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INVESTIGATION OF RARE-EARTH ELEMENTS AND ZIRCONIUM IN THE NORTHERN WINDY FORK PERALKALINE PLUTON, WEST-CENTRAL ALASKA

by

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Units of measure abbreviations used in this report

cps	count per second
ft	foot, feet
g	gram
in	inch
long	longitude
lat	latitude
lb	pound
lb/yd^3	pounds per cubic yard
mi	mile
Ma	million years
pct	percent
ppm	parts per million
µm	micrometer, micron
st	short ton
yd^3	cubic yard

INVESTIGATION OF RARE-EARTH ELEMENTS AND ZIRCONIUM IN THE NORTHERN WINDY FORK PERALKALINE PLUTON, WEST-CENTRAL ALASKA

by
James C. Barker[1]

Abstract

The northern Windy Fork peralkaline pluton was investigated as part of the U.S. Bureau of Mines Strategic and Critical Minerals Program in Alaska. The pluton is about 85 miles south of McGrath, west-central Alaska. Relatively abundant ilmenite, zircon, and rare-earth-element-bearing minerals are liberated by glacial scour and frost fracturing of granitic bedrock and concentrated in glaciofluvial outwash features. An outwash fan is estimated to contain 17 million yds^3 or more at a sub-economic grade of 20–25 lbs/yd^3 of heavy minerals based on surface samples. No subsurface sampling was possible at the time.

The heavy minerals are derived from peralkaline plutonic rocks where they occur as widely disseminated accessory minerals. No evidence was found, either in situ or in float, to indicate significant mineralization occurs as potentially economic lode deposits in the pluton. The northern Windy Fork pluton is deeply eroded and mostly lacking mappable, late-state, volatile-rich hydrothermal fluids or magmas.

INTRODUCTION

In July 1988, the U.S. Bureau of Mines (USBM) conducted a reconnaissance-level investigation of the northern Windy Fork pluton located in the McGrath A-3 Quadrangle (fig. 1). The pluton extends south into the Lime Hills D-3 and D-4 quadrangles, but due to logistical constraints it was not possible to include the Lime Hills area. The project was performed in cooperation with the Alaska Division of Geological & Geophysical Surveys (DGGS), which provided helicopter support and the geological assistance of D.N. Solie. Ten days were spent in the field for the purpose of determining estimated grade-per-unit-volume values for samples containing niobium, titanium, rare-earth elements (REE), yttrium, zirconium, and other associated lithophile elements.

This project was undertaken to follow up on previous studies that indicated the possibility of uranium and REE occurrences in the pluton area. Reed and Miller (1980) reported radioactive zones and anomalous U-Th values in the granite and originally observed the compositional similarity between the Windy Fork and Bokan Mountain plutons. Sampling by Gilbert and Solie (1983) and Solie (1983) of the McGrath A3 Quadrangle showed that the Windy Fork pluton has a peralkaline composition not unlike that of Bokan Mountain in Southeast Alaska, where extensive REE mineral deposits are known (Solie, 1983; Warner and Barker, 1989). There have been no reported mineral discoveries in the Windy Fork area by private industry.

LOGISTICS

The study area was accessed by helicopter in July 1988 from the village of McGrath, which is about 85 air miles north of the Windy Fork pluton. A camp was set up at the confluence of a small stream draining the Windy Fork pluton, and the Windy Fork River (fig. 2) at an elevation of 2,900 ft. Campsites are best placed along the lower portions of side tributaries, where some protection is afforded from the valley winds.

There are several private cabins in the area with short, unimproved airstrips, which could provide future access with permission. The Windy Fork River is cautiously navigable, and an inflatable canoe was used to move to a second spike camp location.

The perimeter of the pluton can be reached on foot along various creeks that drain the central glacial ice and along several ridges that reach up to the contact. Access to the interior of the pluton, which is largely covered in ice, requires mountaineering experience.

GEOLOGY

The Windy Fork pluton intrudes the Dillinger terrane, which locally comprises limestone, shale, and volcaniclastic rocks. Local geology was mapped at 1:63,360 scale by Gilbert and Solie (1983). The pluton is indicated to be Tertiary age; two K-Ar dates (30.1 ± 0.9 Ma and 29.0 ± 0.9 Ma) were reported by Reed and Lanphere (1972).

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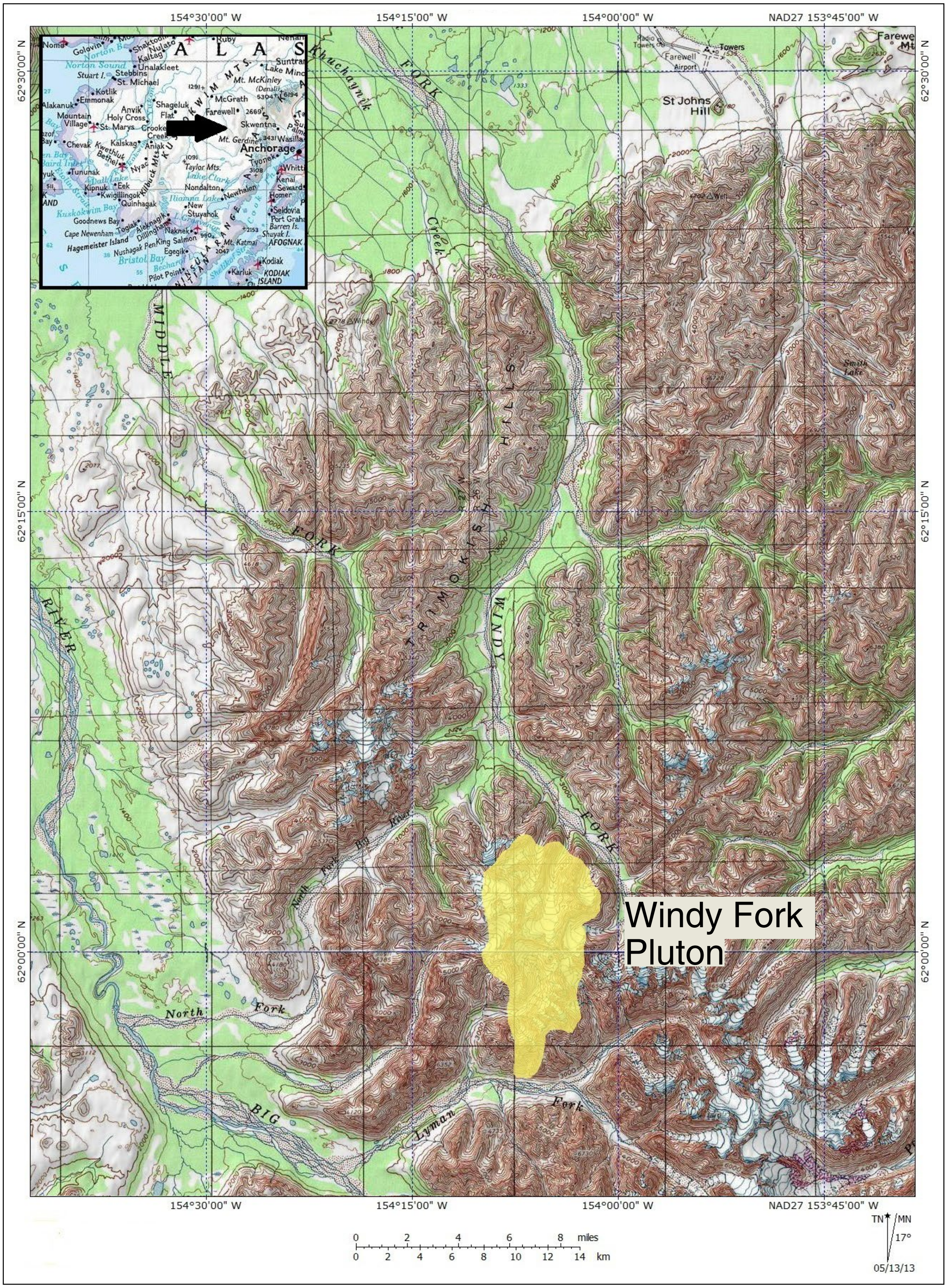

Figure 1. Location of the Windy Fork pluton in west-central Alaska.

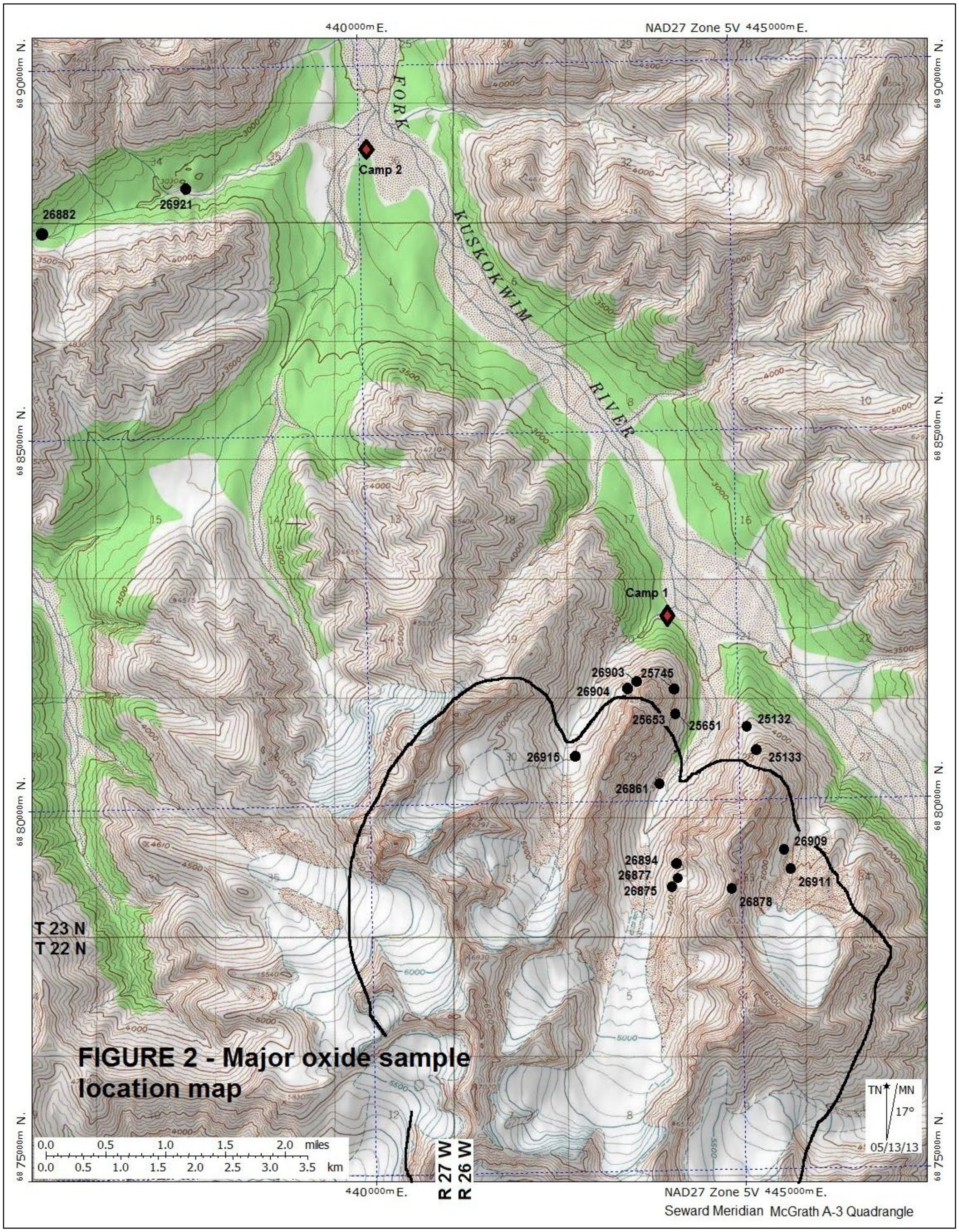

Figure 2. Major oxide sample location map. Red diamonds with black outlines mark the locations of camps used during fieldwork; black dots with sample numbers show sample locations. Black line records approximate north margin of the Windy Fork pluton. Sample descriptions and analytical data are listed in table 1, except for sample number 26903 which was collected for trace-element geochemistry and is presented in appendix A and 25653 which is a pan concentrate sample and are presented in table 2.

The Windy Fork pluton is almost entirely composed of riebeckite granite, with subtle color variations on weathered surfaces. Minor amounts of riebeckite–biotite granite were found, but only in float. In the northern portion of the pluton examined in this study, there are no coarse-grained phases, little aplite, and no syenite or gabbro such as was reported at the Middle Fork pluton nearby (Gilbert and Solie, 1983; Solie, 1983).

The chemical composition of the pluton is generally peralkaline granite. Table 1 lists the oxide percentages, CIPW norms, and sample descriptions for representative rock samples collected from phases of the Windy Fork pluton. Peralkaline granite of unknown extent was also found 5 miles northwest of the pluton (sample KS26882; fig. 2). Additional rock samples (fig. 3) were collected for multi-element analyses and results are presented in Appendix A.

The Windy Fork pluton characteristically exhibits a high radiometric response. Readings taken along foot traverses, using a handheld scintillometer, generally ranged from 600 to 800 counts per second (cps), which is two to three times normal background encountered in Alaska granitic rocks by the author.

Only one relatively small area of differentiated, late-stage intrusive rocks was found. The area forms a crude E–W zone through the central portions of Sections 32 and 33, T23N, R26W, Seward Meridian, and is variably iron-stained. In this area, narrow pegmatite pods, which registered up to 4,000 cps, are present (sample KS26867; fig. 3), as are units of limonitic biotite aplite, fine-grained riebeckite–biotite granite, and rhyolite. Pegmatites are podiform shaped and do not exceed 10 to 20 ft in their longest dimension. The zone is also characterized by an overall higher radiometric background (about 2 times normal) compared to the riebeckite granite elsewhere in the pluton. A fine- to medium-grained riebeckite granite phase found in the zone near the ridge crest of Sec. 33 typically ranges from 900 to 2,000 cps. Minor disseminated accessory allanite and monazite have been tentatively identified to be the cause of the radioactivity (see KS26878 and KS26895, fig. 3, appendix A).

The Windy Fork pluton has been cut by basalt, andesite porphyry, and aplite dikes. One agpaitic dike containing eudialyte was noted by Reed and Miller (1980) (see KS25743 and KS26907–KS26908, fig. 3, appendix A) and further characterized as a REE-poor eudialyte by Johnson and others (1990). It intrudes the Windy Fork pluton and was found to be 2 ft wide, but could be traced for only 30 ft. A chip sample (KS25743) from the eudialyte dike contained 0.49 percent Zr but no appreciable REE (for example, Ce=131 parts per million [ppm]). Sample descriptions and multi-element analytical results from dikes and differentiated zones in the Windy Fork pluton are recorded in Appendix A. Quality control check assays and expanded REE analyses are found in Appendix B.

The Windy Fork granite has a narrow contact zone, generally no more than 200 ft wide, where variable fine-grained textures and silicified zones occur. Country rock has been recrystallized near the intrusive contact, but no skarn-bearing material was noted in situ or in creek float. Hornfels and silicification extends relatively short distances from the contact.

At several locations dikes radiate from within or near the main intrusive body into country rock, however, their relationship to the pluton, if any, was not evident. Dike composition ranges from rhyolite to pyroxenite. The texture is generally fine grained, and the dikes dip almost or close to vertical. Rhyolitic dikes are slightly radioactive; the more mafic dikes are iron-stained from finely disseminated pyrite and pyrrhotite.

MINERALIZATION

Mineralized bedrock in the plutonic complex is limited to small, discontinuous pegmatite pods of little apparent economic interest. However, extensive glacial scouring of the pluton may have formed alluvial placer deposits of heavy minerals in streams draining the Windy Fork pluton. First-order streambeds and fan deposits draining the plutonic rocks contain unusually abundant concentrations of heavy minerals (table 2, fig. 4), and natural bands of black sand are common wherever finer fluvial sediments have accumulated. Natural surface accumulations or bands of heavy minerals, including the immediate outfall at the front (snout) of glacial ice, are noticeably radioactive (up to 600 cps) from contained allanite and thorite. Heavy mineral concentrates are composed of up to 50 percent magnetite and ilmenite with additional zircon and monazite. Heavy mineral grains all passed through 16 mesh screen during field screening and are visually estimated to be less than 35 mesh or finer in size.

At least 4,000 ft of incised vertical relief is present in the Windy Fork pluton from glacial scouring, indicating that massive amounts of granite have been removed. As typified by sample KS26865, taken at the base of a cirque glacier, abundant heavy minerals are present in the fine-grained fraction of recently deposited glacial sediment. Conversely, pan sampling in creeks draining only the surrounding sedimentary rocks showed no appreciable concentrations of heavy minerals (for example, KS25136).

Table 1. Normalized major oxide and CIPW norms, samples from Windy Fork pluton and plutonic float samples to the northwest. Sample locations are depicted in figure 2.

	KS25132	**KS25133**	**KS25651**	**KS25745**	**KS26861**	**KS26875**	**KS26877**	**KS26878**	**KS26882**	**KS26894**	**KS26904**	**KS26909**	**KS26911**	**KS26915**	**KS26921**
SiO_2	75	74.7	74.2	46.7	74.9	76.1	75.86	73.1	71.6	73.8	73.10	74.6	71.9	71.4	75.4
Al_2O_3	13.2	12.6	12.6	11.2	11.3	11.3	11.6	12.1	12.7	12.4	12.60	12.1	12.2	13.5	12.7
CaO	0.37	0.68	4.6	8.52	0.34	0.2	0.22	0.5	0.52	0.62	0.37	0.33	0.57	1.06	0.7
MgO	0.27	0.04	0.01	5.49	0.06	0.01	0.01	0.08	0.01	0.10	0.01	0.01	0.11	0.28	0.01
Na_2O	3.9	3.79	0.44	2.9	4.87	4.24	4.21	4.66	5.53	5.06	5.07	4.57	4.86	4.21	3.79
K_2O	5.47	5.98	4.96	0.41	3.63	4.16	4.45	4.59	4.92	4.58	5.08	4.57	4.65	4.91	4.43
Fe_2O_3	0.37	0.41	0.53	5.48	1.4	1.12	0.86	1.03	1.38	0.98	0.86	0.94	1.08	0.93	0.46
FeO	0.61	0.69	0.88	9.65	2.34	1.86	1.44	1.72	2.3	1.64	1.44	1.57	1.8	1.55	0.76
MnO	0.01	0.02	0.03	0.24	0.12	0.01	0.05	0.06	0.08	0.07	0.05	0.06	0.07	0.05	0.03
P_2O_5	0.02	0.02	0.02	0.33	0.02	0.02	0.01	0.05	0.02	0.04	0.02	0.02	0.04	0.07	0.02
TiO_2	0.13	0.12	0.03	0.24	0.101	0.11	0.11	0.06	0.28	0.23	0.05	0.19	0.07	0.05	0.1
Quartz	30.16	29.04	44.14	4.93	31.48	34.66	33.58	27.76	21.94	26.45	25.66	29.86	25.57	25.59	35.1
Orthoclase	32.54	35.67	29.79	2.55	21.65	24.78	26.68	27.65	29.67	27.2	30.40	27.29	28.18	29.54	26.6
Albite	33.22	31.82	3.78	25.86	38.26	35.27	35.4	37.39	38.18	38.47	36.98	37.18	37.81	36.27	32.59
Anorthite	1.76	—	18.04	17.21	—	—	—	—	—	2.86	—	—	—	3.5	3.4
Aemite	—	0.49	—	—	2.93	0.81	0.65	2.47	4.03	2.86	2.53	1.67	3.22	—	—
Corundum	0.24	—	—	—	—	—	—	—	—	—	—	—	—	—	0.45
Na–Metasilicate	—	—	—	—	—	—	—	—	1.01	0.31	0.83	—	0.17	—	—
Diopside	7.51	1.93	2.07	20.31	1.39	0.77	0.93	1.94	2.2	2.45	1.54	1.36	2.62	1.18	—
Hypersthene	1.3	—	—	—	3.47	2.2	1.58	1.98	2.8	1.71	1.71	1.7	2.24	1.87	0.95
Wollastonite	—	0.45	1.12	12.02	—	—	—	—	—	—	—	—	—	—	—
Magnetite	0.53	0.36	0.78	8.37	0.59	1.23	0.94	0.29	—	—	—	0.54	—	1.37	0.67
Ilmenite	0.25	0.23	0.21	7.97	0.19	0.21	0.21	0.43	0.54	0.44	0.31	0.37	0.41	0.5	0.19
Apatite	0.05	0.05	0.05	0.81	0.05	0.05	0.02	0.12	0.05	0.09	0.05	0.05	0.1	0.17	0.05

DESCRIPTIONS

KS25132	Banded red–brown-weathering rhyolite
KS25133	Peralkaline fine-grained dike intruding a banded siltstone–chert
KS25651	Rhyolite dike
KS25745	Pyroxenite dikes
KS26861	Riebeckite-bearing peralkaline dike cutting medium-grained granite
KS26875	Quartzofeldspathic dike in riebeckite granite
KS26877	Aplite to fine-grained biotite granite (peralkaline)
KS26878	Peralkaline riebeckite granite
KS26882	Peralkaline riebeckite granite with aegirine
KS26894	Equigranular coarse-grained peralkaline granite
KS26904	Equigranular coarse-grained peralkaline granite dike
KS26909	Peralkaline granite porphyry
KS26911	Peralkaline granite
KS26915	Amphibole–biotite porphyritic alkali granite
KS26921	Rhyolite dike

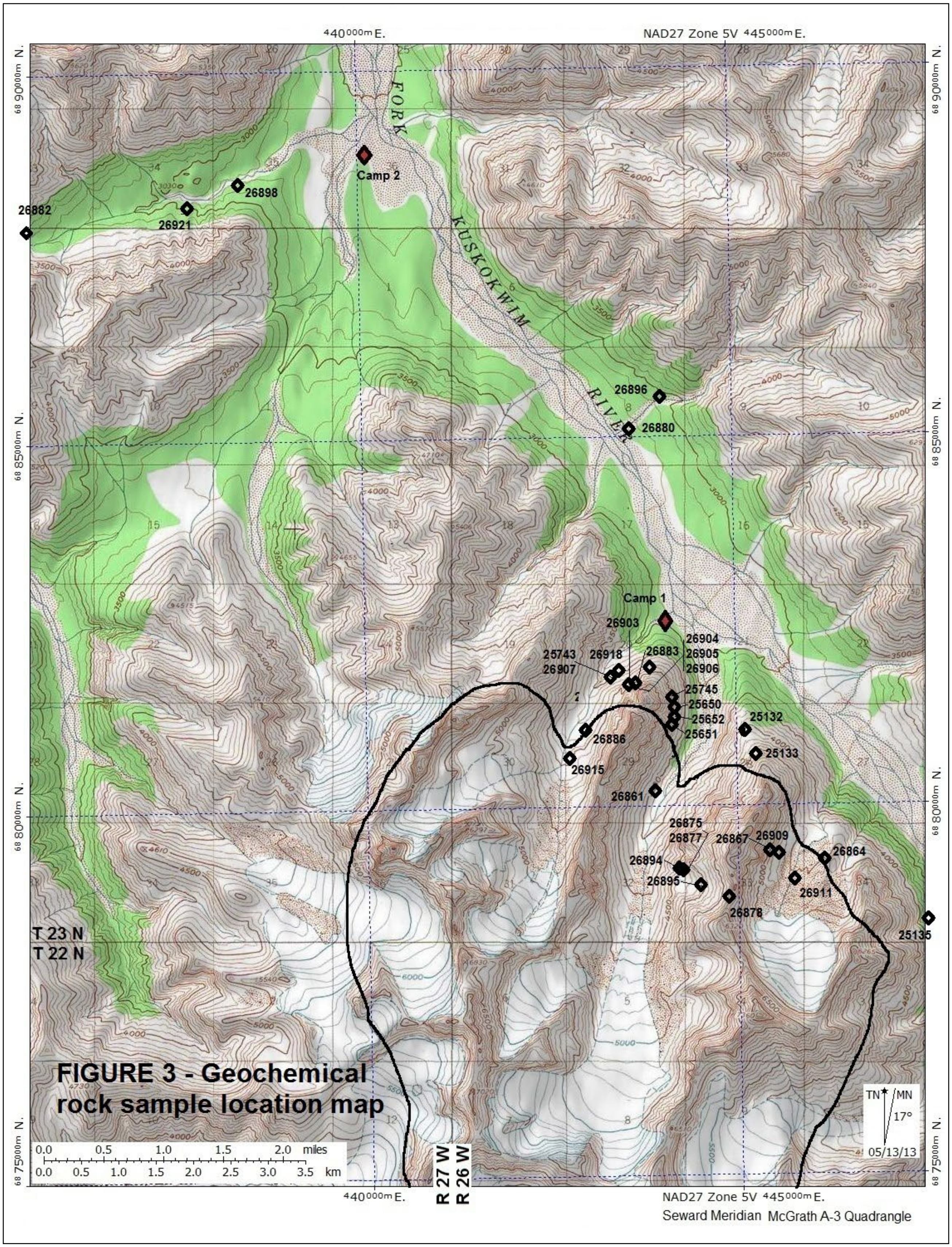

Figure 3. Geochemical rock sample location map. Red diamonds with black outlines mark the locations of camps used during fieldwork; empty black diamonds with sample numbers show sample locations. Black line records approximate north margin of the Windy Fork pluton. Sample descriptions and analytical data are listed in Appendix A.

Table 2. Analyses[a] (in ppm) of pan concentrates from the Windy Fork pluton and vicinity. Sample locations are depicted in Figure 4, except for sample KS25653 which is depicted in figure 2.

Sample Number	Nb	Sn	Ta	Th	Ti	U	W	Y	Zr	La	Ce	Total[b] Sample wt (kg)	Concentrate wt (g)
KS25134	60	2	2	65	4,300	23	3	120	1,800	169	330	35.71	105.4
KS25136	16	11	2	2	2,900	2	3	24	320	39	74	47.62	89.7
KS25653	460	210	2	870	75,000	383	3	380	29,000	2,150	2,890	0.24	242.4
KS26863	210	28	2	200	9,000	83	3	360	8,900	676	1,070	5.43	81.1
KS26866	270	72	2	340	15,000	110	3	500	9,400	1,060	1,700	2.72	35.3
KS26869	20	2	2	2	2,600	2	3	23	410	37	71	35.71	36.5
KS26879	15	10	26	2	7,300	2	3	20	200	25	51	35.71	51.1
KS26881	180	12	2	100	10,000	79	3	150	9,300	417	648		44.3
KS26884	440	110	2	730	48,000	335	12	360	25,000	1,650	2,320	16.35	143.3
KS26885	370	120	2	650	44,000	356	3	350	26,000	1,480	2,070	16.30	164.6
KS26899	30	5	7	2	2,600	3	13	34	600	72	133	47.62	45.6
KS26900	12	7	2	2	3,100	2	3	19	330	40	75	47.62	235.0
KS26919	150	23	2	26	46,000	38	3	76	4,700	179	301	11.90	60.7
KS26920	70	2	19	2	20,000	2	11	52	1,100	83	161	23.81	30.5
KS26922	400	140	<2	510	33,000	202	22	380	13,000	1,500	2,160	38.05	425.8
KS26950	33	9	2	2	5,800	2	23	35	450	60	114	35.71	46.7
Lower Detection Limit	2	2	2	2	5	2	3	2	3	1	5		

[a] Analytical techniques used by Nuclear Activation Services, Ann Arbor, MI, include Nb, Sn, Ta, Th, Ti, U, W, Y, and Zr analyses by X-ray fluorescence. La and Ce analyses by instrument neutron activation analysis.
[b] Total weight is original sample weight, field measured prior to screening.

Descriptions

KS25134	Small drainage, few fines
KS25136	High-energy area directly below glacier; minor black sand
KS25653	Natural ½-in-thick black sand accumulation, black sand is radioactive; sample location is depicted in figure 2
KS26862	Aggregate is 50 percent granite, more silt and clay, less black sand than creek to north
KS26863	Glacial sand-sized material from edge of cirque below ice
KS26866	Sandy silt and grus at base of outcrop
KS26869	Float contains euhedral pyrite, minor galena
KS26879	Limestone and shale with minor mafic intrusive gravel, some Fe-stained carbonate, with sphalerite, minor black sand
KS26881	Mud and sand with black sand accumulations; bedrock is meta-sediment
KS26884	From cirque, sample is sand from between granitic boulders
KS26885	Taken from east tributary, abundant black sand
KS26899	Carbonate gravel, sand, no silt; minor granitic component, almost no black sand
KS26900	Carbonate bedrock with granitic boulders
KS26919	Fine sand and gravel on riebeckite–aegerine granite bedrock
KS26920	From creek draining dike swarm and glacial till, syenite bedrock
KS26922	No description available; field notes not available, and no location available, not depicted on map
KS26950	Creek drains dike swarm, glacial till covers area but creek has cut into bedrock, black sand absent

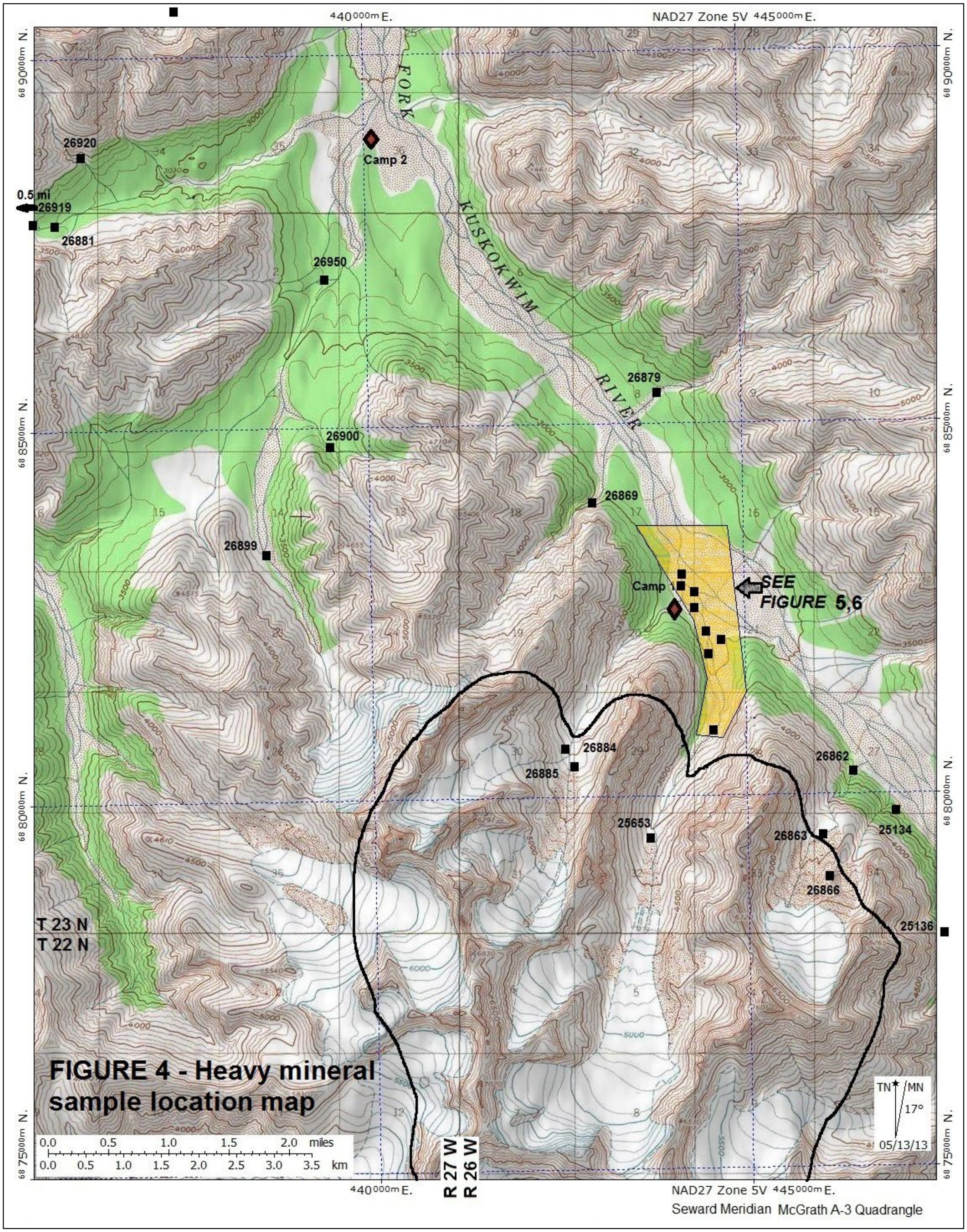

Figure 4. Heavy mineral sample location map. Red diamonds with black outlines mark the locations of camps used during fieldwork; black squares with sample numbers show sample locations. Yellow shaded area shows area of figures 5 and 6. Black line records approximate north margin of the Windy Fork pluton. Sample descriptions and analytical data are listed in table 3.

METHODS

Fluvial features were sampled by screening and panning measured volumes of gravel. The gravel was screened at 2 mesh (0.5 in) and 16 mesh (1 mm) and panned to about 50 percent of the -16 mesh volume. For larger bulk gravel samples (table 3), the partially concentrated sands were then further processed on a Wilfley table to recover the heavier black sands, which were dried, weighed, and split. An unknown amount of very-fine-sized heavy mineral was observed to be unrecoverable by this single-step tabling and was subsequently lost into tailings. One-half of the concentrate was analyzed by Nuclear Activation Services, Ann Arbor, Michigan, and the other half is currently archived at the DGGS Geologic Materials Center, Anchorage, Alaska). Table 2 lists the analytical methods, detection limits, and results for heavy mineral sampling. Quality control check assays and expanded REE analyses were completed at the USBM Albany Research Laboratory, Albany, Oregon (appendix B), and analytical results were found to be consistent with analyses provided in tables 2 and 3.

Grade calculations for samples from the alluvial outwash fan (fig. 5) were made for Ti, Zr, and La+Ce+Y, and compiled in table 3. Volumetric calculations were based on field tests using local gravels in which one loose, wet, cubic yard was calculated to weigh 3,770 lbs. This value was used to calculate grade for the total original sample. Similarly, this weight per cubic yard measurement was used to calculate grade for -0.5-inch size fraction. An in-place cubic yard is estimated to equal the weight of about 1.1 loose yd^3, or about 4,147 lbs.

Table 3. Resource evaluation of the alluvial outwash fan, Windy Fork pluton. Sample locations shown on figures 4 and 5.

Sample Number	Sample and fraction weights			Calculated values per cubic yard[a,b]					
	Total wt. (lbs.)	-0.5 inch (lbs.)	Heavy conc. (lbs.)	Zr		Ti		La +Ce+Y	
				%	lb/yd^3	%	lb/yd^3	%	lb/yd^3
KS25649	131	30	0.43	1.7	0.21	3.6	0.45	0.38	0.05
KS26862	92	34	0.43	1.7	0.30	4.4	0.78	0.49	0.09
KS26871	92	30	0.40	2.0	0.33	5.3	0.87	0.49	0.08
KS26872	84	46	0.94	1.3	0.55	3.3	1.39	0.40	0.17
KS26873	97	38	0.55	1.3	0.28	5.8	1.24	0.42	0.09
KS26887	36	36	0.52	2.5	1.37	6.2	3.39	0.56	0.30
KS26888	36	36	0.18	2.8	0.53	7.1	1.34	0.57	0.11
KS26890	30		0.36	1.3	0.59	1.5	0.68	0.27	0.12
KS26891	36	36	0.25	2.5	0.65	5.6	1.50	0.58	0.16
KS26892	105	36	0.37	1.1	0.15	2.3	0.31	0.34	0.05

[a] *Calculated on basis of unscreened, wet, loose, unconcentrated gravel; one cubic yard = 3,770 lbs.*
[b] *Nb, Sn, Ta, Th, Ti, U, W, Y, and Zr analyses by x-ray fluorescence. La and Ce analyses by instrument neutron activation analysis.*

Descriptions

KS25649 90 percent granite gravel, no silt; sample taken 100 ft below prominent dike swarm
KS26862 40 percent of aggregate composed of granite, a few heavy mineral streaks on river bar near this dry channel bed
KS26871 Sample from low cut bank along active channel, 50 percent granite, some streaks on nearby sand bar
KS26872 Sample from alluvial fan derived from pluton
KS26873 Random sites from old river channel bed
KS26887 High-energy creek with heavy mineral streaks accumulating on sand bars
KS26888 Unstratified glacial till
KS26890 Heavy mineral layer skimmed off creek bed; too fine to pan
KS26891 Sandy gravel layer in dry river channel
KS26892 Main Windy Fork channel at confluence with canyon tributary

RESOURCE EVALUATION

The most significant placer potential is represented by the combined fans of glaciofluvial outwash formed below two creeks draining the approximate northern half of the Windy Fork pluton (fig. 4). A large elongate fan composed mostly of granitic detritus extends downstream at least 0.10 mi from the NW¼ of Sec. 28, T23N, R26W (figs. 5 and 6). The gravel is well rounded with numerous cobbles and very little silt-sized material at the ground surface. Streaks of black sand are common along river bars for at least another 4 mi downstream of the confluence of the two creeks.

The areal extent of placer REE-Zr enrichment in the outwash fan is indicated by coloration of sediment; heavy minerals occur in lighter-colored gravel dominantly composed of granite, as shown looking to the southeast in figure 6. Heavy mineral placer deposition continues an unknown distance downstream beyond the limits of present sampling. Based on available information, however, an area of at least 1,670,000 yd^2 is mineralized (sub-economic). Assuming an average depth of 10 yds, a total inferred resource of about 17 million yd^3 is present.

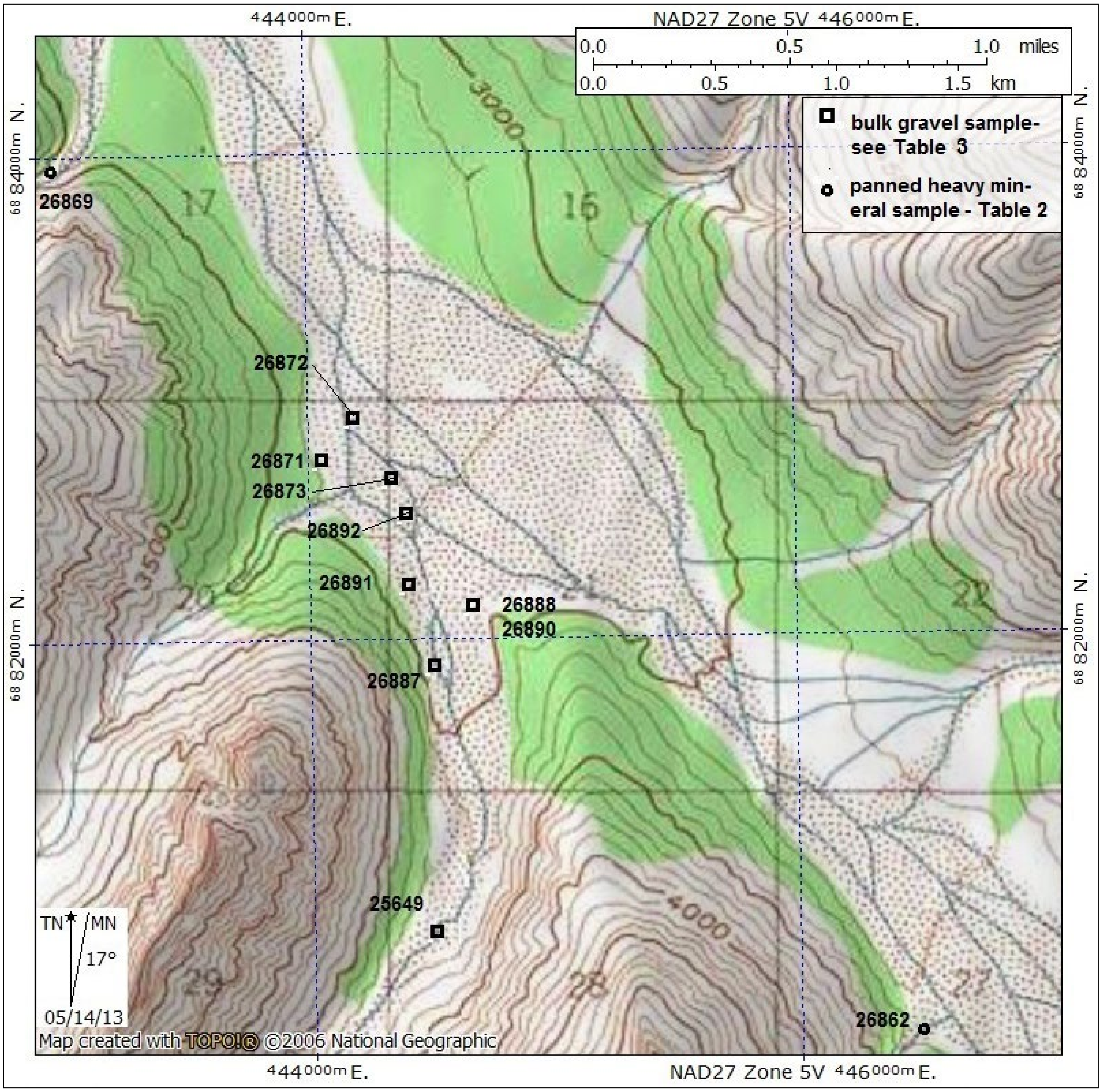

Figure 5. Map of outwash fan with bulk gravel sample locations (empty black squares) and panned heavy mineral sample locations (hollow black circles). Sample descriptions and analytical data are listed in table 3.

Figure 6. Photograph showing light-colored glaciofluvial outwash fan derived from the northern half of the Windy Fork pluton, as outlined in figure 5. Photo taken facing southeast.

Data listed in table 3 indicate the gravel on the surface of the fan contains 20 to 25 lbs/yd^3 of heavy minerals; additional random test panning at the time of the sample collection also confirmed at least this much heavy mineral to be present. Table 3 is a compilation of grade calculations for samples collected from this alluvial fan. It was not possible to test the deposit at depth where higher grade material could potentially exist. Therefore, data indicate grade at the ground surface only and are insufficient to estimate ultimate grade of the deposit.

Samples of the heavy minerals were examined by scanning electron microscope (SEM)[2]. Grains of heavy mineral concentrate (specific gravity greater than 3.6) were mounted on polished sections for study by SEM. Sample splits were made from samples KS26871, KS26891, KS26887, and KS26922. Approximately half of the grains in the samples were composed of heavy minerals. Lighter minerals present include K-Al silicates, a Ca-Fe silicate, quartz, and calcite.

The most abundant heavy mineral grains in the polished sections are ilmenite; titanium is also contained within the rare-earth-element-bearing minerals that are present. The second most abundant heavy mineral constituent is zircon, the only zirconium-bearing mineral present in the samples.

The most abundant rare-earth-element-bearing mineral is chevkinite (also tscheffkinite), $[(Ca,Ce,Th)_4(Fe^{+2},Mg)_2(Ti,Fe^{+3})_3 Si_4O_{22}]$. It is present primarily as liberated grains between 30 and 100 µm in diameter, but is occasionally interlocked with zircon or silicate gangue.

[2]Examinations performed by C.L. Mardock, Mineralogist, Albany Research Center, U.S. Bureau of Mines, Albany, Oregon.

There are lesser amounts of larger (200 µm diameter) grains of rare-earth-element-bearing epidote, allanite or orthite [$(Ce,Ca,Y)_2(Al,Fe^{+3})_3(SiO_4)_3(OH)$] and some 10- to 25-µm-diameter grains of kainosite [$Ca2(Y,Ce)_2Si_4O_{12}(CO_3)H_2O$]. A few grains of bastnaesite also are present, interlocked with iron oxide. These appear to be of secondary origin and account for only trace amounts of the rare-earth content.

Trace to minor amounts of thorite ($ThSiO_4$) occur in the samples. The thorite is altered to a hydrated thorium silicate in some areas. A single grain of uranothorite [$(Th,U)SiO_4$] was identified.

DISCUSSION

The northern Windy Fork pluton is composed of peralkaline riebeckite granite similar to that found at Bokan Mountain in Southeast Alaska (Reed and Miller, 1980). Additionally, its physiographic setting is similar, as both plutons are exposed over several thousand vertical feet that are, or were recently, ice-scoured and feature only first-order drainage development.

There are, however, several mineral-resource potential differences observed by the author between the Bokan Mountain and Windy Fork plutons:

Bokan Mountain has a somewhat concentric outer phase of aegirine granite that surrounds an inner riebeckite phase. An altered, weakly mineralized contact zone is mapped between the two phases. At the margin of the Bokan Mountain stock a pronounced border zone and locally mineralized aplite–pegmatite phase is present, indicating a high degree of magmatic differentiation marking the plutonic contact with wall rocks. Within the aegirine phase, numerous steeply dipping, very-late-stage magmatic occurrences grading to early-stage hydrothermal REE mineralization occur as pegmatites, structurally-controlled altered shear zones, vein-dikes, and contact metasomatic deposits. These occurrences commonly contain 0.5 to 5 percent REE. Mineralized vein-dikes also radiate out into the wall rocks for up to 3 mi; some of these are currently being explored for commercial development.

In contrast, the northern Windy Fork pluton has a narrow or absent border zone and exhibits minimal internal textural variation. REE-mineralized pegmatites and evidence of any significant volatile-rich, late-stage phases, are lacking.

At Bokan Mountain, accessory lithophile minerals are relatively rare in sediments derived from the pluton. Erosion of highly mineralized but narrow, steeply-dipping structures is inadequate to allow significant heavy mineral concentrations to accumulate. Based on about 150 unpublished heavy mineral concentrate samples collected by the author around the Bokan Mountain granite, only a few grams of heavy mineral will be present in a typical 10 kg sample of eroded sediments, as compared to an order of magnitude more heavy mineral as recovered in each of the Windy Fork sample sites listed in tables 2 and 3. The widespread occurrence of heavy minerals at Windy Fork suggests widespread, though low-grade, crystallization of the relatively incompatible lithophile elements into disseminated minerals in a size range that reports to gravity separation. At Windy Fork there is no evidence of partitioning of these minerals into economic-scale, late-stage features within the pluton. Thus, the glaciofluvial occurrence of substantial heavy mineral concentrations is present at all Windy Fork sites that were sampled.

In summary, and based on the present evidence, the apparent lack of magmatic differentiation and associated localized volatile concentration in the northern Windy Fork pluton suggests little economic potential for significant lode deposits, but is favorable for potential placer formation. The reverse is true for Bokan Mountain.

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Appendix A. Multi-element analyses of rock samples from the Northern Windy Fork Pluton area.

Sample procedures and detection limits

Elements	Lower Detection Limit	Units	Method
SiO_2	0.01	%	XRF
Al_2O_3	0.01	%	XRF
CaO	0.01	%	XRF
MgO	0.01	%	XRF
Na_2O	0.01	%	XRF
K_2O	0.01	%	XRF
Fe_2O_3	0.01	%	XRF
MnO	0.01	%	XRF
TiO_2	0.01	%	XRF
P_2O_5	0.01	%	XRF
LOI	0.01	%	XRF
Ag	0.5	PPM	DCP
As	2	PPM	INAA
Au	5	PPB	INAA
B	10	PPM	DCP
Ba	10	PPM	XRF
Be	1	PPM	DCP
Br	1	PPM	INAA
Cd	1	PPM	DCP
Co	1	PPM	INAA
Cs	0.5	PPM	INAA
Cu	0.5	PPM	DCP
Ge	10	PPM	DCP
Hf	1	PPM	INAA
Mo	5	PPM	INAA
Mn	2	PPM	DCP
Nb	10	PPM	XRF

Elements	Lower Detection Limit	Units	Method
Ni	1	PPM	DCP
Pb	2	PPM	DCP
Rb	10	PPM	XRF
Sb	0.2	PPM	INAA
Sc	0.1	PPM	INAA
Se	3	PPM	INAA
Sr	10	PPM	XRF
Ta	1	PPM	INAA
Th	0.5	PPM	INAA
U	0.5	PPM	INAA
V	2	PPM	DCP
W	3	PPM	INAA
Y	10	PPM	XRF
Zn	0.5	PPM	DCP
Zr	10	PPM	XRF
La	0.5	PPM	INAA
Ce	3	PPM	INAA
Nd	5	PPM	INAA
Sm	0.1	PPM	INAA
Eu	0.2	PPM	INAA
Tb	0.5	PPM	INAA
Yb	0.2	PPM	INAA
Lu	0.05	PPM	INAA
Ir	20	PPB	INAA
Cr_2O_3	0.01	%	XRF
SUM	0.01	%	XRF

Appendix A (continued). Multi-element analyses of rock samples from the Northern Windy Fork Pluton area.

Sample Descriptions (locations depicted in fig. 3).

KS25132	Slightly radioactive aphanitic rubble mixed with rhyolite dike swarm
KS25133	Silicified vein in hornfels
KS25135	Green-white marble with calcite lenses from roof pendent
KS25650	Silicified felsic dike swarm dipping toward intrusive contact with unknown black glassy mineral
KS25651	Rhyolite dike
KS25652	Iron-stained rhyolite from same swarm as 25650
KS25743	Representative chips of eudialyte pegmatite dike with pyroxene banding
KS25745	Representative chips of pyroxene dikes
KS26861	Riebeckite peralkaline dike cutting medium-grained granite
KS26864	Quartz veinlet with chalcopyrite–pyrrhotite cutting riebeckite granite
KS26867	Radioactive dike, 3 ft thick, in rubble with monazite crystals
KS26875	Quartz feldspathic dike cutting riebeckite granite
KS26877	Fine-grained peralkaline biotite porphyry
KS26878	Peralkaline riebeckite granite with above background radioactivity (800–2,000 cps)
KS26880	Carbonate breccia with sphalerite in creek float, no sample location available
KS26882	Peralkaline riebeckite granite, with aegirine
KS26883	Red, weathering shear zone in hornfels near contact
KS26886	Peralkaline granite
KS26894	Equigranular coarse-grained peralkaline granite
KS26895	Radioactive area (1,600 cps) of equigranular peralkaline granite
KS26896	Marble with abundant pyrite, no sample location available
KS26898	Earthy, hematite-altered aplite dike, 15 ft wide
KS26903	Light gray aphanitic dike with trace pyrrhotite
KS26904	Equigranular, fine-grained peralkaline granitic dike
KS26905	Orange-colored gossan and staining along selvage of KS26904
KS26906	Iron-stained granitic porphyry
KS26907	Iron-oxidized fine-grained dike cutting bedding
KS26909	Peralkaline granite porphyry
KS26911	Peralkaline granite
KS26915	Amphibole–biotite porphyritic alkali granite
KS26918	Hornfels
KS26921	Fine-grained to aphanitic radioactive (65–850 cps) dike, strikes east–west and is 20 ft thick

Appendix A (continued). Multi-element analyses of rock samples from the Northern Windy Fork Pluton area. Locations depicted on figure 3, except for samples KS26880 and KS26896 for which smaple locations are not availble.

NUCLEAR ACTIVATION SERVICES INCORPORATED[a]

Date: 31-Oct-88 Report: 631 File Number: 634

		SAMPLE NUMBERS																
Element	Unit	KS25132	KS25133	KS25135	KS25650	KS25652	KS26861	KS26864	KS26875	KS26877	KS26880	KS26882	KS26883	KS26894	KS26896	KS26906	KS26909	KS26921
SIO_2	%							71.2	76.1	75.6	13	71.6	74.6	73.8	36.7	46.4	74.6	75.4
AL_20_3	%							9.91	11.3	11.6	0.82	12.7	12.1	12.4	9.83	16.4	12.1	12.7
CAO	%							2.92	0.20	0.22	42	0.52	0.57	0.62	17.9	10.6	0.33	0.70
MGO	%							0.05	<0.01	<0.01	2.87	<0.01	0.06	0.10	5.89	6.73	0.01	<0.01
NA_20	%							3.18	4.24	4.21	0.2	5.53	4.17	5.06	2.03	3.14	4.57	3.79
K_2O	%							3.90	4.16	4.45	0.14	4.92	4.73	4.58	0.15	0.55	4.57	4.43
FE_2O_3	%							4.71	3.19	2.46	5.13	3.94	2.4	2.80	12.3	8.69	2.68	1.30
MNO	%							0.17	0.01	0.05	0.09	0.08	0.02	0.07	0.17	0.16	0.06	0.03
TIO_2	%							0.19	0.11	0.11	0.02	0.28	0.22	0.23	1.31	1.52	0.19	0.10
P_2O_5	%							0.03	0.02	0.01	0.02	0.02	0.03	0.04	0.15	0.43	0.02	0.02
LOI	%							1.77	0.93	0.93	34.9	0.62	0.77	0.54	12.6	5.39	0.77	1.08
CR_2O_3	%							0.02	0.02	0.02	<0.1	0.01	0.02	0.02	<0.01	0.02	0.01	0.01
SUM	%							98.20	100.5	99.80	99.30	100.6	99.90	100.4	99.10	100.2	100.0	99.60
AG	PPM							5.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
AS	PPM							110	140	2	<2	32	2	3	4	7	<2	<2
AU	PPB							<5	<5	<5	<5	<5	8	<5	10	7	<5	<5
B	PPM							30	30	50	10	70	30	40	10	40	20	30
BA	PPM							250	140	50	300	60	200	190	110	170	90	180
BE	PPM							3	6	3	<1	18	2	19	2	1	1	<1
BR	PPM							3	2	2	2	2	3	2	2	2	2	2
CD	PPM							6	<1	<1	45	1	<1	<1	<1	<1	<1	<1
CO	PPM							2	1	2	2	2	2	2	25	13	1	1
CS	PPM							3.1	1.7	3.2	<0.5	7.8	2.6	9.8	0.8	2.9	2.1	2.8
CU	PPM							5,200	34	18	780	15	20	25	140	38	15	10
GE	PPM							<10	<10	<10	10	10	<10	<10	<10	<10	<10	<10
HF	PPM							interfer	interfer	interfer	<1	47	20	20	3	3	13	5
MO	PPM							37	<5	<5	<5	<5	<5	<5	<5	11	<5	<5
NB	PPM							50	210	100	<10	150	50	<10	30	10	20	10
NI	PPM							5	2	3	6	2	4	4	51	17	4	4
PB	PPM							280	18	36	6	40	12	20	8	<2	10	20
RB	PPM							30	300	460	<10	350	260	270	20	50	210	300
SB	PPM							290	3.1	1.1	0.3	1.7	1.2	2.7	1.0	2.4	1.5	0.2
SC	PPM							0.9	0.4	0.3	2.6	0.1	0.9	1.0	25.0	25.6	0.6	0.5
SE	PPM	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
SR	PPM	30	60	1,900	<10	<10	<10	10	<10	<10	620	<10	<10	10	370	790	<10	20
TA	PPM	1	1	<1	1	1	9	1	12	5	<1	6	1	2	<1	1	1	2
TH	PPM	29	26	3.3	29	29	43	24	83	21	0.7	43	24	550	3.4	1.3	14	56
U	PPM	13.2	8.9	3.3	10.6	10.3	69.9	23.1	29.0	23.2	<0.5	21.5	9.0	20.8	1.1	2.7	5.1	24.8
V	PPM	2	2	62	<2	<2	4	4	4	2	10	22	<2	<2	250	170	<2	<2
W	PPM	<3	<3	<3	<3	<3	<3	10	6	<3	<3	<3	<3	4	<3	<3	5	4
Y	PPM	60	70	10	100	80	150	<10	200	190	10	190	110	160	<10	20	70	70
ZN	PPM	18	32	340	81	47	1,700	700	26	250	11,000	270	140	180	94	53	140	71
ZR	PPM	210	220	<10	230	210	1,900	570	890	670	<10	1,900	710	860	60	120	550	150
LA	PPM	67.6	56.5	14.5	62.6	59.5	36.1	86.2	25.9	42.3	4.3	142	76.3	119	11.8	15.2	76.3	49.8
CE	PPM	132	107	28	113	107	86	163	64	97	16	300	146	236	29	37	143	93
ND	PPM	40	41	20	45	40	38	66	17	46	12	123	58	60	16	21	54	32
SM	PPM	7.6	7.2	2	7.5	7.2	10.3	11.8	6.3	10.0	2.7	22.8	11.6	13.2	3.8	4.1	8.7	6.1
EU	PPM	<0.2	<0.2	0.7	<0.2	<0.2	<0.2	0.3	0.3	<0.2	1.1	0.6	<0.2	0.4	1.0	1.3	<0.2	<0.2
TB	PPM	1.8	1.6	<0.5	1.5	1.4	2.9	2.4	2.9	2.7	<0.5	4.2	2.2	2.9	0.8	0.5	1.4	1.0
YB	PPM	5.5	5.2	1.0	5.9	5.5	21.1	8.6	20.1	12.0	0.9	14.7	7.6	11.8	2.1	2.2	5.3	4.5
LU	PPM	0.93	0.88	0.18	0.93	0.90	4.16	1.37	3.21	1.97	0.14	2.22	1.22	2.17	0.34	0.36	0.83	0.99
IR	PPB	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
MN	PPM	56	110	330	240	120	730	910	40	310	630	440	94	440	1,100	900	340	120

[a] NAS Inc. data is missing for KS25132, 25133, 25135, 25650, 25652, 26861.

EXPLANATION OF CODES: Interfer - Detection not possible due to interference

Variable detection limits due to sample composition

Appendix A (continued). Multi-element analyses of rock samples from the Northern Windy Fork Pluton area.

NUCLEAR ACTIVATION SERVICES INCORPORATED

Date: 3-Nov-88 Report: 638 File Number: 633

SAMPLE NUMBERS

Element	Unit	KS25651	KS25743	KS25745	KS26867	KS26878	KS26886	KS26895	KS16898	KS26903	KS26904	KS26905	KS26907	KS26911	KS26915	KS26918
SiO_2	%	74.2	68.6	46.7	74.8	73.1	72.9	74.0	68.3	67.9	73.1	75.3	75.0	71.9	71.4	74.0
Al_20_3	%	12.6	9.85	11.2	10.6	12.1	13	12.2	13.7	14.8	12.6	13.0	12.4	12.2	13.5	12.5
CaO	%	0.44	1.98	9.52	0.18	0.50	0.67	0.40	1.61	1.02	0.37	0.09	0.44	0.57	1.06	0.45
MgO	%	0.01	0.18	5.49	0.08	0.08	0.18	0.09	0.29	0.15	<0.01	<0.01	0.01	0.11	0.28	0.04
Na_20	%	4.60	4.13	2.9	3.56	4.66	4.48	4.96	5.06	4.18	5.07	4.63	4.73	4.86	4.21	4.40
K_2O	%	4.96	6.82	0.41	4.77	4.59	4.75	4.56	3.55	5.36	5.08	5.08	4.80	4.65	4.91	4.94
Fe_2O_3	%	1.51	6.91	16.2	2.97	2.94	2.60	2.81	3.41	3.51	2.46	0.43	1.70	3.09	2.65	1.61
MnO	%	0.01	0.01	<0.01	0.02	0.02	0.02	0.02	<0.01	<0.01	0.02	<0.01	0.01	0.02	0.02	0.01
TiO_2	%	0.03	0.08	0.24	0.09	0.06	0.05	0.06	0.07	0.06	0.05	0.01	0.03	0.07	0.05	0.04
P_2O_5	%	0.11	0.18	3.98	0.36	0.22	0.24	0.20	0.51	0.29	0.16	0.12	0.09	0.21	0.26	0.11
LOI	%	0.02	0.01	0.33	0.05	0.05	0.05	0.04	0.14	0.05	0.02	0.02	0.01	0.04	0.07	0.02
Cr_2O_3	%	0.70	0.70	2.47	0.93	0.85	0.54	0.54	3	1.39	0.16	0.47	0.23	0.39	0.47	0.54
SUM	%	99.30	100.2	98.60	100.3	99.40	99.60	100.2	99.80	98.90	99.20	99.20	99.50	98.30	99.00	98.70
Ag	PPM	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
As	PPM	4	5	5	10	4	4	5	3	<2	2	8	6	3	3	2
Au	PPB	6	<5	7	<5	10	<5	<5	10	<5	<5	<5	<5	<5	5	7
B	PPM	40	80	20	70	40	50	50	70	30	60	50	80	40	50	20
Ba	PPM	50	110	540	120	190	350	170	240	470	40	30	30	170	570	50
Be	PPM	7	10	4	17	13	7	8	6	4	5	6	7	11	7	8
Br	PPM	2	3	1	2	2	3	2	3	2	1	2	2	1	2	2
Cd	PPM	<1	<1	2	<1	<1	<1	1	<1	1	<1	<1	<1	<1	<1	<1
Co	PPM	1	2	38	4	2	3	2	4	2	1	1	2	2	2	2
Cs	PPM	5.3	5.2	7.7	6.2	12.7	6.7	8.0	1.7	1.6	4.9	6.1	7.6	3.8	8.7	6.5
Cu	PPM	25	22	320	19	19	17	13	11	14	21	16	15	13	13	15
Ge	PPM	<10	20	30	30	<10	10	10	<10	<10	<10	<10	<10	<10	<10	<10
Hf	PPM	10	140	6	410	19	14	22	11	12	7	9	8	21	11	10
Mo	PPM	5	<5	<5	<5	<5	<5	<5	7	<5	<5	5	<5	<5	<5	<5
Nb	PPM	30	50	30	1300	<10	40	30	40	20	20	20	30	40	30	40
Ni	PPM	4	5	62	6	5	4	4	4	5	4	3	3	3	6	3
Pb	PPM	20	28	8	44	88	22	10	18	16	14	18	30	20	16	18
Rb	PPM	240	450	<10	480	330	220	270	150	150	220	260	260	270	240	280
Sb	PPM	0.9	0.9	0.7	8.3	1.9	1.3	1.5	0.6	0.3	1.1	1.3	1.4	1.4	1.2	0.4
Sc	PPM	1.5	1.4	36.2	0.2	0.7	1.8	1.3	2.6	1.7	0.2	0.9	1.5	1.0	2.7	1.4
Se	PPM	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Sr	PPM	<10	190	300	50	10	50	<10	70	80	<10	<10	<10	<10	90	<10
Ta	PPM	2	14	1	80	3	1	4	2	1	<1	1	1	2	1	2
Th	PPM	26	21	1.2	880	580	25	220	37	11	17	22	22	36	22	27
U	PPM	8.8	13.6	<0.5	277	30.0	9.2	16.3	15.8	5.7	4.6	13.7	9.9	10.6	9.2	9.9
V	PPM	8	10	530	12	12	16	14	22	14	8	6	8	10	18	6
W	PPM	<3	6	<3	14	4	<3	<3	4	<3	<3	<3	<3	<3	<3	<3
Y	PPM	40	270	20	1400	390	80	120	70	50	60	<10	70	120	60	70
Zn	PPM	49	160	140	200	220	95	270	110	95	140	27	64	170	62	80
Zr	PPM	310	4900	250	9600	910	540	840	330	550	280	220	170	820	400	280
La	PPM	47.0	52.2	11.6	416	361	68.2	182	94.9	44.4	81.6	14.6	51.8	118	60.8	63.8
Ce	PPM	87	131	34	914	670	114	284	152	89	141	29	104	223	117	117
Nd	PPM	27	46	25	404	192	49	86	55	36	61	11	45	67	48	45
Sm	PPM	5.4	14.1	5.3	104	39.6	7.6	13.3	9.7	6.7	8.0	1.8	7.8	13.4	7.5	7.3
Eu	PPM	<0.3	<0.3	2	1.3	0.4	<0.5	0.5	0.9	0.3	0.4	<0.2	<0.2	0.4	0.4	<0.2
Tb	PPM	1	3.7	1.0	34.2	7.5	1.7	2.0	1.6	1.3	0.9	0.5	1.2	2.6	1.5	1.5
Yb	PPM	4.4	23.4	3.4	137	31.0	6.1	10.2	5.7	4.1	4.6	2.1	4.7	9.5	4.5	5.9
Lu	PPM	0.73	3.69	0.47	20.1	4.81	0.94	1.81	0.95	0.67	0.71	0.56	0.75	1.45	0.80	0.89
Ir	PPB	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Mn	PPM	210	430	1800	360	370	350	400	450	380	380	60	170	490	330	250

EXPLANATION OF CODES: VARIABLE DETECTION LIMITS DUE TO SAMPLE COMPOSITION

APPENDIX B. Analytical Report 4343E9s.

Name: Barker, Rule, Mardock **Date (in):** 05/02/89 **(out):** 09/11/89

Sample Description	Sample #	spNb* (%)	spREE* (%)	spZr* (%)	spHf* (%)	spV* (%)	spTi* (%)	spU* (%)	spTh* (%)
2754 ME1973 - KS25136	4343E9	<0.01	**	0.08	<0.01	<0.01	0.20	<0.01	<0.01
2755 ME1973 - KS25134	4344E9	<0.01	**	0.19	<0.01	<0.01	0.23	<0.01	0.02
2756 ME1973 - KS25649 radioactive	4345E9	0.02	**	1.6	0.03	<0.01	1.17	<0.01	0.11
2757 ME1973 - KS26863	4346E9	<0.01	**	0.34	<0.01	<0.01	0.33	<0.01	0.02
2758 ME1973 - KS26900	4347E9	<0.01	**	0.08	<0.01	<0.01	0.22	<0.01	<0.01
2759 ME1973 - KS26885	4348E9	<0.01	**	2.4	0.04	<0.01	1.36	<0.01	0.12
2760 ME1973 - KS26888	4349E9	0.02	**	2.6	0.05	0.01	1.81	<0.01	0.15
2761 ME1973 - KS26872 radioactive	4350E9	<0.01	**	2.0	0.04	0.01	0.73	<0.01	0.05
2762 ME1974 - KS26871 radioactive	4351E9	<0.01	**	1.8	0.04	0.01	1.67	<0.01	0.13

** sp = six-step spectrographic procedure*

Rare-Earth Elements

	Ce (%)	Tm (%)	Yb (%)	Er (%)	Gd (%)	Dy (%)	Y (%)	Pr (%)	Nd (%)	La (%)
4343E9	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.10	<0.01	<0.01
4344E9	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.02
4345E9	0.38	0.01	0.01	<0.01	0.02	0.01	0.08	0.02	0.10	0.14
4346E9	0.08	<0.01	<0.01	<0.01	0.01	<0.01	0.03	<0.01	0.03	0.04
4347E9	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
4348E9	0.39	0.01	0.01	<0.01	0.02	0.01	0.07	0.02	0.09	0.13
4349E9	0.55	0.01	0.01	0.02	0.03	0.02	0.11	0.03	0.13	0.19
4350E9	0.21	<0.01	<0.01	<0.01	0.01	0.02	0.05	0.01	0.06	0.09
4351E9	0.51	0.01	0.01	0.01	0.02	0.02	0.10	0.03	0.14	0.20

*REMARKS: ** Lu, Ho, Sm, Eu all <0.01 percent*

Analyst: Sam
Supervisor: A.J. Mackie