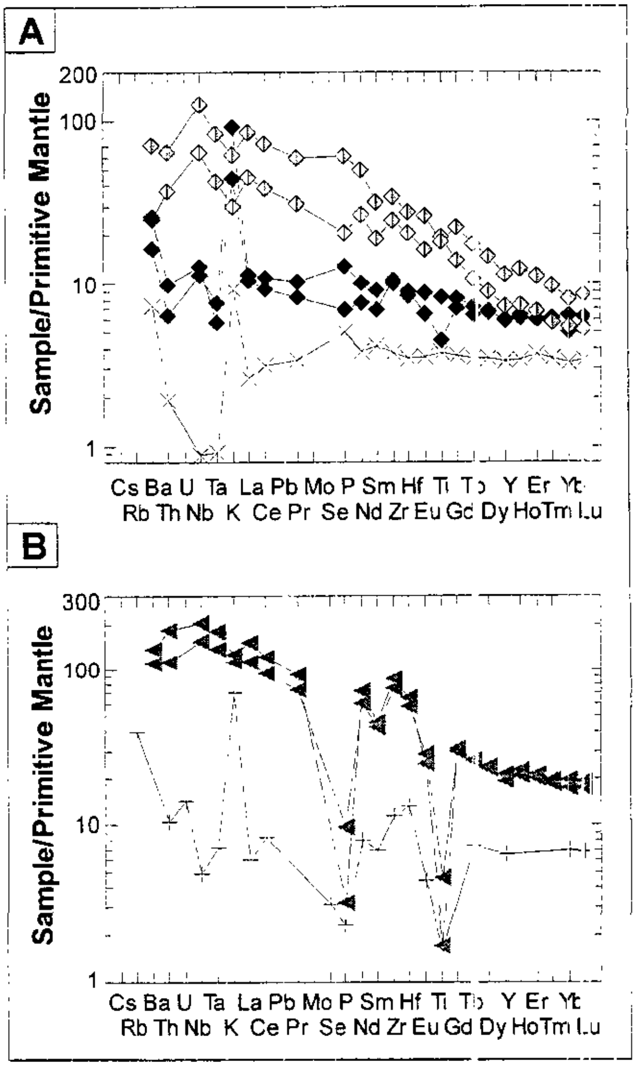

Figure 7. Spider diagrams which compare (a) basalts from Kutcho Creek (x's), French Range (closed diamonds) and Hall Lake (half closed diamonds), and (b) rhyolite from Kutcho Creek (crosses) and the French Range (sideways triangles). Sericitization of the Kutcho Creek rhyolite causes elevation of K (T. Barrett sample number 95-298). Normalizing factors are those of Sun and McDonough, 1989).

overall negative slope, similar to the Hall Lake basalt

A more complete story is shown in the spidergrams of Figure 7. Kutcho basalt chemistry display classic indications of subduction zone influence: a negative Nb-Ta anomaly and enrichment of large ion lithophile elements like Th, Ba and K relative to Ta. In contrast, Hall Lake samples display enrichment in Th, Ba, Ta and Nb, indicative of a within-plate setting. Once again, French Range samples display transitional characteristics, but with a arc-like trough showing Th, Nb and Ta depletion relative to LILs, Ba and K. All basalts display small amounts of enrichment and depletion of Ti and P relative to neighbouring elements, probably reflecting Fe-Ti oxide and apatite fractionation.

Nb-Ta depletion and LIL enrichment is also shown by the Kutcho rhyolite sample (Figure 7b; T. Barrett, data in press, sample 298). French Range rhyolite displays a within-plate signature (contrast with the French Range basalt in Figure 6a). Both samples suites display strong relative depletion of P and Ti.

DISCUSSION

Rhyodacite in the French Range was clearly deposited as part of the stratigraphic succession less than a few hundred metres above Late Permian limestone containing fusulinids of probable Earliest Guadalupian age (Monger, 1969; fossil locality C-75293). A discontinuously exposed section above the rhyodacite includes an approximately 0.5 km thick limestone layer with Tethyan fusulinids of probable Late Guadalupian age (*Yabeina* sp.; fossil locality C-75291; Monger, 1969), the hallmark fossil of the Cache Creek Terrane.

Absolute age limits for the Guadalupian are uncertain due to extensive revisions to Late Permian nomenclature. Some revisions are reflected in Harland *et al.* (1990) and are shown in Figure 8. The Guadalupian sub-epoch includes, from oldest to youngest, the Ufimian, Wordian and Capitanian. Classical use of "Guadalupian" in North America, however, does not include rocks as old as Ufimian. Absolute age limits are interpolated by Harland *et al.* only for the old Kazanian and Tartarian stages of the Late Permian. The Kazanian stage extends from basal Wordian to mid-Capitanian, the lower two thirds of the Guadalupian stage as defined in North America. Interpolated absolute age limits for the Kazanian stage are $254.2\ ^{-18.8}/_{-7.2}$ to $250.5\ ^{+3.5}/_{-13}$ Ma. Asymmetrical errors are calculated as the difference between the maximum or minimum chronogram age (Harland *et al.* 1990, Table 5.4) and the interpolated age (Harland *et al.* 1990, Table 5.8.5). Thusly defined, "Guadalupian" rocks have a permissive age range from less than 237.5 Ma to a maximum of 273 Ma, which brackets the 249 Ma U-Pb age determination from the Kutcho Formation reported by Childe and Thompson (1995; and the circa 242 Ma age for felsic rocks near Ashcroft reported by Childe *et al.*, this volume).

French Range rhyodacite may be Early to Late Guadalupian in age and, therefore, coeval with Childe and Thompson's U-Pb determination. An Isotopic age determination from the rhyolite is required to tighten this possible age linkage. U-Pb isotopic analyses of zircons extracted from the French Range rhyodacite are currently underway at the University of British Columbia Geochronology Laboratory.

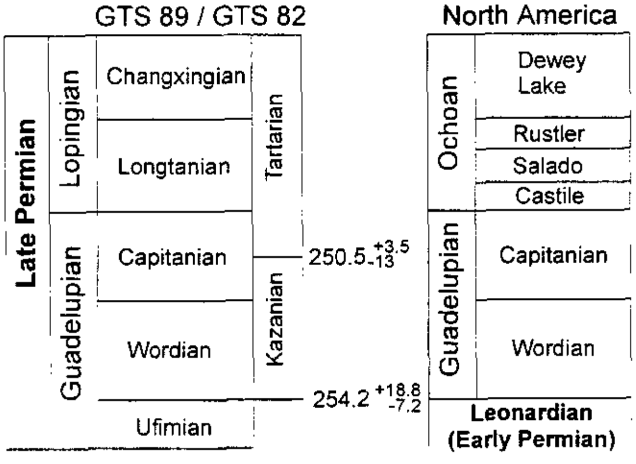

Figure 8. Late Permian stages and estimated absolute age limits with errors (data from Global Time Scale 1989 (GTS 89), Harland *et al.*, 1990 and Global Time Scale 1982 (GTS 82), Harland *et al.*, 1982.).

Correlation of the French Range Formation with the Kutcho Formation carries several important implications. French Range Formation volcanics are intercalated with hemipelagites, presumably part of the oceanic crustal succession. A correlative Kutcho Formation would probably have displayed similar original contact relationships with Cache Creek Terrane crustal rocks. If this is true, they apparently record the first pulse of subduction-related volcanism in an oceanic setting. Although it is not possible to draw regional conclusions from the small geochemical data set presented here, the consistent northward geochemical change from arc to within plate character is intriguing. It may represent the fossilized limit of a Late Permian subduction zone. If correlation can be extended to Late Permian felsic volcanics that are associated with the Cache Creek Terrane along its entire length (Figure 2, inset), and if their distribution is represenative of their original minimum extent, it may be possible to reconstruct belt of nearly synchronous volcanism at least 1250 km long. Infant intraoceanic arc volcanism in the Southwest Pacific (Izu-Bonin-Mariana) occurred nearly synchronously in the Middle Eocene in a zone 300 km wide by several thousands of kilometres long. Such volcanism is characterized by very depleted boninitic and arc tholeiitic lavas (Bloomer *et al.*, 1995). Deposition of the Permian felsic volcanic suite in an incipient arc setting (or forearc as suggested by Barrett *et al.* (in press) for the arc thoeiites at Kutcho Creek) is significant since the attached forearc oceanic crust has a relatively high potential for preservation as ophiolite (e.g. Bloomer *et al.*, 1995) and might help to explain the preservation of ophiolitic rocks in the Cache Creek terrane. A Late Permian intra-oceanic arc that extended well into the paleo-Pacific Ocean basin, may have helped to deliver Tethyan fauna to the North American realm - a journey that is otherwise geodynamically difficult to accomplish between the Late Permian (age of Tethyan fusulinids; Monger, 1969, 1975) and the Late Triassic (age of blueschists emplacement in Cache Creek Terrane near Pinchi Lake; Paterson and Harakel, 1974).

CONCLUSIONS

Recognition of rhyodacite within the French Range Formation calls for a significant upgrading of estimated potential for volcanogenic massive sulphide deposits in the vastness of the northern oceanic Cache Creek Terrane. Significant reduction in the size of the Kawdy Level Mountain Protected Area Strategy study area during 1996 (11000 km^2 to 490 km^2 now known as the Teslin River Wetlands; Figure 2 inset) once again opens the French Range, and most other strata of probable Late Permian age in northern Cache Creek Terrane, to mineral exploration.

Late Permian basalts in northern Cache Creek Terrane display a south to north variation in character from tholeiitic arc of the Kutcho Formation near Kutcho Creek to within plate in the French Range Formation at Hall Lake. Kutcho Formation volcanic rocks share the same lithologic and geochemical characteristics with Sitlika assemblage and coeval rocks at the southern end of the Cache Creek Terrane in the Ashcroft area. If these disparate volcanic assemblages are truly correlative, they could be remnants of a juvenile intraoceanic arc-forearc complex thousands of kilometres long - a possible bridge between Tethyan and North American realms in the Late Permian.

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