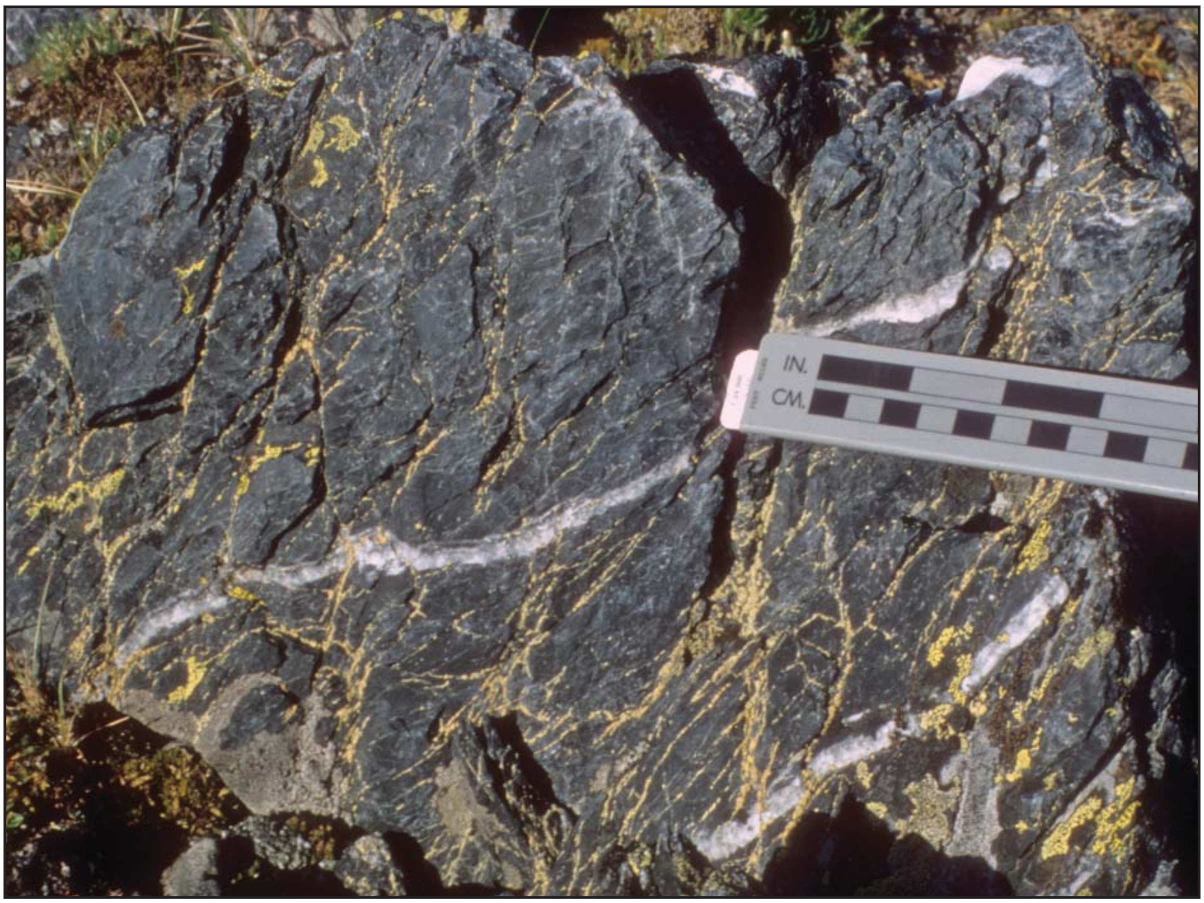
Report of Investigations 2009-2

CHERT GEOCHEMISTRY DISCRIMINANT ANALYSIS AND K-MEANS CLUSTER ANALYSIS: RAMPART PROJECT AREA, TANANA B-1 QUADRANGLE, EAST-CENTRAL ALASKA

by
R.R. Reifenstuhl, R.J. Newberry, S.A. Haug,
K.H. Clautice, S.A. Liss, and F.R.Weber



Rampart Group chert from the northeastern B-1 Quadrangle. Rock has well-developed shear fractures, some filled with yellow lichen, and cross-cutting quartz veins. These chert-rich outcrops lie close to the Victoria Creek Fault, a splay of the Tintina Fault, and are highly tectonized. Photo, Rocky Reifenstuhl

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CHERT GEOCHEMISTRY DISCRIMINANT ANALYSIS AND K-MEANS CLUSTER ANALYSIS: RAMPART PROJECT AREA, TANANA B-1 QUADRANGLE, EAST-CENTRAL ALASKA

by

R.R. Reifenstuhl[1], R.J. Newberry[2], S.A. Haug[3], K.H. Clautice[4], S.A. Liss[5], and F.R.Weber[6]

Abstract

A pilot chemostratigraphy study using discriminant analysis on major oxide and minor element data from 67 chert samples in the Rampart area, southeastern Tanana and southwest Livengood quadrangles, western Yukon–Tanana Upland, Alaska, generally indicates a unique geochemical signature for the cherts of a given rock unit. Chert samples from five known type locales were used as standards of comparison:

- •Livengood Dome Chert (Ordovician),
- •Amy Creek unit (Proterozoic to early Paleozoic),
- •Rampart Group (Mississippian to Triassic),
- •Troublesome Creek unit (Devonian), and
- •Permian–Triassic clastic unit (associated with the Triassic-dated gabbro).

Samples from the above units were compared to chert from Tanana B-1 area units of unknown or uncertain affinity. We have determined that discriminant analysis of chert geochemistry can assign chert profiles to specific units with only minor exceptions, and is useful in geologic mapping of the Tanana B-1 Quadrangle (Reifenstuhl and others, 1997).

INTRODUCTION

Our chemostratigraphic pilot study, completed in 1997, used statistical analyses techniques (discussed below) that were the standard in the 1990s. In 2008, similar statistical manipulations are currently more widely recognized and considered the standard. These include principal component analysis (PCA), in which sample groups are based on minimizing the chemical variance among the data and then testing for a statistical difference between the groups. Since we had five known rock units, our data, and statistical manipulation of that data, remains a valid treatment particularly for this pilot study and remains unchanged from our original 1997 study.

This pilot study addresses the problem of correlating rock units that lack fossils, lack stratigraphic continuity, or are highly structurally disrupted, but that are chert-bearing. In the Tanana B-1 Quadrangle (fig. 1), our mapping revealed that in some cases the same chert-bearing units previously had been mapped as Baldry terrain (Dover, 1994) and Livengood Dome Chert (Chapman and others, 1982).

We set out to test whether the cherts from our five chert-bearing rock units in the Tanana B-1 Quadrangle have some unique and definable geochemical signature, and whether the chert signature could be used to correlate units across large distances in a structurally complex or structurally dismembered area. This chert geochemistry technique is not an established method and our pilot study was intended to test its viability.

Discriminant and K-means cluster analyses were applied to 67 chert samples as a pilot study to determine whether statistical analysis can aid in differentiating chert samples from different lithologic units. The chert samples were collected from the Rampart area, southeastern Tanana Quadrangle, and southwestern Livengood Quadrangle, western Yukon–Tanana Upland, Alaska. This application of statistical analysis was useful in the geologic mapping of the Tanana B-1 Quadrangle (Reifenstuhl and others, 1997). Other geological, geochemical, and geochronological information for the Tanana B-1 Quadrangle are available as part of the

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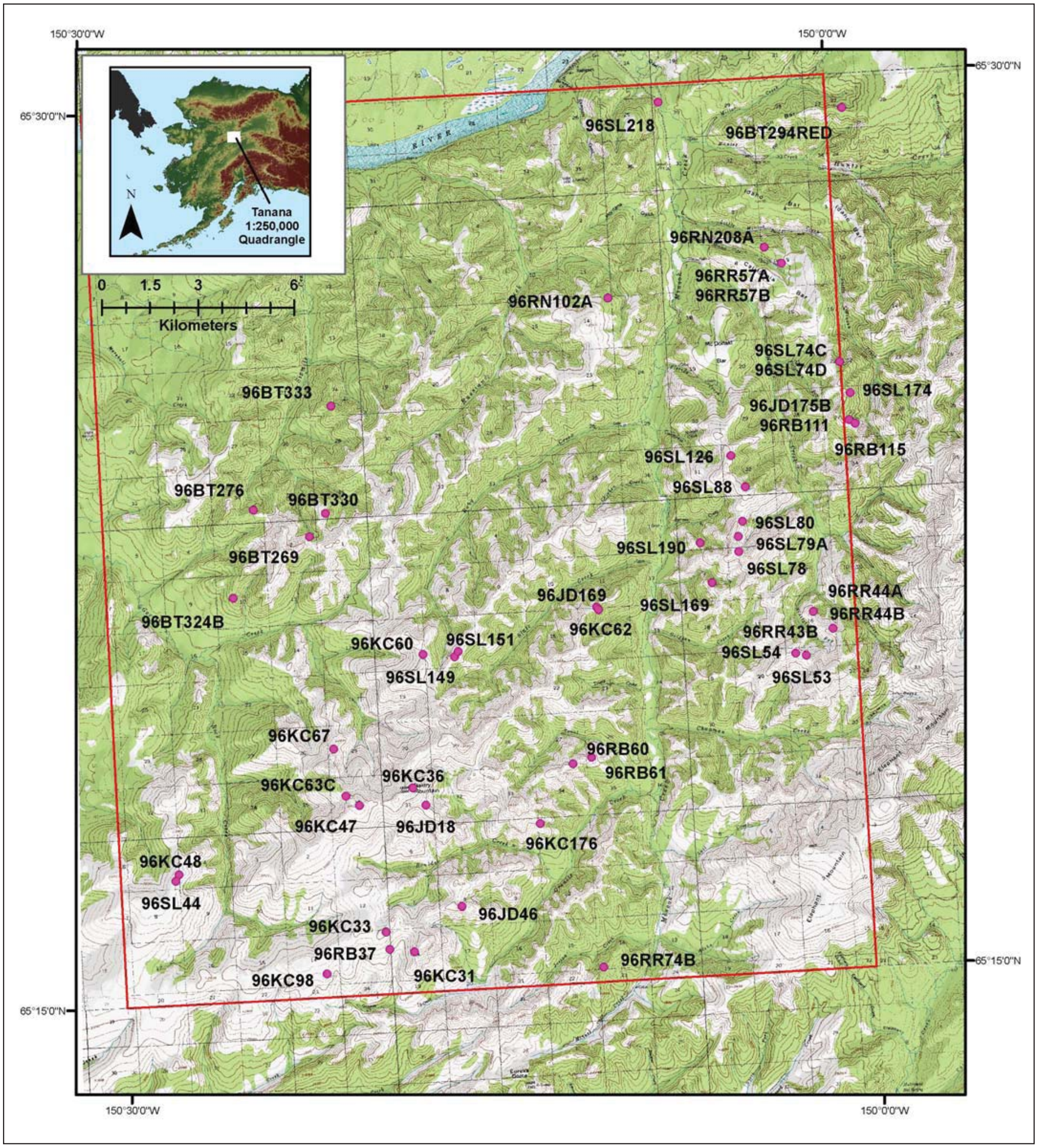

Figure 1. Location map for chert samples in, or adjacent to, the Tanana B-1 Quadrangle (red outline). See text and table 1 for details. Base from U.S. Geological Survey quadrangle maps.

Table 1. Geochemical, location and sample data for chert samples from the Rampart project area. See figure 1 for map location of each chert sample that is in, or adjacent to, the Tanana B-1 Quadrangle.

Sample	Rock unit/Comments	Latitude (dec. degree)	Longitude (dec. degree)	ppm Ba	Ce	Rb	Sr	Y	Zr	Cr	V	La	wt% SiO_2	TiO_2	Al_2O_3	Fe_2O_3*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
96BT294RED	Rampart Group	65.49028	-149.9889	5	31	0	29	10	40	12	24	7	89.4	0.19	4.78	1.80	0.04	1.06	0.31	2.33	0.03	0.03
96BT324B	Rampart Group	65.36295175	-150.4151728	259	18	8	7	4	23	0	19	1	90.5	0.13	3.58	1.94	0.03	2.07	0.00	0.47	0.31	0.01
96BT333	Rampart Group	65.41507949	-150.3430184	30	0	1	43	6	36	7	37	3	88.3	0.17	4.79	0.75	0.04	0.72	2.69	2.50	0.03	0.02
96SL218	Rampart Group	65.49487674	-150.1120449	124	0	9	8	4	11	1	15	0	96.1	0.08	1.67	0.52	0.04	0.61	0.06	0.03	0.31	0.02
96BT269	Rampart Group	65.37894448	-150.3619934	7,166	9	18	69	48	84	173	180	16	81.7	0.30	6.50	2.52	0.09	3.70	0.66	0.93	1.09	0.54
96BT276	Rampart Group	65.38716239	-150.3984426	363	9	26	40	13	35	0	72	7	85.3	0.27	5.81	3.83	0.39	1.84	0.10	0.85	1.17	0.04
96BT330	Rampart Group	65.38520654	-150.3504882	2,881	2	42	22	20	70	15	60	8	81.0	0.37	8.08	4.43	0.40	2.44	0.72	0.21	1.30	0.06
96RN102A	Rampart Group	65.44099	-150.1531	2,607	17	70	22	10	112	8	116	5	76.4	0.45	10.89	4.35	0.12	3.75	0.06	0.72	2.25	0.05
96RN208A	Rampart Group	65.4525957	-150.04654	1,254	4	17	79	14	100	14	168	8	79.2	0.42	9.12	3.89	0.05	3.77	0.94	2.76	0.49	0.06
96RR57A	Rampart Group	65.44784753	-150.0355774	1,311	4	25	5	10	59	5	30	3	89.1	0.17	5.48	1.69	0.10	2.32	0.02	0.03	0.74	0.02
96RR57B	Rampart Group	65.44784753	-150.0355774	2,081	36	82	10	14	88	6	125	10	80.1	0.36	10.06	3.97	0.11	3.79	0.29	0.05	2.00	0.05
96RN12A-C1	Amy Creek Dolomite/Livengood Quadrangle	65.5	-148.725	1,163	4	10	23	4	12	0	74	0	96.2	0.04	1.50	0.85	0.01	0.26	0.00	0.09	0.30	0.03
96RN12A-C2	Amy Creek Dolomite/Livengood Quadrangle	65.5	-148.725	1,193	8	10	25	5	13	0	81	1	95.7	0.05	1.60	0.88	0.01	0.28	0.00	0.09	0.33	0.03
96RN14A	Amy Creek Dolomite/Livengood Quadrangle	65.49167	-148.6167	425	1	8	6	4	10	0	174	0	97.8	0.03	1.07	0.40	0.00	0.14	0.00	0.00	0.19	0.23
96RN14B	Amy Creek Dolomite/Livengood Quadrangle	65.49167	-148.6167	1,194	2	5	16	2	10	0	31	0	97.7	0.03	0.67	0.33	0.00	0.03	0.00	0.00	0.15	0.06
96RN14C	Amy Creek Dolomite/Livengood Quadrangle	65.49167	-148.6167	4,938	15	10	134	48	25	0	157	15	96.4	0.11	2.28	0.24	0.00	0.19	0.00	0.00	0.22	0.76
96KC317	Livengood Dome Chert equivalent or Road River Formation (Yukon Territory)	64.467	-138.333	205	12	4	12	2	5	0	12	1	96.8	0.03	1.01	0.86	0.10	0.45	0.01	0.05	0.12	0.01
96RN13B	Livengood Dome Chert rock pit / Livengood Quadrangle	65.5333	-148.8417	74	2	5	17	1	6	1	7	0	97.8	0.01	0.45	0.55	0.09	0.05	0.00	0.09	0.12	0.01
96RN13C	Livengood Dome Chert rock pit / Livengood Quadrangle	65.5333	-148.8417	119	10	4	22	1	6	2	9	1	97.2	0.01	0.82	0.71	0.32	0.30	0.05	0.08	0.13	0.01
96RN13D2	Livengood Dome Chert rock pit / Livengood Quadrangle	65.5333	-148.8417	123	25	27	40	11	47	11	6	7	96.1	0.27	1.59	1.89	0.06	0.39	0.09	0.03	0.69	0.11
96RN13E	Livengood Dome Chert rock pit / Livengood Quadrangle	65.5333	-148.8417	118	9	4	22	3	9	1	8	1	97.4	0.01	0.77	0.29	0.01	0.09	0.00	0.09	0.13	0.02
96RN15	Livengood Dome Chert rock pit / Livengood Quadrangle	65.09	-150.29	23	6	0	1	0	0	0	4	1	99.1	0.00	0.00	0.03	0.00	0.04	0.02	0.01	0.00	0.00
88AWR52	Devonian age-Troublesome Creek Unit, Livengood Quadrangle	- - -	- - -	89	16	5	104	3	11	9	20	3	93.4	0.03	0.2	0.99	0.06	1.39	2.07	0.72	0.02	0.01
88AWR65D	Devonian age-Troublesome Creek Unit, Livengood Quadrangle	- - -	- - -	2,164	1	6	15	6	21	21	39	5	94.6	0.08	0.3	1.74	0.02	1.20	0.13	0.08	0.20	0.02
96RR43B	Triassic age chert	65.34506431	-150.0157816	186	68	36	35	21	220	35	104	21	75.6	0.66	10.17	8.49	0.22	2.63	0.20	0.81	1.02	0.13
96RR44A	Triassic age chert	65.35008196	-150.0280757	202	0	16	9	10	50	15	64	5	90.6	0.20	3.64	2.96	0.02	1.31	0.00	0.18	0.41	0.05
96RR44B	Triassic age chert	65.35008196	-150.0280757	490	22	22	14	16	70	13	53	9	86.0	0.24	5.49	5.43	0.21	1.89	0.03	0.29	0.62	0.03
96SL53	Triassic age chert	65.33801531	-150.0346592	393	11	27	17	11	60	42	75	21	87.1	0.26	5.81	3.30	0.05	1.66	0.01	0.66	0.75	0.03
96SL54	Triassic age chert	65.33878423	-150.0415366	285	30	1	8	4	111	4	35	4	93.6	0.12	1.73	2.49	0.06	0.89	0.07	0.06	0.01	0.04
96JD169	Livengood Dome Chert?	65.35475869	-150.1724594	109	0	4	6	3	4	0	8	0	98.5	0.03	0.94	0.30	0.05	0.20	0.00	0.02	0.14	0.03
96JD46	Livengood Dome Chert?	65.27337761	-150.2739151	17	11	2	2	0	2	0	5	1	98.4	0.01	0.24	0.16	0.00	0.07	0.00	0.00	0.07	0.01
96KC33	Livengood Dome Chert?	65.2674011	-150.3253691	71	16	6	2	1	3	1	5	1	98.2	0.02	0.69	0.14	0.00	0.13	0.00	0.01	0.18	0.01
96KC48	Livengood Dome Chert?	65.28652011	-150.461303	67	0	5	2	2	4	0	11	0	98.5	0.02	1.12	0.21	0.01	0.18	0.00	0.01	0.20	0.02
96KC60	Livengood Dome Chert?	65.3443815	-150.2904524	51	17	18	4	1	14	5	19	1	94.5	0.08	2.35	1.45	0.05	0.38	0.00	0.03	0.61	0.01
96KC62	Livengood Dome Chert?	65.35414773	-150.1716684	62	32	4	4	2	3	1	7	1	97.7	0.02	0.79	0.19	0.01	0.11	0.00	0.00	0.17	0.02
96KC67	Livengood Dome Chert?	65.31932678	-150.3534493	52	11	8	5	2	9	4	14	1	95.9	0.06	2.16	0.24	0.00	0.27	0.00	0.03	0.40	0.01
96RB37	Livengood Dome Chert?	65.26250054	-150.3234956	61	16	3	3	1	2	0	7	1	97.9	0.02	0.63	0.14	0.00	0.13	0.00	0.01	0.16	0.01
96RB61	Livengood Dome Chert?	65.31304	-150.182	37	1	1	3	1	2	1	5	0	99.1	0.01	0.31	0.09	0.00	0.06	0.00	0.00	0.04	0.02

* All iron reported as Fe2O3

Table 1 - continued. Geochemical, location and sample data for chert samples from the Rampart project area. See figure 1 for map location of each chert sample that is in, or adjacent to, the Tanana B-1 Quadrangle.

Sample	Rock unit/Comments	Latitude (dec. degree)	Longitude (dec. degree)	ppm Ba	Ce	Rb	Sr	Y	Zr	Cr	V	La	wt% SiO_2	TiO_2	Al_2O_3	Fe_2O_3*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
96SL126	Livengood Dome Chert?	65.39488321	-150.0769903	165	1	16	3	3	14	2	21	1	95.2	0.10	2.53	0.71	0.04	0.26	0.00	0.00	0.52	0.04
96SL149	Livengood Dome Chert?	65.34319707	-150.2694664	64	15	6	9	1	2	1	8	1	97.4	0.03	0.99	0.34	0.03	0.20	0.00	0.01	0.23	0.01
96SL151	Livengood Dome Chert?	65.34466422	-150.2667081	55	3	7	8	2	4	2	12	0	97.1	0.03	1.08	0.25	0.03	0.20	0.00	0.01	0.25	0.01
96SL190	Livengood Dome Chert?	65.37095128	-150.1010443	146	25	7	4	2	10	6	14	1	97.1	0.06	1.29	0.35	0.01	0.14	0.00	0.01	0.27	0.01
96SL44	Livengood Dome Chert?	65.28474317	-150.4636932	19	11	4	2	1	1	0	7	1	98.3	0.01	0.73	0.09	0.00	0.13	0.00	0.00	0.15	0.02
96SL80	Livengood Dome Chert?	65.3763367	-150.0718583	32	36	0	3	1	1	1	3	7	99.1	0.00	0.00	0.09	0.00	0.23	0.25	0.01	0.00	0.05
96SL88	Livengood Dome Chert?	65.38592956	-150.0687309	58	21	5	4	1	3	0	8	1	98.2	0.02	0.83	0.15	0.00	0.11	0.00	0.06	0.16	0.01
98KC236	Livengood Dome Chert?	- - -	- - -	27	6	3	1	2	7	49	13	0	96.5	0.03	0.87	1.14	0.25	0.13	0.03	0.003	0.06	0.04
96JD175B	Amy Creek Dolomite? – location approximate	65.402933	-149.9967	1,013	1	11	20	9	17	0	112	6	96.5	0.10	2.47	0.76	0.01	0.39	0.04	0.01	0.46	0.23
96KC176	Amy Creek Dolomite?	65.29523799	-150.2185773	211	6	1	2	1	2	0	84	1	98.3	0.01	0.39	0.11	0.00	0.08	0.00	0.01	0.06	0.04
96KC47	Amy Creek Dolomite?	65.30318071	-150.3383743	119	8	4	3	4	12	0	126	1	98.2	0.03	0.72	0.25	0.00	0.12	0.00	0.01	0.15	0.01
96KC98	Amy Creek Dolomite?	65.25656513	-150.3661935	826	9	22	8	2	20	0	189	1	93.5	0.12	4.28	0.62	0.00	0.85	0.03	0.02	0.93	0.05
96RB111	Amy Creek Dolomite?	65.402933	-149.9967	286	6	3	19	4	5	3	55	1	97.6	0.03	0.71	0.41	0.00	0.10	0.26	0.01	0.12	0.20
96RB121	Amy Creek Dolomite?/Tanana A-1 Quadrangle, S19 T5N R14W	- - -	- - -	101	7	25	8	5	21	1	93	1	93.6	0.11	4.80	0.90	0.01	0.62	0.00	0.01	0.88	0.08
96RB60	Amy Creek Dolomite?	65.31141977	-150.1945329	62	11	5	4	3	6	0	75	1	98.2	0.03	0.73	0.20	0.00	0.15	0.00	0.01	0.18	0.01
96SL169	Amy Creek Dolomite?	65.35969884	-150.0946873	375	40	10	17	11	12	5	76	6	95.8	0.08	2.03	0.40	0.00	0.35	0.09	0.00	0.45	0.12
96SL74C	Amy Creek Dolomite?	65.41936722	-150.0004797	38	2	4	5	2	10	0	57	1	97.9	0.03	0.71	0.24	0.00	0.13	0.00	0.01	0.14	0.02
96SL78	Amy Creek Dolomite?	65.36792277	-150.0756257	231	1	6	60	8	15	0	61	0	96.1	0.08	2.69	0.07	0.00	0.08	0.00	0.22	0.19	0.01
96SL79A	Amy Creek Dolomite?	65.37218449	-150.0752668	47	36	5	2	5	2	0	54	1	97.8	0.02	0.72	0.25	0.00	0.12	0.00	0.00	0.20	0.01
96JD119	Rock unit unknown; approximate location only: Tanana A-1 Quadrangle	- - -	- - -	645	7	13	7	3	17	5	22	3	96.2	0.10	2.64	0.43	0.01	0.38	0.00	0.01	0.53	0.02
96JD18	Not Amy Creek Dolomite	65.30226348	-150.294146	88	10	25	2	2	26	16	27	4	88.8	0.16	5.50	1.56	0.02	1.72	0.00	0.10	1.14	0.01
96KC31	Amy Creek Dolomite? apatite rich!	65.26140029	-150.3071416	87	1	2	84	45	6	0	33	19	92.8	0.01	0.28	0.13	0.00	0.13	4.14	0.02	0.06	2.92
96KC36	Amy Creek Dolomite? apatite rich!	65.30724092	-150.3022135	178	44	14	121	90	25	0	23	40	80.5	0.11	2.63	0.52	0.00	0.85	7.83	0.07	0.60	6.40
96KC63C	Not Amy Creek Dolomite or Devonian age unit	65.30602672	-150.3469967	62	23	16	5	2	19	11	19	1	94.5	0.10	2.85	0.70	0.01	0.72	0.00	0.17	0.53	0.01
96RB115	Livengood Dome Chert? Near sample 96SL174	65.401803	-149.9927	118	13	9	2	2	9	5	20	1	94.2	0.07	2.39	1.38	0.05	1.15	0.00	0.04	0.40	0.01
96RB130	Devonian? or Triassic? SW¼ S19 T5N R13W, Tanana A-1 Quadrangle	- - -	- - -	474	14	14	14	11	18	1	38	3	94.8	0.11	2.76	1.14	0.01	0.70	0.18	0.01	0.63	0.19
96RR74B	Not Livengood Dome Chert	65.2542	-150.1817	130	65	32	23	15	35	10	34	8	90.6	0.18	4.66	1.09	0.02	1.07	0.16	0.00	1.16	0.15
96SL174	Livengood Dome Chert?	65.41049168	-149.9948409	156	8	13	2	2	12	1	22	3	95.2	0.09	2.29	0.60	0.02	0.65	0.00	0.01	0.56	0.02
96SL74D	Amy Creek Dolomite? Livengood Dome Chert?	65.41936722	-150.0004797	50	4	9	2	2	14	3	23	2	94.1	0.09	2.72	1.41	0.04	1.05	0.00	0.00	0.36	0.01

* All iron reported as Fe2O3

Public-Data File series, report PDF 97-29. Geochemical data of all samples taken for the Rampart project are available electronically in PDF 97-29g.

Cherts are most commonly formed on the continental slope (Sue Karl, personal commun., 1997); continental slope depths range from about 200 m to 4,000 m, have an average slope of 4 degrees, and currently cover some 28 million km^2 (Emery, 1970).

SAMPLE PREPARATION AND GEOCHEMICAL ANALYSIS

A total of 67 chert samples were collected from the Rampart project area (fig. 1). Of those samples, 42 were collected from areas in which the unit was not known with certainty and 25 were from the following type locales: Rampart Group (7), Amy Creek unit (5), Livengood Dome Chert (6), Devonian-age Troublesome Creek unit (2), and Chert and Gabbro unit (5) of Triassic-age (232.1±4.5 Ma lead-zircon age, Weber and others, 1992). Chert samples include a wide variety and range of colors including gray, black, red, green, and tan. Globally, chert is considered a group of highly siliceous, non-clastic sedimentary rocks (Jones and Murchey, 1986), the majority of which contain up to 98 percent SiO_2 (Murry and others, 1992). Samples collected for our pilot study range between 76 and 99 percent SiO_2.

The collected cherts were crushed and pelletized for X-Ray Fluorescence analyses at the University of Alaska Fairbanks (using a Rigaku machine operating at 55 kV and 35 mA). The pellets were analyzed (table 1) for 19 elements: ten major-oxide elements measured in weight percent (aluminum, calcium, iron, potassium, magnesium, manganese, sodium, phosphorous, silicon, and titanium) and nine trace elements measured in parts per million (barium, cerium, chromium, lanthanum, rubidium, strontium, vanadium, yttrium, and zirconium).

DISCRIMINANT ANALYSIS: METHODS AND RESULTS

Discriminant analysis of the geochemical data was applied first to the type locale chert samples to test whether our analysis could distinguish between the five type locales, and whether each type locale showed a separate and unique signature. On the basis of the elemental characteristics of the cherts, the discriminant analysis yields five different groupings that correspond with the five different type locales (table 2). A multiple linear regression equation determines the discriminant functions (or discriminant scores) for each sample considering all 19 measured elemental compositions of each chert (SPSS for Microsoft Windows, 1997 version).

TYPE LOCALE CHERT SAMPLES

When the discriminant functions of each type locale sample are graphed, each of the five units (Livengood Dome Chert unit, Amy Creek unit chert, Rampart Group unit chert, Devonian-age Troublesome Creek unit chert, and the Triassic-age unit chert) plot in distinct and separate clusters (fig. 2). The discriminant analysis also produced a 1.0 correlation between the type locale units and the predicted units generated by the statistical analysis (table 2), thus assuring discriminant analysis is a viable means for differentiating the chert samples into the five different units.

Twelve of the 17 samples that were hypothesized during field work to be Livengood Dome chert samples are assigned to the Livengood Dome chert unit. The remaining five chert samples (KC60, KC62, KC67, SL190, SL88) are assigned to the Amy Creek chert unit.

Of the chert samples field-hypothesized to be Amy Creek chert samples, nine of the 11 are assigned to the Amy Creek chert unit. The two samples not assigned to the Amy Creek chert unit are assigned to the Livengood Dome chert unit.

Table 2. Discriminant analysis applied to the type locale cherts produces a 100 percent correlation between the type locale units and the predicted group based on the statistical analysis.

Unit Classification Results

Unit	**#Cases**	**R**[a]	**A**[a]	**D**[a]	**T**[a]
Rampart	11	100%	0	0	0
Amy Ck	5	0	100%	0	0
Livengood	6	0	0	0	0
Devonian	2	0	0	100%	0
Triassic	5	0	0	0	100%

[a]R=Rampart unit; A=Amy Creek unit; L=Livengood Dome unit; D=Devonian-age unit; T=Triassic-age unit.

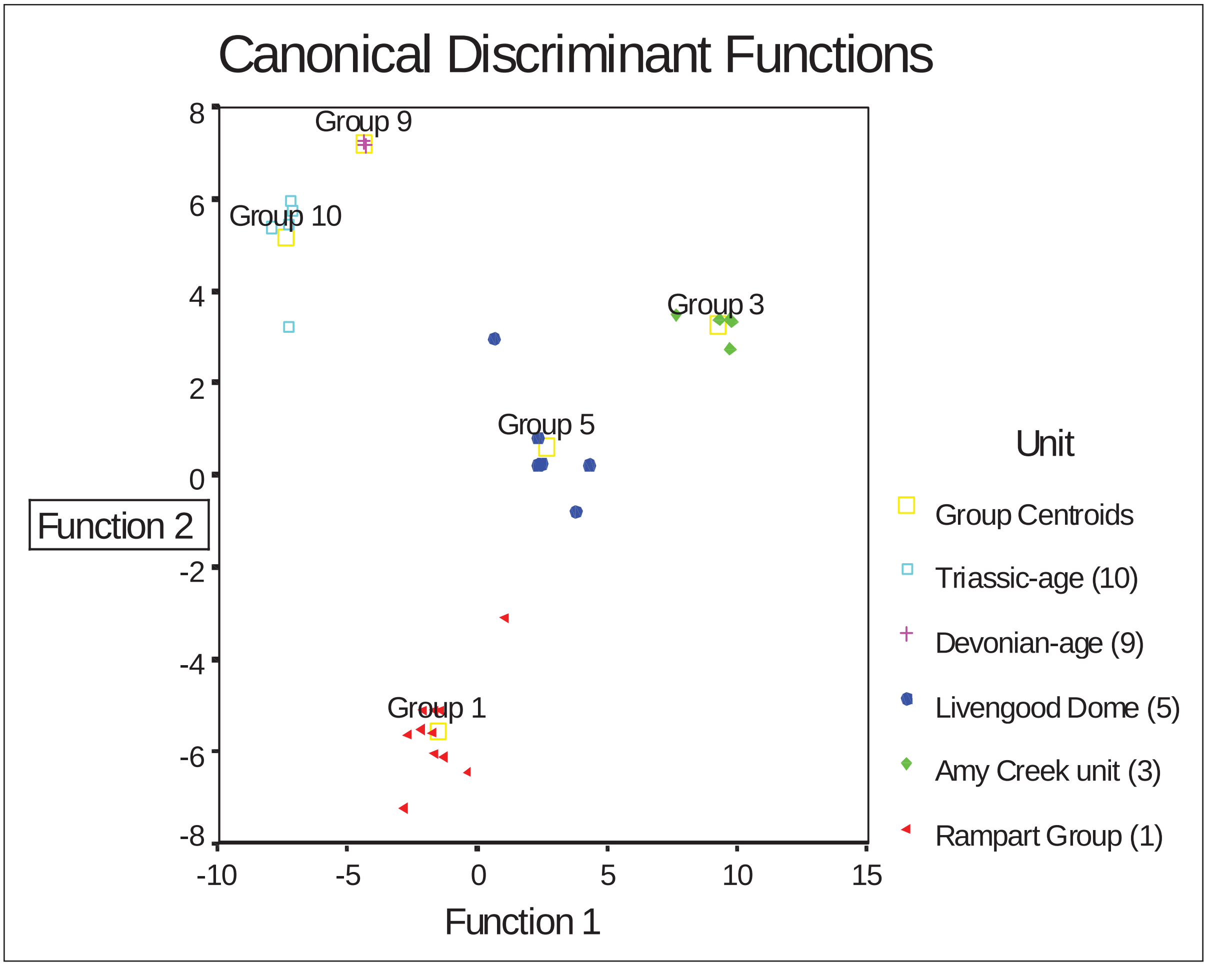

Figure 2. Type locale chert samples. See table 1 for geochemical analyses and tables 2 through 6 for statistical data.

The two chert samples statistically assigned to the Rampart Group chert unit, JD18 and RR74B, are located in the southern Tanana B-1 Quadrangle (see fig. 1) where the Rampart Group unit has not previously been mapped. The two samples most likely do not represent slivers of the Rampart Group in the south of the quadrangle. Instead, the geochemistry of these rock samples reflects the heterogeneous nature of Rampart Group cherts. This heterogeneity is seen in the K-means cluster analysis (see section K-Means cluster analysis: methods and results).

UNKNOWN CHERT SAMPLES

Discriminant analysis was then applied to the chert samples of unknown units along with the cherts from the five type locales. The program placed each unknown sample into the group it most closely resembled. The samples and statistical results are shown in table 3, where column one is the sample, column two is the hypothesized unit, as determined by the geologist in the field based on the physical characteristics and lithologic associations, column three is the predicted unit assigned by discriminant analysis, and the remaining columns the unique discriminant functions for each sample. Function graphs of the unknown cherts plotted along with the type locale cherts, based on the discriminant functions delineated group affinities (figs. 3 and 4).

The discriminant analysis of the chert samples of unknown units assigned 19 samples to Livengood Dome chert unit, 15 samples to Amy Creek chert unit, 2 samples to Rampart Group chert unit, and 2 samples to Triassic-age chert unit. (table 4).

Likewise, the two unknown chert samples (KC31 and KC36) assigned to the Triassic-age chert unit by the discriminant analysis do not represent Triassic-age cherts, but are merely most closely related to that group. KC31 and KC36 have highly anomalous P_2O_5 (2.92 weight percent and 6.4 weight percent, respectively), common to cherts formed at the base of the continental slope and thereby difficult to correlate with any of the

Table 3. Type locale data unit predictions based on discriminant analysis

Sample	Type Unit	Predicted	1st Prob+	2nd Prob	Function1*	Function2*
BT294red	R?	R	R/1	L/.0000	-1.2758	-6.09
BT324B	R?	R	R/1	L/.0000	-2.1321	-5.471
BT333	R?	R	R/1	R/1	-1.6196	-5.9991
SL218	R?	R	R/.6262	L/.3738	1.1007	-3.0629
BT269	R	R	R/1	L/.0000	-1.6723	-5.5661
BT276	R	R	R/1	L/.0000	-2.6616	-5.6
BT330	R	R	R/1	L/.0000	-1.4291	-5.0974
RN102A	R	R	R/1	L/.0000	-0.3812	-6.4065
RN208A	R	R	R/1	L/.0000	-1.6358	-5.08
RR57A	R	R	R/1	R/1	-2.7974	-7.1917
RR57B	R	R	R/1	L/.0000	-2.0953	-5.0872
RN12A-C1	A	A	A/1	L/.0000	9.7136	3.3984
RN12A-C2	A	A	A/1	L/.0000	9.7298	2.7673
RN14A	A	A	A/1	L/.0000	9.3493	3.4139
RN14B	A	A	A/1	L/.0000	7.6387	3.5277
RN14C	A	A	A/1	A/1	9.7896	3.3673
KC317	L	L	L/1	A/.0000	4.3324	0.2345
RN13B	L	L	L/1	T/.0000	0.678	2.9805
RN13C	L	L	L/1	R/.0000	3.8038	-7.685
RN13D2	L	L	L/1	R/.0000	2.4489	0.2701
RN13E	L	L	L/1	R/.0000	2.3211	0.8341
RN15	L	L	L/1	R/.0000	2.3391	0.2485
AWR52	D	D	D/1	D/1	-4.3924	7.281
AWR65D	D	D	D/1	D/1	-4.3229	7.1862
RR43B	T	T	T/1	T/1	-7.9479	5.4019
RR44A	T	T	T/1	T/1	-7.2913	3.2383
RR44B	T	T	T/1	T/1	-7.1312	5.7771
SL53	T	T	T/1	T/1	-7.2764	5.5037
SL54	T	T	T/1	T/1	-7.1829	5.99

*These functions are plotted in figure 2.

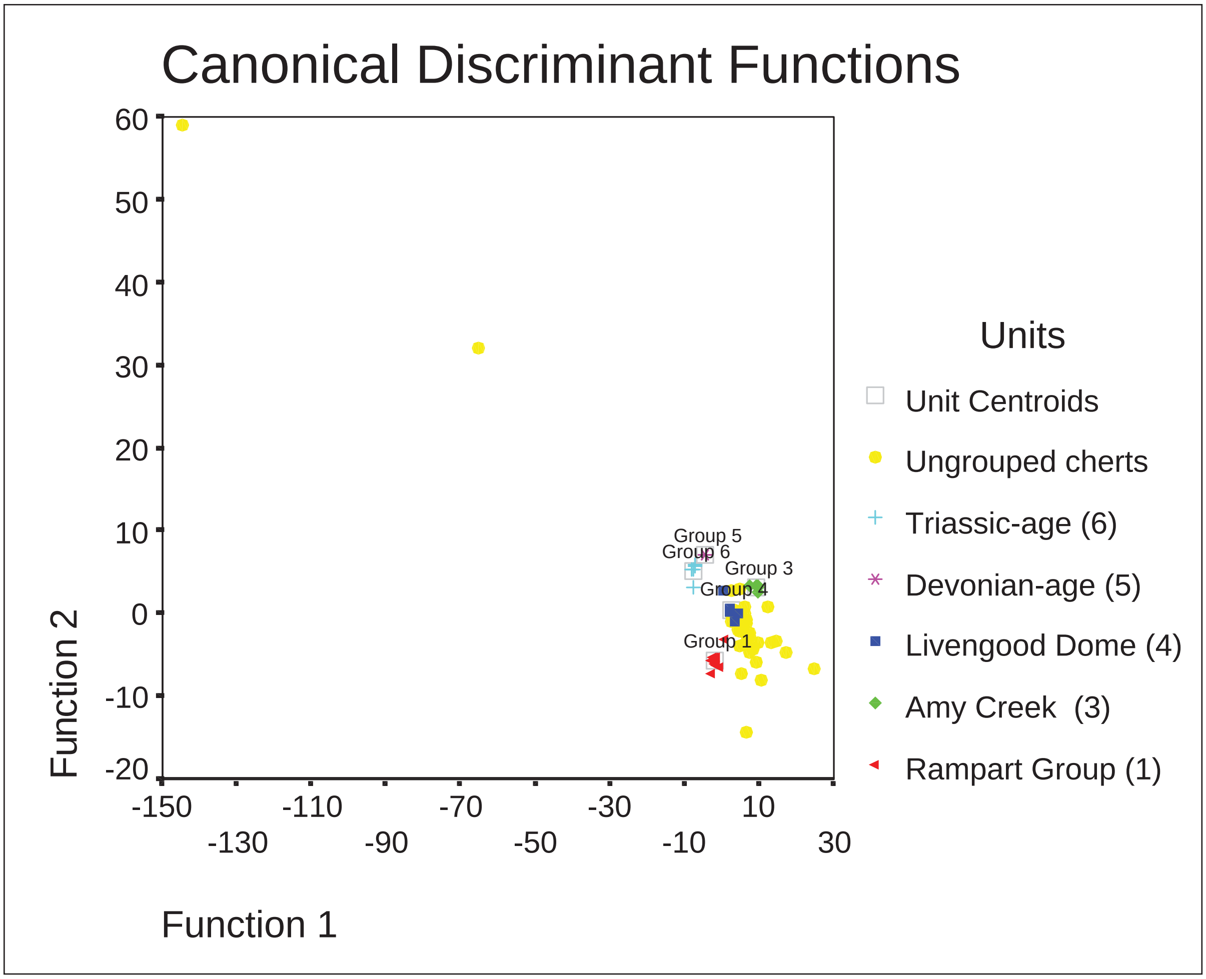

Figure 3. Unknown chert samples; each type locale unit plots separately and uniquely. Function 1 and Function 2 are generated by the discriminant analysis and are listed in table 4 for each sample. The two outliers, KC31 and KC36, have highly anomalous phosphorous, common to rocks formed at the base of the continental slope (Sue Karl, personal commun., 1997). See table 1 for geochemical analyses and tables 2 through 6 for statistical data.

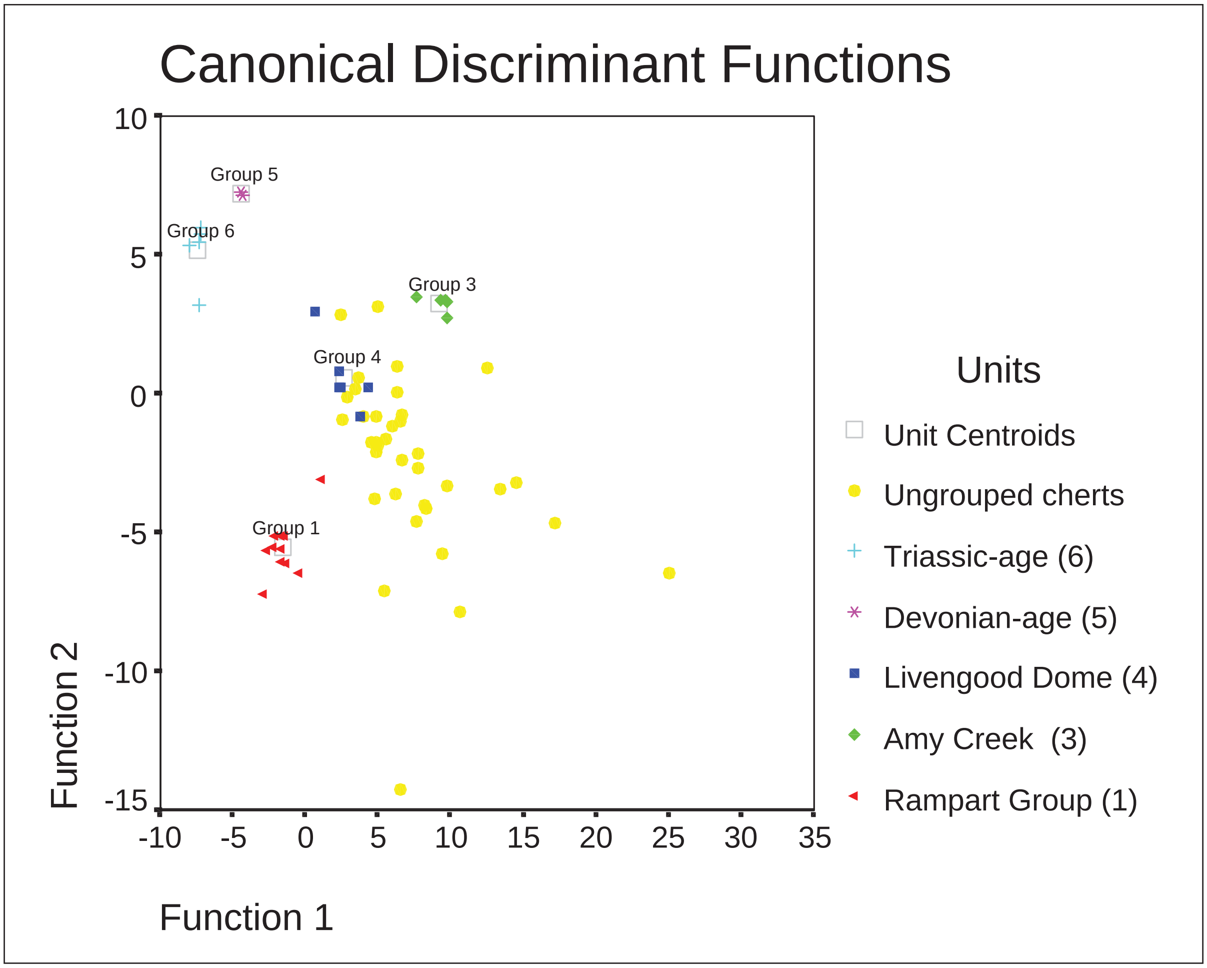

Figure 4. Unknown chert samples (excluding samples KC31 and KC36; see text). Function 1 and Function 2 are generated by the discriminant analysis and are listed in table 4 for each sample. The two outliers, KC31 and KC36, have highly anomalous phosphorous, common to rocks formed at the base of the continental slope (Sue Karl, personal commun., 1997). See table 1 for geochemical analyses and tables 2 through 6 for statistical data.

Table 4. The hypothesized rock unit for each chert sample shown next to the predicted unit generated by the discriminant analysis. The hypothesized unit is based on sample characteristics and lithologic associations.

Sample	Hypothesized Unit	Predicted	1st Prob.	2nd Prob.	Function1*	Function*2
JD169	L?	L	L/1	A/.0000	4.9521	-0.7805
JD46	L?	L	L/1	R/.0000	2.9101	-0.0916
KC33	L?	L	L/1	A/.0000	5.5187	-1.5855
KC48	L?	L	L/0.9227	A/.0773	6.6415	-0.7175
KC60	L?	A	A/.5036	L/.4964	6.3422	1.0126
KC62	L?	A	A/.7907	L/.2903	8.3293	-4.1132
KC67	L?	A	A/.8943	L/.1057	8.2794	-4.0013
RB37	L?	L	L/1	A/.0000	5.065	-1.8275
RB61	L?	L	L/1	A/.0000	3.7293	0.6237
SL126	L?	L	L/1	A/.0000	4.6168	-1.7303
SL149	L?	L	L/.9925	A/.0075	6.6097	-0.9541
SL151	L?	L	L/1	R/.0000	2.5396	-0.8896
SL190	L?	A	A/1	L/.0000	9.7917	-3.3067
SL44	L?	L	L/1	A/.0000	4.8719	-1.7257
SL80	L?	L	L/.9942	A/.0058	6.0588	-1.1092
SL88	L?	A	A/.6395	L/.3605	7.7571	-2.1321
KC236	L?	L	L/1	L/1	2.5233	2.8937
SL79A	A?	A	A/1	L/.0000	9.4273	-5.7065
JD175B	A?	A	A/1	A/1	12.5831	0.9572
KC176	A?	A	A/.9887	L/.0113	6.3598	0.1134
KC47	A?	A	A/1	L/.0000	7.7975	-2.658
KC98	A?	A	A/1	A/1	25.0369	-6.4501
RB111	A?	L	L/.9925	A/.0075	5.0246	3.1642
RB121	A?	A	A/1	A/1	17.1892	-4.6323
RB60	A?	A	A/.7618	L/.2382	6.6416	-2.3722
SL169	A?	A	A/1	R/.0000	10.6421	-7.8404
SL74C	A?	L	L/1	A/.0000	3.4261	0.1758
SL78	A?	A	A/1	A/1	14.6018	-3.1858
SL74D	L?A?	L	L/1	A/.0000	4.026	-0.7625
RB115	L?	L	L/1	A/.0000	4.9499	-2.0604
SL174	L?	L	L/.9972	R/.0028	4.7693	-3.7573
RB130	?	L	L/.9984	A/.0016	6.2407	-3.558
RR74B	?	R	R/1	R/1	6.5921	-14.2
JD119	?	A	A/1	A/1	13.4427	-3.39225
JD18	?	R	R/1	L/.0000	5.4927	-7.0479
KC63C	?	L	L/.9983	A/.0017	7.642	-4.537
KC31	A?	T	T/1	T/1	-64.9091	32.1456
KC36	A?	T	T/1	T/1	-144.3837	59.0735

*These functions are plotted in figures 3 and 4.

R=Rampart unit — R?=Hypothesized Rampart Group unit
A=Amy Creek unit — ?=Hypothesized Amy Creek unit
L=Livengood Dome unit — L?=Hypothesized Livengood Dome unit
T=Triassic-age unit

units (Sue Karl, personal commun., 1997).

None of the unknown chert samples are assigned to the Devonian-age Troublesome Creek chert unit from the central Livengood Quadrangle. This may be due to the small sample size of the Devonian-age type locale samples, resulting in a very small range of geochemical signatures. Known Devonian cherts were not easily accessible and consequently were not abundantly sampled.

K-MEANS CLUSTER ANALYSIS: METHODS AND RESULTS

Using SPSS for Windows, K-Means cluster analysis was applied to the geochemical data to test whether this statistical method could find natural clusters in the data. Hierarchical cluster analysis using normalized geochemical data was also performed, but was found not to be any different from K-means cluster analysis using raw data. After trying K-means cluster analysis with many different numbers of clusters, eight clusters was found to be the most descriptive in clustering the samples, allowing for clusters to be distinguished.

TYPE LOCALE CHERT SAMPLES

K-means cluster analysis was first applied to the geochemical data of the type locale chert samples. Final cluster centers, an analysis of variance table, and the cluster classifications are found in table 5. As shown in the cluster classification chart, the Rampart Group chert samples clearly do not cluster well into any one group. Amy Creek unit chert clusters well: three samples group together in cluster 3, one sample groups with cluster 2, and one sample groups with cluster 5. The Livengood Dome chert unit clusters very well with all six samples grouping together in cluster 1. The Devonian-age Troublesome Creek chert samples do not cluster together, but due to the small sample size this is not very significant. The Triassic-age chert samples cluster fairly well with two chert samples in cluster 1 and three samples in cluster 2. A large number of the samples from various rock units group into cluster 1, indicating that the data as a whole, due to a lack of compositional uniformity, does not cluster as well into five distinct groups as discriminant analysis suggests.

UNKNOWN CHERT SAMPLES

K-means cluster analysis applied to the geochemical data of the samples of uncertain rock unit affinity was conducted in two ways. First, K-means cluster analysis was applied to the original data. Of the chert samples that were hypothesized to be Livengood Dome chert, all samples group together in cluster 1. The hypothesized Amy Creek chert samples cluster in three different groups; two samples with cluster 2, two samples with cluster 4, and seven samples with cluster 1. Of the samples that are of unknown affinity two samples group with cluster 2 and eight samples group with cluster 1 (figs. 3 and 4).

The second method used the assignments given to the unknown chert samples by discriminant analysis previously conducted to see how well those assignments clustered. The cherts assigned to Rampart Group do not cluster well; one sample groups with cluster 8, two samples group with cluster 2, two samples group with cluster 3, two samples group with cluster 5, one sample groups with cluster 6, and five samples group with cluster 1. Chert samples assigned to Amy Creek unit also do not cluster well, although slightly better than the Rampart Group: three samples group with cluster 2, two samples group with cluster 4, three samples group with cluster 3, one sample groups with cluster 7, and ten samples group with cluster 1. Chert samples assigned to Livengood Dome chert unit cluster well; two samples group with cluster 2, and 24 samples group with cluster 1. The Devonian-age Troublesome Creek chert samples only have two assignments, making the sample size too small to make generalizations. The chert samples assigned to the Triassic-age unit cluster well; three samples group with cluster 2, and four samples group with cluster 1.

Table 6 displays the K-means cluster analysis of original data from chert samples of unknown units, the final cluster centers, analysis of variance (ANOVA) data, and cluster classifications of samples. Table 7 shows K-means cluster analysis of discriminant analysis data, final cluster centers, and ANOVA.

Table 5. K-means cluster analysis of type locale chert data, final Cluster Centers

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Al_2O_3	2.5	3.9	3.7	5.2	2.3	6.5	8.1	10.9
Ba	108.2	369.3	1223.2	2122.7	4938.0	7165.5	2881.4	2606.8
CaO	.46	.03	.19	.21	.00	.66	.72	.06
Ce	14.9	15.4	4.6	18.4	14.9	9.0	2.5	17.3
Cr	7.8	9.9	3.9	13.8	.00	173.3	15.2	8.3
Fe_2O_3	1.7	2.9	1.5	2.9	.24	2.5	4.4	4.4
K_2O	.25	.51	.40	1.1	.22	1.1	1.3	2.3
La	4.0	7.0	2.3	7.2	15.2	15.6	7.9	5.4
MgO	.75	1.4	1.3	2.5	.19	3.7	2.4	3.8
MnO	.08	.12	.03	.07	.00	.09	.40	.12
Na_2O	.58	.39	.59	.07	.00	.93	.21	.72
P_2O_5	.03	.06	.04	.04	.76	.54	.06	.05
Rb	9.3	15.2	13.4	44.0	9.8	18.5	41.6	70.4
SiO_2	93.2	90.0	91.6	87.4	96.4	81.7	81.0	76.4
Sr	28.6	15.4	29.6	12.7	134.5	69.5	22.4	21.9
TiO_2	.1371	.18	.14	.22	.11	.30	.37	.45
V	25.8	71.3	76.9	82.0	157.5	180.3	60.3	115.8
Y	6.0	8.5	7.1	10.1	47.7	48.5	19.7	10.4
Zr	36.8	51.6	38.6	54.8	24.7	83.6	70.5	111.9

Highlighted cells are element values that characterize the particular cluster.

Cluster Classification:

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Total
Rampart Group	3 samples	2	2	1		1	1	1	**11**
Amy Creek		1	3		1				**5**
Livengood Dome	6								**6**
Devonian-age	1			1					**2**
Triassic-age	2	3							**5**
Total	**12**	**6**	**5**	**2**	**1**	**1**	**1**	**1**	**29**

Analysis of Variance (ANOVA)

Variable	Cluster MS	DF	Error MS	DF	F	Prob.
Al_2O_3	14.6700	7	10.342	21	1.4184	.250
Ba	10590625.3902	7	5020.674	21	2109.4030	.000
CaO	.1788	7	.469	21	.3805	.903
Ce	91.4051	7	252.545	21	.3619	.914
Cr	3811.8904	7	131.311	21	29.0294	.000
Fe_2O_3	3.2977	7	3.975	21	.8296	.575
K_2O	.8044	7	.181	21	4.4429	.004
La	42.4401	7	36.625	21	1.1588	.367
MgO	2.9663	7	1.103	21	2.6870	.037
MnO	.0187	7	.010	21	1.8032	.140
Na_2O	.1605	7	.730	21	.2196	.977
P_2O_5	.1009	7	.002	21	38.4377	.000
Rb	823.9582	7	246.988	21	3.3360	.015
SiO_2	73.3862	7	246.988	21	3.3360	.015
Sr	2069.6027	7	590.047	21	3.5075	.012
TiO_2	.0226	7	.028	21	.8018	.595
V	6303.1727	7	30.716	21	15.0360	.000
Y	461.8463	7	30.716	21	15.0360	.000
Zr	1203.5393	7	2649.203	21	.4543	.856

Highlighted elements show significant variability between clusters at the 95 percent confidence level

Table 6. K-means cluster analysis of original data, chert samples from unknown units, final Cluster Centers.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Al_2O_3	1.9	3.2	3.7	3.4	9.5	5.2	2.3	6.5
Ba	92.5	399.6	1223.2	919.4	2744.1	2122.7	4938.0	7165.5
CaO	.41	.07	.19	.04	.39	.21	.00	.66
Ce	14.5	16.0	4.6	4.7	9.9	18.4	14.9	9.0
Cr	4.8	7.4	3.9	.00	11.8	13.8	.00	173.3
Fe_2O_3	.80	2.0	1.5	.69	4.4	2.9	.24	2.5
K_2O	.30	.48	.40	.69	1.8	1.1	.22	1.1
La	3.3	5.4	2.3	3.4	6.6	7.2	15.2	15.6
MgO	.47	1.0	1.3	.62	3.1	2.5	.19	3.7
MnO	.04	.08	.03	.00	.26	.07	.00	.09
Na_2O	.18	.24	.59	.01	.46	.07	.00	.93
P_2O_5	.24	.09	.04	.14	.06	.04	.76	.54
Rb	8.7	13.2	13.4	16.4	56.0	44.0	9.8	18.5
SiO_2	95.1	92.5	91.6	95.0	78.7	87.4	96.4	81.7
Sr	16.6	15.0	29.6	13.8	22.1	12.7	134.5	69.5
TiO_2	.08	.14	.14	.11	.41	.22	.11	.30
V	28.0	61.9	76.9	150.1	88.0	82.0	157.5	180.3
Y	6.5	7.9	7.1	5.9	15.0	10.1	47.7	48.5
Zr	16.9	36.1	38.6	18.3	91.2	54.8	24.7	83.6

Highlighted cells are element values which characterize the particular cluster.

Cluster Classification:

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Total
Rampart Group	3	2	2		2	1		1	**11**
Amy Creek		1	3				1		**5**
Livengood	6								**6**
Devonian-age	1					1			**2**
Triassic-age	2	3							**5**
Hypothesized Liv	17								**17**
Hypothesized Amy	7	2		2					**11**
Unknown unit chert	8	2							**10**
Total	**44**	**10**	**5**	**2**	**2**	**2**	**1**	**1**	**67**

Analysis of Variance (ANOVA)

Variable	Cluster MS	DF	Error MS	DF	F	Prob.
Al_2O_3	22.5801	7	5.108	59.0	4.4203	.001
Ba	12793546.7485	7	5843.948	59.0	2189.1956	.000
CaO	.2048	7	1.421	59.0	.1440	.994
Ce	108.0647	7	220.859	59.0	.4893	.839
Cr	4022.6693	7	93.883	59.0	42.8476	.000
Fe_2O_3	6.0746	7	1.954	59.0	3.1083	.007
K_2O	.8429	7	.123	59.0	6.8070	.000
La	50.2703	7	45.115	59.0	1.1143	.366
MgO	4.5446	7	.564	59.0	8.0457	.000
MnO	.0161	7	.006	59.0	2.4600	.028
Na_2O	.2241	7	.314	59.0	.7132	.661
P_2O_5	.1191	7	.799	59.0	.1491	.993
Rb	928.2761	7	129.649	59.0	7.1599	.000
SiO_2	116.3523	7	26.159	59.0	4.4478	.001
Sr	2422.8500	7	616.478	59.0	3.9301	.001
TiO_2	.0431	7	.012	59.0	3.3955	.004
V	11375.1142	7	1301.690	59.0	8.7387	.000
Y	489.1197	7	168.833	59.0	2.8971	.011
Zr	2720.3168	7	1169.045	59.0	2.3270	.036

Highlighted elements show significant variability between clusters at the 95 percent confidence level.

Table 7. K-means cluster analysis of discriminant analysis data, final Cluster Centers

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Al_2O_3	1.9	3.2	3.7	3.4	9.5	5.2	2.3	6.5
Ba	92.5	399.6	1223.2	919.4	2744.1	2122.7	4938.0	7165.5
CaO	.41	.07	.19	.04	.39	.21	.00	.66
Ce	14.5	16.0	4.6	4.7	9.9	18.4	14.9	9.0
Cr	4.8	7.4	3.9	.00	11.8	13.8	.00	173.3
Fe_2O_3	.80	2.0	1.5	.69	4.4	2.9	.24	2.5
K_2O	.30	.48	.40	.69	1.8	1.1	.22	1.1
La	3.3	5.4	2.3	3.4	6.6	7.2	15.2	15.6
MgO	.47	1.0	1.3	.62	3.1	2.5	.19	3.7
MnO	.04	.08	.03	.00	.26	.07	.00	.09
Na_2O	.18	.24	.59	.01	.46	.07	.00	.93
P_2O_5	.24	.09	.04	.14	.06	.04	.76	.54
Rb	8.7	13.2	13.4	16.4	56.0	44.0	9.8	18.5
SiO_2	95.1	92.5	91.6	95.0	78.7	87.4	96.4	81.7
Sr	16.6	15.0	29.6	13.8	22.1	12.7	134.5	69.5
TiO_2	.08	.14	.14	.11	.41	.22	.11	.30
V	28.0	61.9	76.9	150.1	88.0	82.0	157.5	180.3
Y	6.5	7.9	7.1	5.9	15.0	10.1	47.7	48.5
Zr	16.9	36.1	38.6	18.3	91.2	54.8	24.7	84.0

Highlighted cells are element values which characterize the particular cluster.

Cluster Classification:

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Total
Rampart Group	5	2	2		2	1		1	**13**
Amy Creek	10	3	3	2			1		**19**
Livengood	24	2							**26**
Devonian-age	1					1			**2**
Triassic-age	4	3							**7**
Total	**44**	**10**	**5**	**2**	**2**	**2**	**1**	**1**	**67**

Analysis of Variance (ANOVA)

Variable	Cluster MS	DF	Error MS	DF	F	Prob.
Al_2O_3	22.5801	7	5.108	59.0	4.4203	.001
Ba	12793546.7485	7	5843.948	59.0	2189.1956	.000
CaO	.2048	7	1.421	59.0	.1440	.994
Ce	108.0647	7	220.859	59.0	.4893	.839
Cr	4022.6693	7	93.883	59.0	42.8476	.000
Fe_2O_3	6.0746	7	1.954	59.0	3.1083	.007
K_2O	.8429	7	.123	59.0	6.8070	.000
La	50.2703	7	45.115	59.0	1.1143	.366
MgO	4.5446	7	.564	59.0	8.0457	.000
MnO	.0161	7	.006	59.0	2.4600	.028
Na_2O	.2241	7	.314	59.0	.7132	.661
P_2O_5	.1191	7	.799	59.0	.1491	.993
Rb	928.2761	7	129.649	59.0	7.1599	.000
SiO_2	116.3523	7	26.159	59.0	4.4478	.001
Sr	2422.8500	7	616.478	59.0	3.9301	.001
TiO_2	.0431	7	.012	59.0	3.3955	.004
V	11375.1142	7	1301.690	59.0	8.7387	.000
Y	489.1197	7	168.833	59.0	2.8971	.011
Zr	2720.3168	7	1169.045	59.0	2.3270	.036

Highlighted elements are significant at the 95 percent confidence level.

CONCLUSIONS

Discriminant analysis of the type locale cherts results in data that distinguish between the five different rock units, verifying that discriminant analysis is a viable means for differentiating between our chert units based on geochemistry. Applying discriminant analysis to both the major oxide and minor element data results in better correlation between the type locale cherts and the predicted units than major or minor element analysis alone. However, simple plots such as a plot of vanadium versus magnesium oxide (fig. 5) in most cases shows pronounced and distinct differences between chert samples from our different known rock units. These types of ratios can be calculated using modern principal component analysis (PCA) and then tested to evaluate potential statistical groupings.

K-means cluster analysis suggests that the Rampart Group chert unit is heterogeneous in nature and does not cluster well into any one group. All the Rampart samples were collected from the area previously mapped as Rampart Group in the Tanana B-1 Quadrangle (Reifenstuhl and others, 1997; Wilson and others, 1998) on the basis of the associated gabbros and basalts. Due to the structural complexities and numerous faults in the area, the heterogeneous nature of the Rampart Group cherts suggested by cluster analysis may indicate that some of the chert samples previously mapped as Rampart Group cherts are in fact not Rampart Group cherts, but fault slivers from other units.

The K-means cluster analysis is most applicable in differentiating the Livengood Dome chert unit, which clusters very well, suggesting a homogenous nature. Chert sample KC317, which was collected from the Yukon Territory, Canada, from similar Ordovician-age stratigraphy and with similar lithologic associations, falls into the Livengood chert unit, indicating a long-distance correlation. In contrast, discriminant analysis differentiates into the five distinct units, but the difference between Livengood Dome unit chert and Amy Creek unit chert is often difficult to assess based on chemical analysis alone.

The tendency for the Amy Creek chert unit and the Triassic-age chert unit to form distinct compositional clusters is between that of Livengood and Rampart. Consequently, discriminant analysis is a generally useful tool in assigning unknown chert samples to those units.

In general, when discriminant analysis is applied and the data are assigned to predetermined groupings, there is little difficulty assigning each sample to a group. In contrast, when K-means cluster analysis is applied, creating natural clusters, it is more difficult to distinguish between different groups.

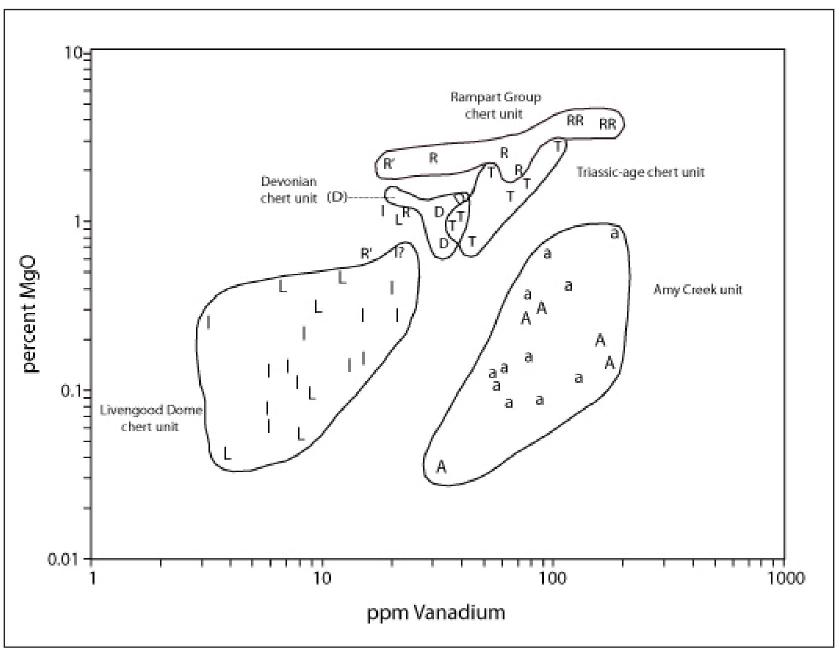

Figure 5. Plot of magnesium oxide (MgO) versus vanadium (V) for chert samples. R=Rampart Group type locale chert, R'=hypothesized Rampart Group chert, T=Triassic-age chert, D=Devonian-age Troublesome Creek chert, L=Livengood Dome type locale chert, l=hypothesized Livengood Dome chert, A=Amy Creek type locale chert, a=hypothesized Amy Creek chert. See table 1 for geochemical data.

Our pilot study suggests that chert samples from our five mappable units generally have distinguishable geochemical signatures. However, all units, and especially the Devonian unit, must be carefully considered due to small sample size, which may or may not be representative of the entire unit. Correlations generated by discriminant analysis and K-means cluster analysis are useful, but should be tempered with geologic field relationships, lithologic associations, and considerations of the original depositional environment. We encourage others to further test the application of this potentially powerful tool.

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