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PETROGRAPHY AND RADIOMETRIC AGES FOR SELECTED ROCKS FROM THE LIVENGOOD QUADRANGLE, ALASKA

By

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INTRODUCTION

The U.S. Geological Survey conducted multidisciplinary reconnaissance studies in the Livengood 1:250,000-scale quadrangle, Alaska, from 1986 to 1988, to define the mineral resource potential of the area. The Livengood quadrangle covers about 14,500 square kilometers (5,600 square miles) between 65° and 66° north lattitude and between 147° and 150° west longitude, and lies about 8 kilometers (5 miles) north of Fairbanks, Alaska. The Elliott, Dalton, and Steese Highways provide access to parts of the quadrangle. The Trans-Alaska Pipeline traverses the quadrangle from southeast to northwest.

The U.S. Geological Survey is required by the Alaskan National Interests Lands Conservation Act (Public Law 96-487, 1980) to survey certain Federal lands to determine their mineral values, if any. Results from the Alaskan Mineral Resource Assessment Program (AMRAP) must be made available to the public and be submitted to the President and the Congress. This report presents previously unpublished data that were compiled in conjunction with the Livengood AMRAP studies; specifically: petrographic data on the Pedro Dome, Elephant Mountain, Sawtooth Mountain, Huron Creek, Wolverine Mountain, East Wolverine, and West Wolverine plutons; petrographic data for the mafic rocks of the Rampart Group; and a compilation of K-Ar radiometric dates from various rocks throughout the quadrangle.

SUMMARY OF GEOLOGY

The Livengood quadrangle lies within the western part of the Yukon-Tanana Upland as defined by Wahrhaftig (1965). It is underlain by a northeastward trending sequence of Precambrian to Tertiary sedimentary, metasedimentary, and lesser volcanic and metavolcanic rocks metamorphosed mainly to greenschist facies, and intruded by widely scattered granitoid plutons of Cretaceous and Tertiary ages that form prominent topographic features (Chapman and others, 1971; Weber and others, 1992, 1997). The major faults in the area are strike-slip splays of the Tintina fault zone, and northwest-verging thrust faults. The southeastern part of the quadrangle is underlain by crystalline rocks of the Yukon-Tanana metamorphic complex; the oldest rocks in the complex are crystalline schists. The metamorphic rocks range from greenschist and epidote-amphibolite facies to garnet-amphibolite facies (Robinson and others, 1990). The metamorphic grade generally decreases toward the northwest across the quadrangle. Scattered throughout the central and southern parts of the quadrangle are Cretaceous and Tertiary granitoid plutons. Precambrian-Cambrian argillites, Ordovician mafic volcanic rocks, Silurian and Devonian limestone, and Mississippian(?) quartzite form the White Mountains, a highly faulted and folded block in the central part of the quadrangle. Mesozoic basinal deposits, north and west of the White Mountains, extend southwestward across the quadrangle and consist of conglomerate, sandstone, siltstone, and shale. North of the basinal deposits is a belt of grit, slate, mafic-ultramafic rocks, dolomite, chert, conglomerate, shale, and limestone of Precambrian to Triassic age. In the western part of the quadrangle, a major structural feature is displayed in a Mesozoic sequence that is folded around a core of Paleozoic and Precambrian sedimentary and volcanic rocks. The northwestern third of the quadrangle is underlain by mafic volcanic and intrusive rock and related chert and clastic sedimentary rocks of Mississippian to Triassic age. Gravel, sand, and silt of Holocene to Early Tertiary age blanket most of the area in the quadrangle.

PETROGRAPHY AND RADIOMETRIC AGES OF SELECTED UNITS

The locations of rock units discussed in this report are shown in Fig. 1. Pedro Dome is located in the Livengood A-1 1:63,360 scale quadrangle in the southeastern part of the Livengood 1:250,000 scale quadrangle. The other plutons discussed (Elephant Mountain, Sawtooth Mountain, Huron Creek, Wolverine, East Wolverine, and West Wolverine) are in the Livengood B-6 1:63,360 quadrangle, in the west-central part of the Livengood 1:250,000 quadrangle. The mafic rocks of the Rampart Group are located in the northern part of the Livengood 1:250,000 scale quadrangle, north of a northeast trending regional fault that transects the quadrangle.

Table 1 is a compilation of K-Ar radiometric ages from units throughout the quadrangle, including dates reported in the literature as well as new dates not previously reported. More detailed geologic setting and unit descriptions can be found in Weber and others , 1997. Table 2 lists a comparison between the Sawtooth Mountain and Elephant Mountain plutons. Table 3 lists modes of the granitic rocks of the Livengood B-6 1:63,360 scale quadrangle. Table 4 lists chemical analyses of major elements and CIPW norms for selected samples from the plutons in the Livengood B-6 quadrangle. Table 5 lists chemical analyses and other parameters for selected samples of mafic rocks of the Rampart Group.

<u>Pedro Dome plutons</u>--Scattered exposures indicating multiple bodies occupying about 3 or 4 square miles in the southeasternmost part of the quadrangle. Largest bodies are granodiorite elongate northeastward parallel to the regional structural grain. About 10 to 15 per-cent of the outcrop area is occupied by small bodies of quartz-feldspar porphyritic granite that locally intrude the granodiorite. The granodiorite is fine to medium grained, equigranular, hypautomorphic-granular, massive, fairly homogeneous, light gray to gray, weathering light brown to buff. It is characterized by $\leq$ 2mm epidote veinlets along incipient joints, and contains sparse mafic enclaves. Local variations to somewhat more felsic rock were seen. Its approximate average mode, in percent, is:

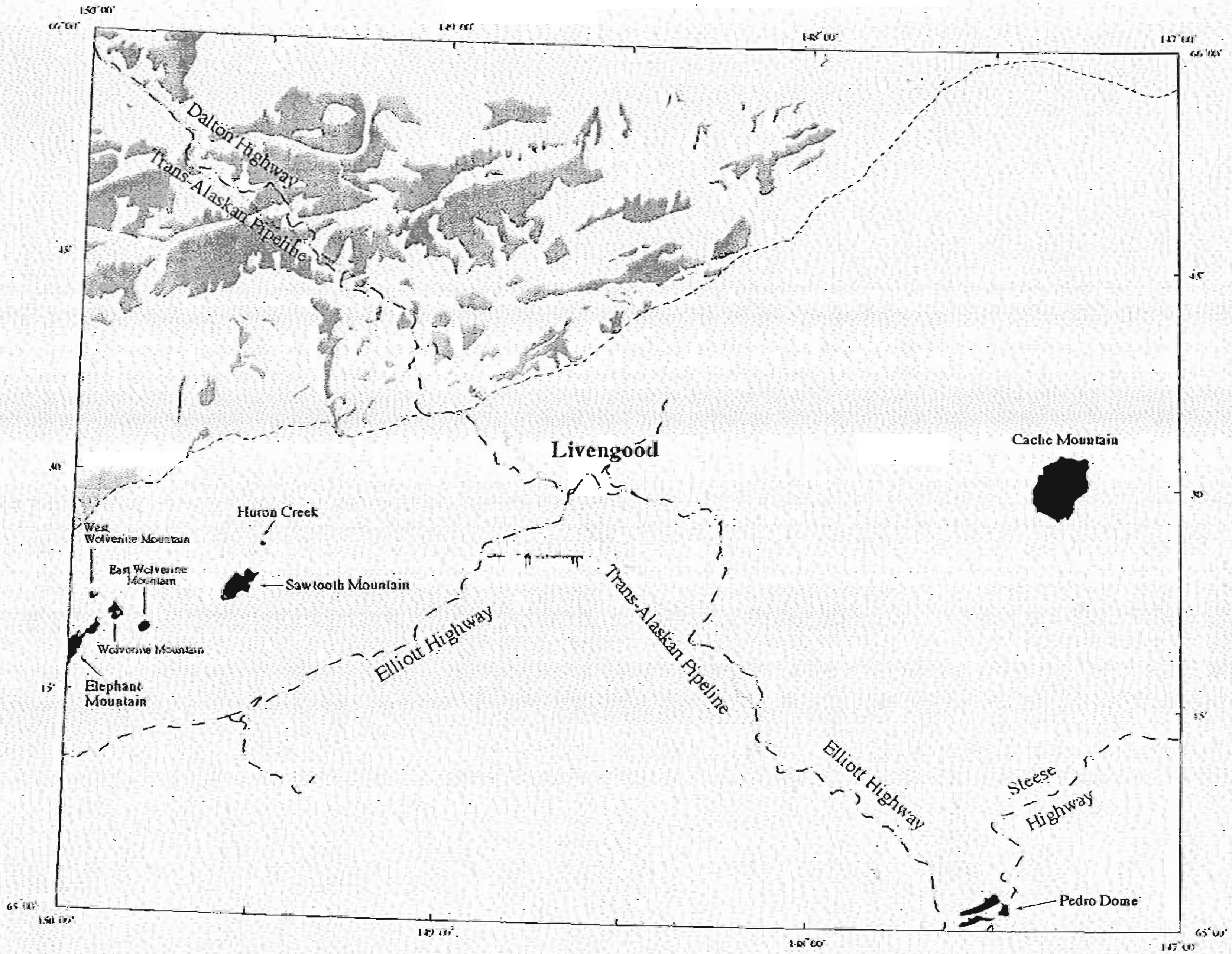

Figure 1. Index map of the Livengood quadrangle showing location of selected plutons (dark shading) and mafic rocks of the Rampart Group (light shading). Northeast trending fault (dashed line) indicates southern limit of Rampart Group Geology after Weber and others, 1997.

Table 1. K/AR Radiometric ages for selected rocks form the Livengood quadrangle, Alaska

[Constants used were $^{40}K/K = 1.167 \times 10^{-4}$ mol/mol; $\lambda_{\gamma} = 4.962 \times 10^{-1}$/year; $\lambda_{\epsilon}+\lambda_{\epsilon'} = 0.581 \times 10^{-1}$/year]

Sample ID	Latitude	Longitude	Location	Mineral dated	Rock type	mean K_2O	$^{40}Ar_{rad}$ (moles/gram)	$^{40}Ar_{rad}$ (moles/gram) (duplicate)	%$^{40}Ar_{rad}$ (mean)	K/Ar age, my	Error, my	Reference	Comments
ECPD-1	65.033	147.494	Pedro Dome	hornblende	quartz diorite	0.991	1.36×10^{-10}	1.37×10^{-10}	56.9	93.3	5.1	Britton, 1970; Swainbank and Forbes, 1975	
LK8-10-4	65.021	147.479	Pedro Dome	biotite	quartz monzonite					95.3	5.0	Britton, 1970; Forbes, and others, 1968; Forbes, 1982	
LK8-10-8	65.063	147.463	upper Cleary Creek	muscovite	garnet-quartz-mica schist					141.4	2.0	Forbes, 1982	
LK8-10-11	65.06	147.35	near VABM Chatham	biotite	quartz-mica schist					128	4	Forbes, 1982	approx. location
LK8-11-7	65.085	147.727	Chatanika River	whole rock	garnet-mica schist					133.1	4.0	Forbes, 1982	
F49	65.039	147.659	Elliott highway borrow pit	hornblende	eclogite	0.200	1.575×10^{-10}		64.3	478	35	Swainbank and Forbes, 1975; Forbes, 1982	low K_2O values
F71	65.038	147.659	Elliott highway, mile 6.1, borrow pit	muscovite	pelitic schist	8.206	1.4475×10^{-9}		80.1	119	3	Swainbank and Forbes, 1975; Forbes, 1982	
F136	65.038	147.659	Elliott highway, mile 6.1, borrow pit	hornblende	garnet-hornblende-mica schist	0.496	1.01×10^{-10}		42.0	136	9	Swainbank and Forbes, 1975, Forbes, 1982	
F136	65.038	147.659	Elliott highway, mile 6.1, borrow pit	biotite	garnet-hornblende-mica schist	8.245	1.36×10^{-9}		76.2	111.1	3.4	Swainbank and Forbes, 1975; Forbes, 1982	
F136	65.038	147.659	Elliott highway, mile 6.1, borrow pit	muscovite	garnet-hornblende-mica schist	5.989	9.425×10^{-10}		40.5	106.1	3.4	Swainbank and Forbes, 1975; Forbes, 1982	
LK8-10-9	65.088	147.427		muscovite	garnet-mica schist					166.2	2.2	Forbes, 1982	minimum age
LK8-11-6	65.159	147.911	Elliott highway, north of Washington Creek	whole rock	quartz-mica schist					88	3	Forbes, 1982	
LK8-11-5	65.182	148.039	Elliott highway, south of Wickersham Dome	whole rock	quartz-mica schist					171	31	Forbes, 1982	

Table 1 (continued). K/AR Radiometric ages for selected rocks form the Livengood quadrangle, Alaska

[Constants used were $^{40}K/K = 1.167 \times 10^{-4}$ mol/mol; $\lambda_\beta = 4.962 \times 10^{-10}$/year; $\lambda_e + \lambda_{e'} = 0.581 \times 10^{-10}$/year.]

Sample ID	Latitude	Longitude	Location	Mineral dated	Rock type	mean K_2O	$^{40}Ar_{rad}$ (moles/gram)	$^{40}Ar_{rad}$ (moles/gram) (duplicate)	%$^{40}Ar_{rad}$ (mean)	K/Ar age, my	Error, my	Reference	Comments
LK8-11-4	65.209	148.103	Elliott highway, west of Wickersham Dome	whole rock	phyllonite					182	5	Forbes, 1982	
LK8-11-3	65.212	148.128	Elliott highway, west of Wickersham Dome	whole rock	phyllonite					93	4	Forbes, 1982	
LK8-11-2	65.227	148.129	Elliott highway, west of Wickersham Dome	whole rock	phyllonite					262	8	Forbes, 1982	
LK8-11-1c	65.246	148.142	Globe Creek quarry	whole rock	purple slate					234	7	Forbes, 1982	
LK8-11-1b	65.246	148.142	Globe Creek quarry	whole rock	gray meta-siltstone					478	14	Forbes, 1982	
LK8-11-1a	65.246	148.142	Globe Creek quarry	whole rock	green slate					281	8	Forbes, 1982	
87ANk99a	65.58	147.384	Fossil Creek vicinity	white mica	gray-green slate	8.327	2.413×10^{-8}		82.3	1352	40.6	this report	
87ANk104r	65.178	148.074	Wickersham dome, southwest flank	white mica	quartz-muscovite schist	7.14	1.15457×10^{-9}		26.1	109	3.27	this report	
DT87-15	65.517	148.553		hornblende	hornblende gabbro	0.179	1.84751×10^{-10}		48.3	548.4	16.45	this report	
DT87-16	65.462	148.675	west fork Tolovana River	hornblende	hornblende gabbro	0.169	1.04258×10^{-10}		57.5	385.5	11.57	this report	
DT87-17	65.462	148.445	Amy Dome	hornblende	hornblende gabbro	0.128	1.22931×10^{-10}		48.2	566.4	16.99	this report	
DT87-18	65.500	148.429	Amy Dome	hornblende	hornblende gabbro	0.126	1.18613×10^{-10}		49.7	558	16.74	this report	
DT87-19	65.500	148.421	Amy Dome	hornblende	hornblende gabbro	0.135	1.25866×10^{-10}		14.6	552.3	16.57	this report	
87ANk126a	65.508	149.626	Raven Creek Hill	biotite	pelitic schist	8.625	9.07810×10^{-10}		90.8	71.68	2.15	this report	
87ANk126b	65.509	149.628	Raven Creek Hill	biotite	pelitic schist	8.649	8.44073×10^{-10}		82.5	66.56	2.00	this report	
87APr92	65.17	149.48	New Minto road	amphibole	amphibolite	0.021	5.285×10^{-12}		8.5	163.9	21.13	this report	
62ACh65	65.264	148.928	Tolovana Hot Springs Dome	biotite	quartz monzonite	8.46	8.05×10^{-10}		90.0	64.9	2.5	Chapman and others, 1971; Marvin and Dobson, 1979	

Table 1 (continued). K/AR Radiometric ages for selected rocks form the Livengood quadrangle, Alaska

[Constants used were $^{40}K/K = 1.167 \times 10^{-4}$ mol/mol; $\lambda_\beta = 4.962 \times 10^{-10}$/year; $\lambda_\epsilon+\lambda_{\epsilon'} = 0.581 \times 10^{-10}$/year.]

Sample ID	Latitude	Longitude	Location	Mineral dated	Rock type	mean K_2O	$^{40}Ar_{rad}$ (moles/gram)	$^{40}Ar_{rad}$ (moles/gram) (duplicate)	$\%^{40}Ar_{rad}$ (mean)	K/Ar age, my	Error, my	Reference	Comments
69ACh96	65.364	149.581	Sawtooth Mountain	biotite	quartz monzonite	9.07	1.219×10^{-9}		78	91.0	3.0	Chapman and others, 1971	
69ACh151	65.503	149.597	Raven Creek Hill	muscovite	alaskite	10.84	1.082×10^{-9}		66	88.1	2.0	Chapman and others, 1971	
71AWr513	65.495	147.345	Cache Mountain pluton	biotite	quartz monzonite	8.33	7.292×10^{-10}		61	59.8	1.8	Holm, 1973	minimum age
81Bu1	65.48	147.12	Roy Creek stock	biotite	aegirine-augite syenite					85.4	6.4	Burton, 1981	minimum age, decay constants unknown, approx. location
81Bu2	65.49	147.08	Roy Creek stock	biotite	aegirine-augite syenite					86.7	3.6	Burton, 1981	minimum age, decay constants unknown, approx. location
79AWs101	65.485	147.097	Roy Creek stock	biotite	lamprophyre	9.05	1.197×10^{-9}	1.207×10^{-9}	81.0	90.0	0.8	Wilson and others, 1985	
84AWr188	65.502	148.424	Amy Dome	hornblende	gabbro					539.5	16.2	Blum, pers. comm.	
74 3E216	65.513	148.551	Money Knob, west flank	hornblende	diorite	0.159	17.7×10^{-11}		38.6	643	19	Weber and others, 1988	
84AWr187	65.465	148.683	west side of North Fork	hornblende	diorite					518.3	15.5	Blum, pers. comm.	
87ARl37	65.338	149.876	Wolverine Mountain	biotite	quartz monzonite	8.90	1.171×10^{-9}	1.178×10^{-9}	90.2	89.4	0.9	this report	
87ARl43	65.306	149.976	Elephant Mountain	biotite	quartz monzonite	9.27	1.222×10^{-9}	1.220×10^{-9}	90.5	89.3	1.0	this report	
88AWr51	65.423	149.484	Huron Creek stock	biotite	quartz monzonite	8.57	1.112×10^{-9}	1.099×10^{-9}	84.7	87.5	1.4	this report	
88AWr51	65.423	149.484	Huron Creek stock	hornblende	quartz monzonite	1.35	1.842×10^{-10}		84.0	92.5	1.8	this report	

quartz 25, K-feldspar 10, plagioclase 40, biotite 15, hornblende 10, and not uncommonly, a trace to a percent or two of clinopyroxene and, less commonly, orthopyroxene. Accessory minerals include magnetite, sphene, apatite, zircon, and rarely allanite. Plagioclase is mainly twinned and oscillatory zoned andesine with labradorite cores; it is locally altered to sericite and less commonly to epidote and calcite. Both quartz and K-feldspar are interstitial.

The granite is massive, medium to coarse grained, very light gray, weathering light yellowish brown, porphyritic with 3-12 mm-phenocrysts of light-gray K-feldspar, 2-8mm phenocrysts of medium-dark-gray equant quartz, and $\leq$ 6mm-phenocrysts of very light-gray, rectangular plagioclase. Phenocrysts compose about 75 percent of the rock. The rock is not as homogeneous as the granodiorite and shows more local variations in texture and composition; it is locally associated with pegmatite. Its approximate average mode, in percent, is: quartz 31, K-feldspar 26, plagioclase 37, biotite 3, and chlorite (after biotite) 3. Alteration is minor to moderate; alteration products are sericite and, locally, epidote and calcite, in plagioclase, clay in K-feldspar, and chlorite in biotite. Accessory minerals are magnetite, zircon, sphene, and hornblende.

A metamorphic aureole in the Fairbanks schist unit surrounding the plutons is not large, and forms a zone of several hundred feet in which the metamorphosed rocks are mainly harder and denser. Foliation is preserved in the quartz-mica schist, which is mineralogically unchanged. Calc-magnesian schist, however, is converted to skarn assemblages that indicate hornblende hornfels facies.

Radiometric ages of 93.3 $\pm$ 5.1 Ma (hornblende) for the granodiorite (Chapman and others, 1971), and 95.3 $\pm$ 5 Ma (biotite) for the granite (Forbes, and others, 1968; Forbes, 1982), were obtained by the $^{40}K/^{40}Ar$ method, confirming the consanguinity of the two granitoids.

The foregoing information relies heavily on the works by Brown (1962) and Britton (1970). Noteworthy is the fact that seven chemical analyses representing the two rock types are included in the appendix of Britton's thesis, but apparently were not received by him until after his report was written, but before it was submitted to the library. The analyses show the granite to be peraluminous and chemically similar to granite of the Cache Mountain pluton, 30 miles to the north. Samples collected during the present study, also show much petrographic similarity to the Cache Mountain unit This is only fortuitous, however, inasmuch as the granite of Cache Mountain has a $^{40}K/^{40}Ar$ age of about 60 Ma (Holm, 1973).

Elephant Mountain pluton--Massive, texturally varied, coarse- to medium-grained equigranular to trachytoid monzonite porphyry, typically displaying darker shades of gray, and relatively homogeneous in composition. Like rocks of the Sawtooth Mountain pluton, the trachytoid fabric is locally gneissic, but trends are varied and are traceable for only a few tens of feet. Also, like the Sawtooth Mountain, the K-feldspar tablets tend to lie in steeply dipping or vertical planes that commonly show divergent or random planimetric trends. In contrast to the Sawtooth Mountain, the K-feldspar tablets in the Elephant Mountain pluton are significantly smaller, only locally measuring as much as an inch across, and the trachytoid texture is not as widespread. A biotite-oikocrystic phase, which is otherwise equigranular, similar to a phase of the Sawtooth Mountain pluton, was found near the central part of the pluton about a mile southwest of its northeastern extremity. Comparison between the two plutons is summarized on table 2.

Microscopically, the chief texture is xenomorphic- and hypautomorphic-granular, except for the porphyritic rocks, in which the matrix texture is generally xenomorphic-granular. Plagioclase is mainly anhedral, abundantly twinned and zoned andesine, occurring both as sub-phenocrysts and as ubiquitous smaller grains in the matrix. Most is only slightly altered. K-feldspar is present, chiefly as phenocrysts only, in the coarse trachytoid rocks, but also as both phenocrysts and late interstitial fillings in weakly porphyritic and seriate, and non-porphyritic rocks. It locally forms anhedral poikilitic crystals--presumably late--that enclose the smaller crystals of the matrix. Quartz is present in only small amounts as late interstitial fillings. Dark minerals include, in decreasing order of abundance: clinopyroxene, hornblende, and biotite, that together, compose an average color index of about 30. Clinopyroxene is typically present as equant, colorless, pale grayish-tan to pale-green, equant anhedral poikilitic crystals with corroded borders, which, except for the corrosion, would be euhedral. Hornblende is almost entirely uralitic, and is present in highly varied amounts, mostly as anhedra with augite cores, or as mantles partly or wholly enclosing augite crystals. Biotite is typically present as subhedral or anhedral pleochroic shreds that are tan to deep reddish brown-locally black. Radiometric ages on biotite from quartz monzonite from the Elephant Mountain pluton are 89.3 Ma $\pm$1.0 Ma (table 1).

Sawtooth pluton--Highly varied massive, medium- to coarse-grained, equigranular to trachytoid porphyritic rock, typically displaying darker shades of gray, and spanning an apparently gradational compositional range of lamprophyre to both quartz- and olivine-bearing (not in same specimen) syenite. Widespread coarse trachytoid texture, defined by equant K-feldspar tablets both alined and random, as much as 6 inches broad by 1/2 inch thick, is the most striking field characteristic. Modal analyses on sawn, etched, and stained slabs were made for seven representative samples (table 3).

The K-feldspar tablets, which are commonly in the 3/4 to 1 1/2 X 1/4-inch range, in many places define a local, steeply dipping or vertical gneissosity, but nowhere is the strike consistent over more than a few tens of feet. On horizontal or subhorizontal surfaces, trends of cross-sections of individual K-feldspar tablets show near-random orientations , but on steeply inclined or vertical surfaces, it is apparent that the tablets tend to lie in steeply dipping or vertical planes.

The matrix of the trachytoid rocks is commonly a medium-grained, equigranular, biotite-rich intergrowth of that mineral, other equant mafic minerals, and feldspar. Sparkling black cleavages of biotite dominate the appearance of the assemblage, although clinopyroxene is commonly somewhat more abundant. This matrix assemblage, without the tabular K-feldspar phenocrysts, is another common rock type of the Sawtooth pluton, and thin-section study shows it to be minette and kersantite, lamprophyres composed essentially of biotite, clinopyroxene, plagioclase and/or K-feldspar. Both gradual and abrupt transitions occur between lamprophyre and trachytoid rock, but no sharp contacts were seen. Generally massive, the rocks locally show layering, defined by relative abundances of dark- and light-colored constituents. Although the names "minette" and "kersantite" conveniently fit samples studied, their use is not to be considered restrictive of the chemical composition of lamprophyric variants of the Sawtooth pluton, for there is no doubt that compositional variation is large.

A third distinctive rock type in the Sawtooth Mountain pluton, is monzonite that is typically dark gray and medium grained, but is mostly finer grained than the lamprophyric rocks or the matrix of the trachytoid rocks. It is fairly homogeneous with a color index generally below 30, belying its dark hue. Its distinctive feature is the presence of equant, centimeter-size, bronze biotite oikocrysts--large crystals that apparently grew late in the crystallizing sequence and therefore grew around, and poikilitically enclosed a varied multitude of smaller crystals, giving the enclosing biotite a sponge or lace texture. These rocks are distinctive in the field because of light reflections off the large biotites in an otherwise much finer-grained rock.

All three of the above rock types are believed to intergrade, largely because of the abundance of petrographically intermediate types. Although variations abound, crosscutting relations among rock types were not seen, but their existence is by no means precluded, largely because of poor exposures.

Microscopically, no dramatic additional differences among the three rock types were found. All have xenomorphic-granular texture, including the matrix of the porphyritic rocks. Color index averages near 40, ranging from a low of about 20 to near 90 in the lamprophyre. The major dark minerals are augite and biotite, augite generally the more abundant. The augite--colorless, pale grayish-green, locally brownish-lavender (titanaugite?)--is typically equant, anhedral to subhedral, commonly somewhat poikilitic, and altered in varied amounts to uralitic hornblende. Biotite is typically in anhedral shreds or in large, open, reticulate networks of connected shreds, all in optical continuity. It is pleochroic in tan or orange-tan to dark reddish-brown, locally almost opaque at maximum absorption. Other common dark minerals, present in small amounts, are olivine, orthopyroxene, and hornblende, the latter locally in discrete crystals that do not appear to be augite replacements. Plagioclase is present in anhedral to subhedral, twinned and generally zoned crystals. K-feldspar, other than megacrysts, is anhedral, commonly interstitial, and locally poikolitic. Irregular micropegmatitic zones or patches were seen in several of the megacrysts, which almost invariably show Carlsbad twinning. Quartz, in minor amounts, is present only locally and is interstitial. Accessory minerals are apatite, sphene, magnetite, zircon, monazite, and locally, allanite.

Chemical analyses of four samples approximately representative of the Sawtooth pluton are listed on table 4. The four rocks represent the three broad types described here: 26b, lamprophyre (foidite, according to the TAS system of classification of LeBas, and others, 1986); 50a, monzonite, representing the medium-grained biotite-phyric (oikocrystic) rock; 56b and c, monzonite, representing the megacrystic trachytoid porphyry. Samples 50a and 56b and c are monzonite using the chemical classification of Streckeisen and LeMaitre (1979), and also using the modal classification of Streckeisen (1973).

Table 2 lists a comparison of general features between the Elephant Mountain and Sawtooth Mountain plutons. Table 3 lists the modes of granitic plutons in the Livengood B-6 quadrangle. The radiometric (K/Ar) age on biotite in quartz monzonite from Sawtooth Mountain is 91.0 Ma $\pm$3.0 Ma (Chapman and others, 1971).

Table 2. Comparison between Sawtooth Mountain and Elephant Mountain plutons

SAWTOOTH MOUNTAIN	ELEPHANT MOUNTAIN
Coarse, widespread trachytoid texture	Trachytoid texture not as coarse, not as widespread
Fairly widespread centimeter-size biotite oikocrysts	Biotite oikocrysts sparse
Lamprophyre phase	No lamprophyre phase
Abundant clinopyroxene; orthopyroxene and olivine fairly common	Clinopyroxene fairly common; trace orthopyroxene; no olivine
Modally a monzonite	Modally a monzonite, but somewhat more siliceous
Chemically a monzonite	Chemically a monzonite, but more MgO and CaO, less Na_2O and K_2O (significantly lower Differentiation Index).
Quartz present only locally, in trace or small amounts	Quartz poor, but no quartz-free samples seen

Table 3. Modes of granitic plutons in Livengood B-6 quadrangle.

Samp. no.	plag	K-f	qtz	mafic minerals	Pluton
87Ri-23d	27	43	0	30	
87Ri-26c	33	34	0	33	
87Ri-42a	35	45	0	20	
87Ri-42b	26	51	0	23	Sawtooth Mountain
87Ri-55a	25	31	1	43	
87Ri-56b	31	44	1	24	
87Ri-56c	25	50	1	25	
87Ri-43a	29	37	4	30	
87Ri-44	27	44	<1	29	
87Ri-45a	35	39	0	26	
87Ri-45b	27	43	3	27	Elephant Mountain
87Ri-45c	32	38	3	27	
87Ri-45d2	28	34	4	34	
87Ri-48b	29	37	1	33	
87Ri-48c	29	33	3	35	
87Ri-38b	20	36	3	41	
87Ri-38c	29	27	2	42	West Wolverine
87Ri-39a	28	42	6	24	
87Ri-40a	35	40	8	17	
87Ri-40b	33	41	13	13	East Wolverine
87Ri-41a	33	40	10	17	
87Ri-41bl	29	45	8	18	
88Ri-2d	39	40	9	12	
87Ri-35f	37	34	15	14	
87Ri-36a	36	37	16	11	Wolverine Mountain
87Ri-36b	36	38	16	10	
87Ri-37	31	39	17	13	
87Ri-49a	49	27	12	12	Huron Creek
87Ri-49c	43	31	13	13	

Huron Creek pluton--Exposed mainly as near-outcrop rubble (Light and Rinehart, 1988), the pluton consists of massive porphyritic quartz monzonite in which blocky euhedral K-feldspar phenocrysts as much as 2 cm across, but averaging less than one cm, constitute 15-20 percent of the rock. The rest is divided equally between subangular to rounded broad plagioclase laths 2 mm long and a microcrystalline matrix. Quartz occurs as sparse rounded phenocrysts and also constitutes one-third of the fine-grained matrix. The remainder of the matrix is divided equally between mafic minerals and K-feldspar. Color index averages 13. In thin sections, milled-off corners of phenocrysts and mosaic-textured matrix that locally resembles recrystallized mortar suggest previous moderate cataclastic deformation. K-feldspar phenocrysts are somewhat perthitic and sparsely poikilitic. Plagioclase (oligoclase/andesine) is twinned and strongly zoned. Color index is made up of broad, subequant, ragged crystals of biotite and hornblende in about equal amounts. Accessory minerals are apatite, monazite(?), opaque minerals (most are raggedly exsolved in biotite), and sparse allanite. Radiometric ages (table 1) for quartz monzonite samples from the Huron Creek pluton are: 87.5 Ma ±1.4 Ma (biotite); and 92.5 Ma ±1.8 Ma (hornblende).

East Wolverine pluton--Massive, homogeneous, porphyritic quartz monzonite with K-feldspar phenocrysts more euhedral, generally smaller, and more tablet-shaped than the blocky, subhedral, equant K-feldspar phenocrysts in the highly similar Wolverine pluton. Large areas in the pluton are characterized by trachytoid texture--subparallel disposition of K-feldspar tablets--that is especially typical of the Sawtooth Mountain, Elephant Mountain, and West Wolverine plutons. A local fine-grained intrusive phase was observed crosscutting trachytoid rock. Maximum phenocryst dimension averages a little less than a centimeter and grades serially to less than a millimeter. Although most of the K-feldspar occurs as phenocrysts, a small amount is present as late interstitial filling in the groundmass. Plagioclase laths, one-half to one-third the size of the K-feldspar phenocrysts, also grade serially into fine-grained matrix. At an exposed contact with knotted pelitic hornfels, no textural or compositional effects were noted in the quartz monzonite. Small (1-3cm) fine-grained mafic enclaves are widespread but are not abundant.

Microscopically the texture is mainly xenomorphic-granular with a strong suggestion that the rock has previously undergone weak to moderate crushing, followed by recrystallization. Both plagioclase (oligoclase/andesine) and K-feldspar are conspicuously zoned, the latter somewhat poikilitic with zonal distribution of included crystals; it is also commonly perthitic. Quartz, averaging about 10 percent, is entirely late and interstitial. Average color index of 15 is made up of biotite, hornblende, and clinopyroxene with ratios of about 2:1:1; much of the hornblende is uralitic. Accessory minerals are apatite, sphene, zircon, sparse opaque minerals, and rare allanite.

Wolverine Mountain pluton--Coarse, massive, homogeneous, porphyritic quartz monzonite characterized by blocky, nearly equant K-feldspar phenocrysts as much as 2 cm across that grade serially to about 3 mm. A very little K-feldspar also occurs as sparse interstitial fillings in the matrix. Plagioclase (oligoclase to labradorite), in laths, is also serial in size from maximum lengths of about 6 mm down to microscopic. Quartz averages about 15 percent and much consists of fairly coarse equant aggregates, or broken single crystals that measure as much as 3 mm across, and grade downward in size to that of the finest matrix constituents.

Microscopically, the texture is xenomorphic- to hypidiomorphic-granular seriate, showing evidence of some granulation and recrystallization. Both plagioclase and K-feldspar are strikingly zoned, the latter commonly somewhat perthitic and sparsely poikilitic. Color index averages about 12 and is made up of nearly equal amounts of shreddy reddish-brown biotite and subhedral to anhedral green to brown hornblende, the latter locally containing cores of clinopyroxene. Accessory minerals are typically apatite sphene, zircon, opaque minerals, and sparse allanite.

The K/Ar radiometric age for biotite from quartz monzonite from the Wolverine pluton is 89.4 Ma ±0.9 Ma (table 1).

West Wolverine pluton--Fairly dark-gray, massive, mainly non-porphyritic, but varied textured monzonite and quartz-poor quartz monzonite. Includes a common phase in which 4-6-mm, dull, sub-equant aggregates and crystals of clinopyroxene, and broad shiny biotite crystals similar in size, locally give a porphyritic appearance to the rock. K-feldspars are typically thin wafers less than a centimeter in broad dimension, locally in subparallel orientation forming trachytoid texture. Using several parameters, the West Wolverine is the most mafic of all the plutons in the western part of the Livengood quadrangle. Chemically it is the least siliceous (54 percent), has the highest normative color index (34), and has the lowest differentiation index (.50). Petrographically it is low in quartz (3+ percent), and has the highest color index (40+).

Microscopically the texture is xenomorphic- to hypidiomorphic-granular and seriate. The texture is largely dominated by large tabular, subhedral, locally perthitic and somewhat poikilitic K-feldspar, and equally sized clinopyroxene crystals or aggregates that locally impart glomeroporphyritic texture to the rock. A minor amount of K-feldspar is late and interstitial. Most K-feldspar is clouded with argillic(?) alteration products. Strongly zoned subhedral to anhedral plagioclase (oligoclase to labradorite) is generally, but not everywhere, smaller than the K-feldspar and is also seriate. Quartz is present only as interstitial fillings. Mafic minerals are mostly represented by sub- to anhedral clinopyroxene and euhedral to anhedral biotite in varied ratios of 4:1 to 1:1. A little uralitic hornblende is present in all samples, and in the most felsic, has nearly replaced all clinopyroxene except sparse remnants that remain as cores in hornblende crystals. Accessory minerals are apatite, zircon(?), monazite(?), sphene, opaque minerals, and sparse allanite.

Table 4. Chemical analyses, in weight percent, of major elements, and CIPW norms of representative samples of granitoid rocks in Livengood B-6 quadrangle, Alaska

[Elements determinied by X-ray fluorescence; DI, differentiation index of Thornton and Tuttle (1960); Nrm CI, normative color index; --, no data; all sample numbers prefixed 87RI-, except *, which are prefixed 88Ri-]

	Sawtooth Mountain				Elephant Mountain		West Wolverine	East Wolverine	Wolverine Mountain			Huron Creek
Sample No.	26b	50a	56b	56c	44	48b	38b	41a	37	28-1*	2D	49
					Chemical analyses, in weight percent							
SiO_2	40.30	55.90	56.70	57.20	56.70	56.80	53.90	63.50	67.50	65.80	65.80	63.30
Al_2O_3	10.50	17.60	16.90	16.80	14.70	14.50	14.40	15.10	15.50	15.30	15.20	16.40
Fe_2O_3	1.82	1.63	1.42	1.47	0.75	1.03	0.74	0.61	0.35	1.10	0.80	0.88
FeO	12.30	5.50	5.20	5.40	5.70	5.50	7.00	3.30	2.40	2.10	3.00	4.10
MgO	12.10	2.18	2.46	2.58	4.54	5.14	5.41	1.87	0.99	1.50	1.90	1.34
CaO	9.09	4.29	4.49	4.55	5.96	6.68	6.14	3.38	2.36	2.50	3.00	2.79
Na_2O	0.46	3.00	3.32	3.27	2.47	2.27	1.94	3.06	3.55	3.40	3.30	3.94
K_2O	5.69	7.29	6.24	6.33	5.80	5.09	5.44	5.87	5.34	5.60	6.00	4.32
H_2O-	0.16	0.05	0.13	0.15	0.07	0.20	0.14	0.17	0.06	0.19	0.06	0.14
H_2O+	2.16	2.30	0.95	0.63	0.98	0.71	1.68	0.59	0.49	0.58	0.52	0.75
TiO_2	2.91	0.92	0.81	0.86	0.76	0.77	0.97	0.43	0.36	0.36	0.41	0.74
P_2O_5	1.35	0.49	0.38	0.39	0.37	0.41	0.45	0.20	0.15	0.14	0.19	0.31
MnO	0.17	0.11	0.12	0.13	0.12	0.12	0.14	0.07	0.04	0.08	0.09	0.09
CO_2	0.14	0.10	0.16	0.01	0.40	0.01	0.83	0.82	0.40	0.01	0.07	0.08
Total	99.15	101.36	99.28	99.77	99.32	99.23	99.18	98.97	99.49	98.66	100.34	99.18
					CIPW norms and other parameters							
Q	--	--	--	--	0.95	3.10	--	13.00	18.98	16.95	14.01	14.39
C	--	--	--	--	--	--	--	--	--	--	--	0.93
or	--	43.55	37.61	37.79	35.02	30.60	33.30	35.62	32.02	33.81	35.57	25.99
ab	--	25.80	28.65	27.95	21.35	19.54	17.01	26.59	30.48	29.39	28.01	33.94
an	10.12	13.17	13.04	12.60	12.15	14.59	15.04	10.40	10.74	10.16	8.97	12.03
lc	27.27	--	--	--	--	--	--	--	--	--	--	--
ne	2.18	0.03	--	--	--	--	--	--	--	--	--	--
di	19.48	4.28	5.95	6.35	12.79	13.37	11.07	4.54	0.12	1.29	3.89	-
hy	--	--	8.75	9.65	14.28	14.84	18.52	7.64	6.09	5.74	7.18	9.25
ol	28.22	8.07	1.44	0.95	--	--	0.87	--	--	--	--	--
mt	2.73	2.39	2.10	2.15	1.11	1.52	1.11	0.91	0.52	1.63	1.16	1.30
hm	--	--	--	--	--	--	--	--	0.17	--	--	--
il	5.72	1.77	1.57	1.65	1.48	1.49	1.91	0.84	0.69	0.70	0.78	1.43
ap	3.23	1.15	0.90	0.91	0.88	0.97	1.08	0.48	0.35	0.33	0.44	0.73
D. I.	29.50	69.20	66.30	65.70	57.32	53.20	50.31	75.20	81.50	80.20	77.60	74.33
Nrm CI	56.20	16.50	19.80	20.80	29.70	31.20	33.60	13.90	7.40	9.40	13.00	12.00
	Foidite	Monzonite					Syeno-diorite	Adamellite				

Mafic rocks of the Rampart Group--It has been noted in most written descriptions of rocks of the Rampart Group, that mafic igneous rocks, excluding tuff, are enormously abundant throughout the unit (Mertie, 1937; Brosge' and others, 1969; Chapman and others, 1971; Jones and others, 1984). As assessed from exposures that occupy probably less than one percent of the mapped extent of the unit in the Livengood quadrangle, the mafic rocks range from aphanitic greenstone to coarse-grained gabbro--and locally diorite--but are mostly medium-and fine-grained, originally holocrystalline rocks. Ultramafic rocks were found at two localities--a peridotite along the Yukon River 5 miles west of the quadrangle boundary, west-southwest of Maypole Hill; and a thin layer of lherzolite in layered gabbro at hill VABM Kermit, near the quadrangle's northeastern limit of the unit. The mafic rocks are medium to dark green, grayish green, and greenish black, and weather to varied shades of yellow, brown, and reddish brown. They are hard with blocky, irregular fracture, and commonly form prominent bold ridges, knobs, and bluffs. The rocks are typically massive, but sparse pillow structure has been reported from several localities in the western part of the unit and as far east as approximate longitude 148° 53' on Hess Creek. Also, amygdaloidal structure was seen in at least two places. However, clear indications of the intrusive or extrusive character of the mafic rocks are generally sparse, but both types are documented at scattered localities. Intrusions, where documented, are sills rather than dikes. Sills were inferred at a few localities where greenstone, interlayered with sedimentary rocks, shows a consistent increase in grain size away from both contacts.

Attempting to discriminate between extrusive and intrusive varieties is a frustrating, often fruitless quest. A typical example can be found along the Yukon River a mile and a quarter west of Kalka Island, west of the quadrangle boundary. There, dark colored, dense, almost featureless rock, that appears to be massive lava, is exposed in steep bluffs. On closer inspection, massive greenstone is in seemingly normal depositional contact with a sequence of thin-bedded chert and argillite. At one place, however, aphanitic greenstone grades into coarser medium-grained gabbro over a span of 50 feet, and nearby, the gabbro intrusively truncates several feet of the sedimentary sequence. Analyses of the two rocks (table 5, 75a and 75b) are similar;

the difference in rock name reflects the difference in texture--diabasic and hypautomorphic-granular.

Thin-section study of the mafic rocks, supplemented by 15 chemical analyses (including the two ultramafic rocks), shows a fairly narrow compositional range from fine-grained greenstone (lava) to medium-grained gabbro(table 5); chemically all are subalkaline tholeiites. Although zones of breccia and gouge are not uncommon among exposures visited in the field, thin sections reveal only massive structure, and evidence of penetrative deformation is entirely absent. The rocks are pervasively altered, but are not clearly metamorphosed, judging from common preservation of zoning in the plagioclase, the absence of albite, and the ubiquitous presence of chlorite, commonly accompanied by various serpentine minerals. The latter two minerals are typically associated with a host of microcrystalline alteration products, some of which completely obscure or obliterate the identity of the plagioclase species while preserving its morphological outline. Other less common alteration products include: calcite, sericite, biotite, stilpnomelane(?), prehnite, zeolite, talc, and various amorphous-appearing isotropic and cryptocrystalline brown, reddish-brown, yellowish, and greenish yellow materials. Textures are typically diabasic or hypautomorphic-granular, rarely ophitic.

The common essential minerals are: clinopyroxene, andesine/labradorite, with lesser amounts of orthopyroxene, uralitic amphibole, and opaque minerals. Minerals commonly present in accessory amounts are quartz, apatite, zircon, monazite(?), and sphene. Clinopyroxene is subhedral, pale tan, pale green, or colorless, and is the least altered mineral. Plagioclase is mostly subhedral, lath shaped, twinned, and perhaps less commonly zoned, although lack of zoning may be due to the near opacity of much plagioclase, owing to dense clouding of the crystals by cryptocrystalline alteration products. Orthopyroxene is present sparsely, only as remnant crystals, apparently being especially vulnerable to alteration to chlorite and serpentine minerals. Chlorite and serpentine psuedomorphs suggestive of orthopyroxene, and locally olivine, were seen in several thin sections that contained neither of those primary minerals. Interstitial quartz is common--but not ubiquitous--in trace amounts to as much as 3 or 4 percent.

Table 5. Chemical analyses and other parameters of some mafic rocks from the Rampart Group, Alaska

[Elements determined by X-ray fluorescence; nrm, normative; A, Na_2O+K_2O; F, $FeO+Fe_2O_3$; M, MgO; DI, differentiation index of Thornton and Tuttle(1960); CI, color index; cpx, clinopyroxene; opx, orthopyroxene; ol, olivine; tr, trace; sample numbers prefixed 87]

Sample no.	Gabbro Ri-11a	Gabbro Ri-11c	Gabbro Ri-12	Gabbro Ri-13a	Lherzolite Ri-14b	Diabase Ri-17	Gabbro Ri-18	Gabbro Ri-19b	Gabbro Ri-20	Peridotite Ri-64e	Gabbro Ri-65	Gabbro Ri-71	Diabase Ri-74a	Diabase Ri-75a	Gabbro Ri 75b
SiO_2	50.10	48.50	38.20	44.30	43.40	48.60	46.60	47.00	49.60	43.60	49.00	48.00	48.10	49.30	48.60
Al_2O_3	14.80	15.70	11.80	12.70	4.27	14.60	14.30	11.40	15.00	5.23	13.30	14.80	14.20	13.80	13.60
Fe_2O_3	2.75	2.11	10.12	6.99	3.43	3.34	3.09	4.03	1.66	4.25	2.89	1.95	2.95	1.97	2.47
FeO	7.60	5.60	14.10	10.80	13.10	7.70	9.00	12.20	7.20	7.60	10.80	9.40	8.50	9.20	9.20
MgO	6.42	7.92	6.41	6.13	24.80	8.03	7.57	5.55	7.13	22.80	6.39	7.06	7.56	6.47	8.17
CaO	9.98	12.40	10.30	10.20	6.85	12.50	10.20	9.84	12.50	8.75	10.50	11.70	12.20	9.69	9.71
Na_2O	2.32	2.51	1.37	2.19	0.73	1.82	2.76	2.24	2.24	0.51	2.06	2.02	1.98	2.25	1.97
K_2O	0.44	0.54	0.38	0.29	0.17	0.18	0.66	0.39	0.42	0.16	0.20	0.17	0.25	0.54	0.51
TiO_2	1.58	0.89	3.87	3.04	0.67	1.43	1.70	3.78	1.27	0.63	2.38	1.78	1.48	1.79	1.65
P_2O_5	0.18	0.09	0.07	0.15	0.07	0.13	0.12	0.24	0.07	0.07	0.21	0.16	0.13	0.19	0.16
MnO	0.18	0.13	0.20	0.20	0.26	0.19	0.17	0.25	0.15	0.21	0.21	0.19	0.18	0.18	0.18
H_2O+	3.13	2.95	2.85	2.73	2.27	1.44	3.39	2.39	2.25	5.13	2.16	2.61	0.00	3.13	3.48
H_2O-	0.46	0.43	0.30	0.30	0.17	0.27	0.30	0.40	0.26	0.65	0.10	0.17	0.00	0.58	0.60
CO_2	0.09	0.02	0.01	0.03	0.01	0.01	0.05	0.03	0.23	0.03	0.07	0.02	0.17	0.02	0.03
Total	100.03	99.79	99.98	100.05	100.20	100.24	99.91	99.74	99.98	99.62	100.27	100.03	97.70	99.11	100.33
Other parameters															
nrm qtz	5	0	2	2	0	1	0	4	<1	0	4	<1	<1	3	1
modal qtz	<5	0	0	<1	0	0	0	<1	<1	0	<1	<1	?	3	<1
A	14	17	6	10	2	10	15	11	14	2	10	11	11	14	11
F	52	41	74	67	39	52	52	66	47	33	61	55	53	54	52
M	33	43	20	24	59	39	33	23	39	65	29	35	36	32	37
DI	28	25	14	21	7	17	28	26	22	6	23	19	19	27	22
nrm cpx	47	67	51	53	27	57	57	59	63	35	50	52	58	46	40
nrm opx	53	13	0	35	13	43	10	41	37	22	50	48	42	54	60
modal opx	0	?	0	0	tr	0	?	0	tr	tr	0	0	?	0	tr
nrm ol	0	20	50	11	60	0	34	0	0	44	0	0	0	0	0
modal ol	0	0	0	0	tr	0	0	0	0	tr	0	0	0	0	0
nrm CI	42	43	60	54	84	51	46	53	47	82	50	49	51	46	50
modal CI	40-50	70	70	60	80-90	60	65	60	60-70?	90	40	20?	50	40-50	50

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