STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

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Report of Investigations 83-16

THE MIDDLE FORK PLUTONIC COMPLEX, McGRATH A-3 QUADRANGLE, SOUTHWEST ALASKA

By
Diana N. Solie

STATE OF ALASKA
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THE MIDDLE FORK PLUTONIC COMPLEX, McGRATH A-3 QUADRANGLE, ALASKA

By
Diana N. Solie

INTRODUCTION AND ACKNOWLEDGMENTS

The Middle Fork plutonic complex, located in the west-central Alaska Range in the McGrath A-3 Quadrangle, covers an area of approximately 125 km^2. The rock units present are biotite-olivine-pyroxene gabbro, olivine-pyroxene syenite, peralkaline arfvedsonite granite, and a heterogeneous unit of biotite- and hornblende-bearing lithologies ranging from granite to monzonite of Streckeisen's classification (1967). The Middle Fork complex is thought to be coeval with the Oligocene Windy Fork pluton 8 km to the southeast, based on mineralogical and lithological similarities. Both igneous bodies intrude lower to mid-Paleozoic clastic and carbonate rocks, and are surrounded by hornfelsed aureoles from 1 to 3 km wide.

The Middle Fork plutonic complex was mapped in 1982 as part of the DGGS McGrath Quadrangle resource investigations project (Gilbert and Solie, 1983). Previous mapping of the plutonic complex was of a reconnaissance nature (Reed and Elliott, 1968, 1970; Herreid, 1968. These workers reported the occurrence of several of the igneous phases in the complex, but no internal contacts or relationships between phases were described. This report describes the rock types present in the Middle Fork plutonic complex, presents major-oxide analyses, and draws some preliminary conclusions regarding the petrogenesis and crystallization history of the complex.

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GEOLOGIC SETTING

The Middle Fork plutonic complex forms the rugged topography at the head of the Middle Fork of the Kuskokwim River. It is drained by several glacially scoured valleys, with drift present along lower valley walls and bottoms. Above the drift, bedrock exposure is good, obscured only by talus and ice. However, accessibility is limited because of extreme steepness.

Hosting the plutonic complex are deep-water to foreslope clastic and carbonate rocks that range in age from Cambrian to Devonian (Gilbert and Bundtzen, 1983). This Paleozoic sedimentary package is part of the Dillinger tectonostratigraphic terrane (Jones and others, 1981), which occurs south of the Farewell fault and extends from the Talkeetna Quadrangle in the east to the Sleetmute Quadrangle in the southwest. In contact with the plutonic complex are Cambro-Ordovician silty limestones, Ordovician to Lower Silurian black shales, and Middle Silurian to Lower Devonian(?) calc-sandstones and silty limestones (Gilbert and Solie, 1983). These rocks form large northwest-verging nappe structures. Small-scale isoclinal folds are common.

The Farewell fault zone, which occurs along the northern front of the Alaska Range, is about 30 km north of the Middle Fork plutonic complex. This zone, part of the Denali fault system, is thought to have a right-lateral offset of perhaps 38 km (Reed and Lanphere, 1974). Vertical uplift is also evident along the fault zone, where recently active north-facing fault scarps cut Quaternary units. This vertical movement is related to uplift of the Alaska Range and to block faulting within the fault zone. A structurally controlled break in the topography of the Alaska Range occurs just west of the Middle Fork plutonic complex along the Big River. There, a southwest-striking fault cuts the west edge of the plutonic complex, marking the start of the southwestward trend of the western Alaska Range.

The Middle Fork plutonic complex is probably part of the youngest known plutonic activity in the Alaska-Aleutian Range batholith. Work by Reed and Lanphere (1969, 1970, 1972, 1973, 1974) shows that the batholith encompasses several major plutonic episodes. The oldest episode, in Early to Middle Jurassic time, formed an arcuate belt of plutons near the southeast rim of the batholith. These rocks are largely diorite and quartz diorite with minor granodiorite. A Late Cretaceous and early Tertiary episode is represented by a north-trending belt of predominantly granites and quartz monzonites in the northwestern part of the batholith. The youngest plutonic activity, perhaps a later phase of the mid-Tertiary episode, is dated at 25-30 m.y. (Reed and Lanphere, 1972). These K-Ar dates are from the northeast prong of the Tired Pup pluton and from the Windy Fork pluton, which are located about 40 and 10 km respectively, southeast of the Middle Fork complex.

Volcanic rocks in the area are calc-alkaline and range from Late Cretaceous to early Tertiary (Solie and others, 1982). A 5-km-wide swarm of vertical, east-west-striking felsic to mafic dikes intrudes the Paleozoic sedimentary rocks east of the Middle Fork plutonic complex and locally intrudes the eastern part of the complex itself.

ROCK UNITS

Alkali Gabbro

Biotite-olivine-pyroxene gabbro is present predominantly in the northwest part of the Middle Fork plutonic complex. This alkali gabbro is fine- to medium grained, dark-greenish brown, and generally forms distinctive rounded dark-green brown grus-covered outcrops. Thin leucocratic dikes commonly intrude the unit. The dikes are composed of quartz and alkali feldspar, locally in graphic intergrowth, with traces of biotite and opaque minerals.

Compositional layering occurs in two locations within the Middle Fork plutonic complex. One location is along the stream flowing westward to the north of sample location 1 (fig. 1). The other occurs in the upper reaches of 'Camp Creek,' where layered gabbro clearly intrudes syenite. Elsewhere, the contact between the alkali gabbro and other igneous units is diffuse or indeterminate.

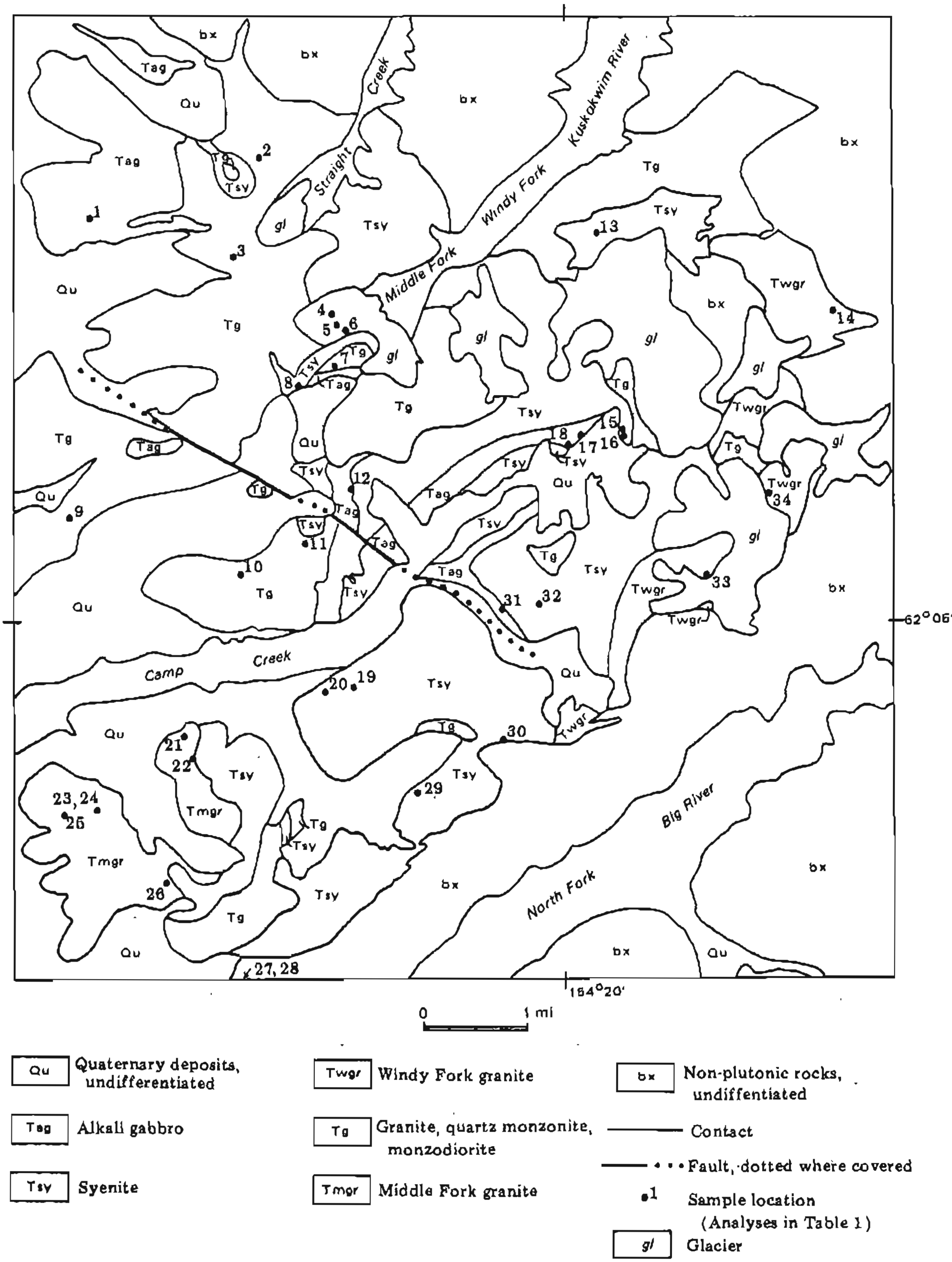

Figure 1. Generalized geology of Middle Fork plutonic complex (after Gilbert and Solie, 1983).

Typical composition of the alkali gabbro is andesine (30-55 percent), clinopyroxene (10-25 percent), iron-rich olivine (5-20 percent), biotite 2-30 percent), and hornblende (1-2 percent). Minor minerals include alkali feldspar (0-5 percent), orthopyroxene (0-5 percent), and opaque minerals (1-10 percent). Apatite in trace amounts is ubiquitous. Secondary minerals include chlorite, iddingsite, serpentine(?), actinolite, and carbonate. At one locality apophyllite ($KCa_4[Si_8O_{20}]8H_2O$) was found on a fracture surface and identified by X-ray diffracation (N. Veach, analyst, DGGS).

The texture is subophitic. Crystallization sequence is olivine followed by clinopyroxene, followed by biotite and greenish to brown hornblende. The clinopyroxene generally has a pale, mottled pinkish-green color in thin section. Hornblende typically replaces the pyroxene, and biotite forms large randomly oriented flakes.

Classification of this gabbroic unit presents a problem. On the basis of modal plagioclase composition, which ranges from An_{30} to An_{40}, the rock is a diorite. However, with the abundance of olivine, low SiO_2 content (43.69-50.99 weight-percent), and color index generally above 50, the unit falls within the gabbro family. The high percentage of biotite, fairly high K_2O content (average of 1.46 weight-percent), and local occurrence of alkali feldspar suggest that it is most closely related to the alkali gabbro group.

The alkali gabbro unit has considerable chemical variability. Analytical data and corresponding CIPW normative mineral assemblages are shown in table 1.

Olivine appears as a CIPW normative mineral in all samples but 82DNS62. Normative orthoclase is present in all samples, ranging from 4.727 weight-percent to 15.718 weight-percent. Only sample 82DNS62 is quartz normative, with 2.927 weight-percent quartz. None are nepheline normative.

Figure 2 shows variation diagrams of each of the major oxides (weight-percent) plotted against SiO_2 (weight-percent) for all samples analyzed. The gabbroic samples consistently have a large vertical spread compared to other rock types in each diagram. The weight-percent SiO_2 ranges from 43.69 to 50.99. The samples lowest in SiO_2 content have anomalously high MgO contents (up to 23.27 weight-percent) and low Al_2O_3 contents (as low as 7.60 weight-percent).

Using the Shand (1927) classification system, the alkali gabbros are metaluminous, that is, $Al_2O_3 < (CaO+Na_2O+K_2O)$; $Al_2O_3 > (Na_2O+K_2O)$ via oxide values and subaluminous, that is, $Al_2O_3 \approx (Na_2O+K_2O)$ via normative values. The rocks are subalkaline and plumasitic, that is, $Na_2O+K_2O < Al_2O_3$; $Na_2O+K_2O < 1/6SiO_2$). All are alkali-olivine basalts in the classification of Macdonald and Katsura (1964) except sample 82DNS145, which plots as a tholeiite (fig. 2).

The differentiation index (DI = normative q+ab+or) varies from 15.8 (sample 82DNS178a) to 45.4 (sample 82DNS62). These samples also represent the range of normative color index (CI = normative di+hy+ol+mt+hm+il) from 71.6 to 26.3, respectively, with an average color index for the seven gabbroic samples

Table 1. Major-oxide analyses and CIPW norms.[a]

	Alkali gabbro							Syenite					
Sample no.	21	17	31	1	12	2	18	20	19	8	33	16	30
Field no.	82DNS62	82DNS105	82DNS145	82DNS170	82DNS178a	82DNS196	82AR12	82DNS79	82DNS80	82DNS127	82DNS195b	82DNS210	79AR6
SiO_2	50.99	47.63	48.72	46.98	43.69	46.65	46.90	62.79	62.53	65.99	64.94	60.62	63.20
TiO_2	2.52	3.42	1.20	1.39	0.99	1.28	3.17	0.66	0.61	0.64	0.58	0.64	0.45
Al_2O_3	16.10	14.28	11.17	15.03	7.60	10.54	13.70	16.07	15.79	15.81	14.66	16.00	16.40
Fe_2O_3	1.66	0.57	1.83	2.70	2.80	2.17	1.60	1.52	1.56	0.87	1.80	3.17	1.30
FeO	6.92	11.11	10.22	10.68	13.96	12.45	17.10	4.87	6.13	2.99	4.48	5.30	4.00
MnO	0.16	0.22	0.19	0.24	0.25	0.23	0.37	0.17	0.20	0.06	0.15	0.16	0.13
MgO	3.00	4.39	14.95	7.26	23.27	16.78	2.87	0.04	0.11	0.89	0.28	0.19	0.16
CaO	7.26	8.77	7.91	8.11	5.60	6.92	7.49	2.06	2.79	3.14	2.11	2.49	2.00
Na_2O	3.16	2.97	2.11	2.72	1.31	1.83	3.36	5.53	5.76	4.25	5.21	4.77	5.40
K_2O	2.66	1.78	1.15	1.24	0.80	1.19	1.38	6.07	5.78	4.20	5.53	5.84	6.10
P_2O_5	0.62	1.36	0.28	0.35	0.23	0.35	0.99	0.04	0.11	0.13	0.09	0.09	0.06
H_2O-	0.37	0.32	0.16	0.22	0.15	0.06	0.02	0.27	0.21	0.16	0.14	0.12	0.25
LOI	3.31	0.03	0.18	0.44	0.02	0.13	0.03	0.13	0.09	0.51	0.36	0.19	0.20
CIPW Norms													
Quartz	2.93	-	-	-	-	-	-	1.80	2.05	16.33	8.17	2.97	2.99
Orthoclase	15.72	10.52	6.80	7.33	4.73	7.03	8.15	35.87	34.15	24.82	32.56	34.51	36.05
Albite	26.74	25.13	17.85	23.01	11.08	15.48	28.43	46.79	44.51	35.96	44.05	40.36	45.69
Anorthite	21.89	20.37	17.61	25.14	12.49	17.03	18.22	1.10	2.40	11.66	0.34	5.00	2.49
Diopside	8.34	11.91	15.96	10.54	11.08	12.13	10.74	7.88	9.51	2.59	8.36	6.04	6.21
Hypersthene	10.81	13.59	11.97	9.25	2.73	8.37	9.10	2.83	4.57	4.74	2.38	5.29	2.90
Olivine	-	4.50	23.97	14.07	51.91	33.96	13.65	-	-	-	-	-	-
Magnetite	2.41	0.83	2.65	3.91	4.06	3.15	2.32	2.20	2.26	1.26	2.61	1.70	1.89
Hematite	-	-	-	-	-	-	-	-	-	-	-	-	-
Ilmenite	4.79	6.49	2.28	2.64	1.88	2.43	6.02	1.25	1.16	1.22	1.10	1.22	0.86
Apatite	1.44	3.15	0.65	0.81	0.53	0.81	2.29	0.09	0.25	0.30	0.21	0.18	0.14
Leucite	-	-	-	-	-	-	-	-	-	-	-	-	-
Nepheline	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca-orthosilicate	-	-	-	-	-	-	-	-	-	-	-	-	-
Na-metasilicate	-	-	-	-	-	-	-	-	-	-	-	-	-
Corundum	-	-	-	-	-	-	-	-	-	-	-	-	-
Wollastonite	-	-	-	-	-	-	-	-	-	-	-	-	-
Acmite													
Diff. index	45.38	35.65	24.65	30.34	15.81	22.52	36.58	84.46	80.71	77.11	84.81	77.83	84.72
Color index	26.34	37.33	56.83	40.41	71.67	60.04	41.83	14.17	17.50	9.80	14.45	14.24	11.95
Plag. comp.	45.02	44.78	49.66	52.21	52.99	52.38	39.06	2.29	5.12	24.48	0.77	11.02	5.19

[a]Samples with prefix 82DNS analyzed using X-ray fluorescence by D.C. Veach, DGGS. Samples with prefix 79Ar and 82Ar collected by B.L. Reed, analyzed by U.S. Geological Survey. Sample locations shown on figure 1.

Table 1. (Cont.)

	Syenite (cont.)				Windy Fork granite				Middle Fork granite				
Sample no. Field no.	29 82AR10	15 82AR11	27 82DNS155	28 82DNS203	34 82DNS162	14 82DNS193	35 82DNS137	36 (avg)*	22 82DNS64	23 82DNS67a	24 82DNS67b	26 82DNS208	25 82AR9
SiO_2	60.80	60.40	38.47	47.92	72.11	74.84	74.04	73.50	62.22	62.88	66.59	67.44	66.50
TiO_2	0.57	0.66	2.18	0.95	0.26	0.18	0.22	0.23	0.95	0.91	0.60	0.61	0.50
Al_2O_3	15.00	16.40	12.50	18.38	11.89	11.16	11.83	12.65	16.31	15.58	15.15	15.29	14.52
Fe_2O_3	1.62	1.30	1.58	1.44	1.98	1.28	1.29	1.36	1.21	2.42	0.99	3.83	1.87
FeO	6.94	5.74	4.13	3.80	1.07	1.43	1.56	1.61	4.54	4.06	3.53	1.55	2.19
MnO	0.22	0.17	0.06	0.09	0.04	0.03	0.05	0.07	0.12	0.12	0.09	0.12	0.06
MgO	.10	0.19	6.40	5.00	0.12	0.05	0.12	0.18	0.77	0.80	0.52	0.58	0.35
CaO	3.19	2.72	29.04	16.10	0.85	0.28	0.63	0.84	3.29	2.34	1.95	1.60	1.42
Na_2O	4.67	4.80	1.43	2.14	4.52	4.41	4.52	4.44	4.67	4.14	4.34	4.87	4.22
K_2O	5.43	5.99	0.22	1.30	4.84	4.63	4.62	4.91	5.32	5.29	5.67	5.81	5.79
P_2O_5	0.08	0.08	0.02	0.25	0.02	0	0.02	0.05	0.17	0.17	0.09	0.09	0.09
H_2O-	0.03	0.03	0.14	0.25	0.21	0.09	0.29	0.29	0.19	0.20	0.12	0.19	0.06
LOI	0.22	0.05	1.67	2.27	0.70	0.35	0.33	0.04	0.12	0.76	0.18	0.83	0.72
					CIPW Norms								
Quartz	3.74	1.33	-	-	26.71	31.83	28.91	27.05	5.85	11.40	13.76	9.13	15.86
Orthoclase	32.09	35.40	-	7.68	28.60	27.36	27.30	29.01	31.44	31.26	33.21	34.33	34.21
Albite	39.51	40.61	-	10.40	34.21	31.63	35.13	37.57	39.51	35.03	36.72	41.21	36.33
Anorthite	3.93	5.51	27.13	36.71	-	-	-	0.09	7.83	8.31	5.26	2.20	4.12
Diopside	10.14	6.60	19.95	33.32	2.50	1.23	2.62	3.23	6.33	1.86	3.30	2.04	1.95
Hypersthene	5.51	5.68	-	-	-	1.86	1.24	0.36	4.66	5.22	4.44	-	1.71
Olivine	-	-	6.62	0.62	-	-	-	-	-	-	-	-	-
Magnetite	2.35	1.88	2.29	2.09	1.09	-	0.49	1.97	1.75	3.51	1.42	4.59	2.71
Hematite	-	-	-	-	-	-	-	-	-	-	-	0.68	-
Ilmenite	1.08	1.25	4.14	1.80	0.49	0.34	0.42	0.44	1.80	1.73	1.14	1.16	0.95
Apatite	0.18	0.18	0.05	0.58	0.05	-	0.05	0.12	0.39	0.39	0.21	0.19	0.21
Leucite	-	-	1.02	-	-	-	-	-	-	-	-	-	-
Nepheline	-	-	6.46	-	-	-	-	-	-	-	-	-	-
Ca-orthosilicate	-	-	28.36	-	-	-	-	-	-	-	-	-	-
Na-metasilicate	-	-	-	-	-	0.35	-	-	-	-	-	-	-
Corundum	-	-	-	-	-	-	-	-	-	-	-	-	-
Wollastonite	-	-	-	-	0.49	-	-	-	-	-	-	0.87	-
Acmite	-	-	-	-	3.55	3.70	2.75	-	-	-	-	-	-
Diff. index	75.34	77.34	7.48	22.26	89.52	90.81	91.33	93.63	76.80	77.69	83.69	84.67	86.[illegible]
Color index	19.08	15.42	32.99	37.83	4.09	3.43	4.77	6.01	14.55	12.32	10.30	5.65	[illegible]
Plag. comp.	9.05	11.95	71.58	67.89	0	0	0	0.23	16.54	19.16	12.53	6.15	10.[illegible]

*Average from Reed and Miller, 1980.

Table 1. (Cont.)

	Monzodiorite and quartz monzonite									
Sample no.	10	11	9	6	7	13	3	4	32	5
Field no.	82DNS75b	82DNS77b	82DNS82	82DNS112b	82DNS125	82DNS184	82DNS197	82DNS209	79AR7	82DNS111
SiO_2	71.24	51.98	69.17	51.66	61.19	50.64	67.97	52.11	70.60	53.00
TiO_2	0.34	1.57	0.53	2.17	0.72	2.04	0.54	2.95	0.38	1.80
Al_2O_3	14.38	15.72	15.13	14.38	16.15	15.28	14.87	15.81	13.80	15.70
Fe_2O_3	1.01	1.43	1.19	10.53	1.48	1.24	0.70	0.86	0.95	0.63
FeO	2.37	7.07	2.15	3.96	4.42	7.67	2.37	7.59	2.40	7.65
MnO	0.07	0.16	0.07	0.31	0.12	0.16	0.06	0.15	0.04	0.15
MgO	0.17	5.84	0.48	1.90	0.51	5.05	0.65	4.00	0.47	4.61
CaO	1.27	9.05	1.77	6.75	2.72	8.63	2.48	7.83	1.40	8.62
Na_2O	4.50	3.35	4.01	3.92	4.91	3.33	3.69	3.42	3.30	3.06
K_2O	5.71	1.81	5.52	1.94	4.98	2.66	4.88	2.03	5.70	1.90
P_2O_5	0.05	0.24	0.07	0.53	0.11	0.59	0.89	0.46	0.06	0.50
H_2O-	0.27	0.24	0.16	0.21	0.23	0.16	0.04	0.11	0.43	0.01
LOI	0.15	1.28	0.44	0.67	0.13	0.55	0.31	0.55	0.02	0.05
					CIPW Norms					
Quartz	19.80	-	19.69	8.68	5.78	-	22.70	2.11	24.78	2.52
Orthoclase	33.74	10.70	32.62	11.46	29.43	15.72	28.84	12.00	33.68	11.23
Albite	38.07	28.34	33.93	33.17	41.54	28.18	31.22	28.94	27.92	25.89
Anorthite	2.17	22.51	6.98	15.91	7.32	18.89	6.49	21.79	6.01	23.49
Diopside	3.32	16.99	1.13	10.21	4.73	16.48	-	11.57	0.47	13.22
Hypersthene	1.77	9.55	2.84	-	4.75	1.48	4.61	12.89	4.00	15.78
Olivine	-	4.53	-	-	-	9.51	-	-	-	-
Magnetite	1.46	2.07	1.73	7.48	2.15	1.80	1.02	1.25	1.38	0.91
Hematite	-	-	-	5.37	-	-	-	-	-	-
Ilmenite	0.65	2.98	1.01	4.12	1.37	3.87	1.03	5.60	0.72	3.42
Apatite	0.12	0.56	0.16	1.23	0.26	1.37	2.06	1.07	0.14	1.16
Leucite	-	-	-	-	-	-	-	-	-	-
Nepheline	-	-	-	-	-	-	-	-	-	-
Ca-orthosilicate	-	-	-	-	-	-	-	-	-	-
Na-metasilicate	-	-	-	-	-	-	-	-	-	-
Corundum	-	-	-	-	-	-	1.14	-	-	-
Wollastonite	-	-	-	0.42	-	-	-	-	-	-
Acmite	-	-	-	-	-	-	-	-	-	-
Diff. index	91.61	39.04	86.24	51.32	76.75	43.89	82.76	43.04	86.19	39.64
Color index	7.21	36.12	6.71	27.18	12.99	33.14	6.65	31.31	6.57	33.33
Plag. comp.	5.40	44.26	17.06	32.42	14.98	40.13	17.22	42.96	17.71	42.52

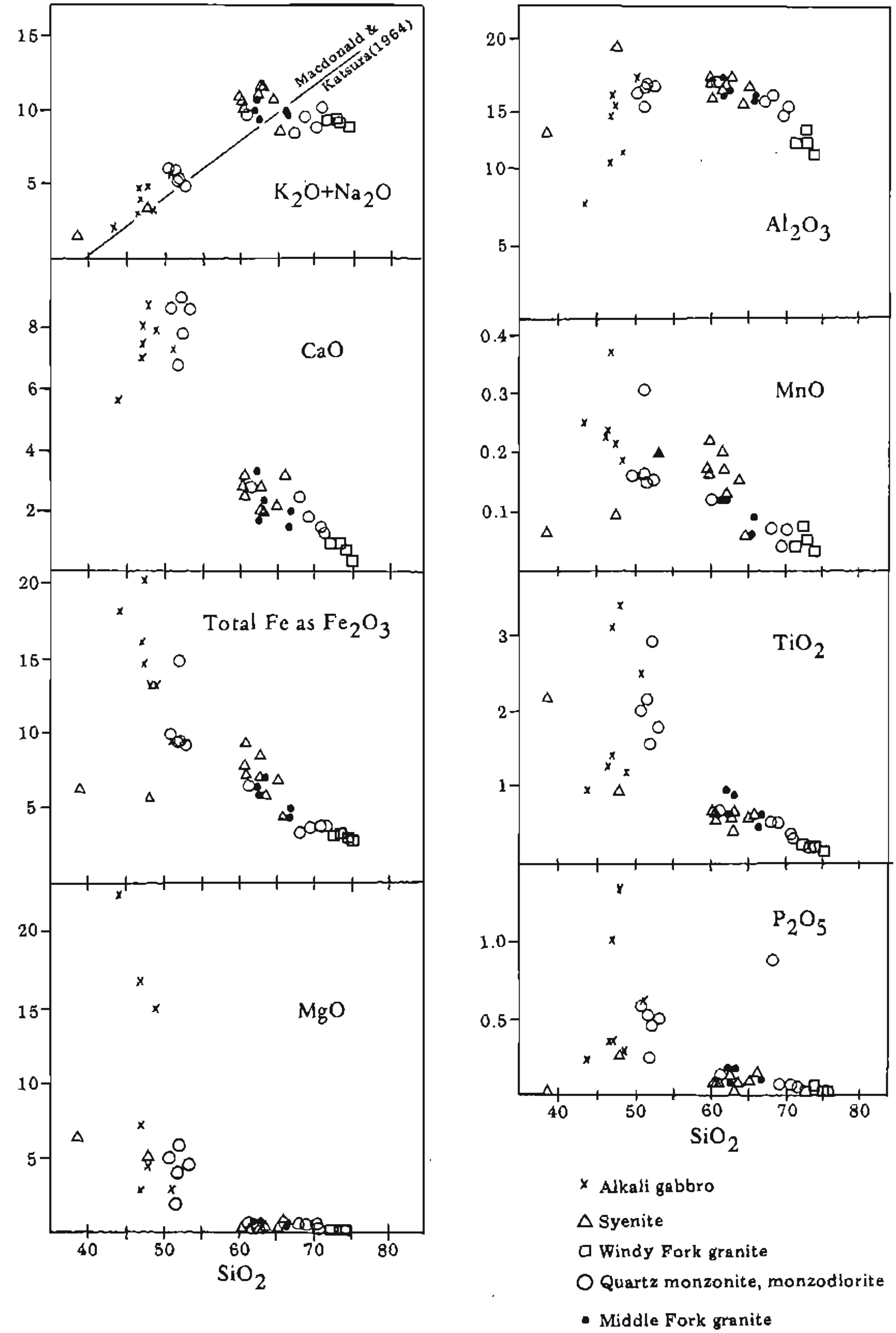

Figure 2. Plots showing major-element oxide variation with SiO_2 contents.

of 47.7. The average normative plagioclase composition for the seven samples is $An_{48.0}$, with a range from $An_{39.1}$ (82Ar12) to $An_{53.9}$ (82DNS178a).

Syenite

Through the central portion of the Middle Fork complex is a large, fairly homogeneous unit of olivine-clinopyroxene syenite that is medium to coarse-grained. Fresh surfaces of the rock are greenish gray; on weathering they bleach white and are commonly pervasively iron-stained. The syenite typically forms massive, jointed cliffs with large xenolithic blocks of hornfels.

The syenite is composed predominantly of perthitic alkali feldspar (45-90 percent), clinopyroxene (3-10 percent), iron-rich olivine (1-7 percent), plagioclase (3-10 percent), interstitial quartz (0-10 percent), and green-brown hornblende forming after pale mottled pinkish-green clinopyroxene (1-20 percent). Minor constituents are biotite (0-3 percent), opaque minerals (1-2 percent), and traces of rutile needles, apatite, zircon, fluorite(?), and monazite(?). Secondary minerals include chlorite, carbonate, iddingsite, actinolite, and epidote.

The texture of the syenite is hypidiomorphic-granular. Quartz content locally classifies the unit as a quartz syenite. Quartz and olivine, in apparent equilibrium, are not uncommonly seen together in thin section.

Strongly hornfelsed Paleozoic rocks just southwest of the intrusive are probably shallowly underlain by syenite. Silica-deficient dikes intrude the hornfels. These dikes, rich in calcium, contain modal nepheline, perovskite, a trace of biotite, an unidentified pale-green mineral, and an abundant black elongate mineral. This elongate mineral is an unusual dark pink to red in thin section and is tentatively identified as a pyroxene based on X-ray diffraction pattern (N. Veach, analyst, DGGS).

Major-oxide analysis of eight syenite samples (table 1) reveal weight-percent SiO_2 ranging from 60.40 to 65.89, K_2O content up to 6.10 weight-percent and TiO_2 content less than 1 weight-percent. Total alkali (K_2O+Na_2O) content is as high as 11.60 weight-percent; the ratio $K_2O:Na_2O$ is generally greater than one.

All eight samples are quartz normative (table 1) with a range of 1.33 to 16.33 weight-percent. Thus, normative olivine is absent, despite its presence modally. Orthoclase and albite account for the bulk of each syenite sample, together averaging 75.4 wt percent of the rock. Albite content exceeds orthoclase content by an average of 9.0 weight-percent.

Syenite samples are plotted as triangles on the variation diagrams of figure 2. In each diagram the syenites plot as a group, with the exception of sample 82DNS127, which is noteably more silicic and less alkalic than the more typical syenites.

According to Macdonald and Katsura (1964), the syenites are alkali-olivine based on the K_2O+Na_2O vs SiO_2 plot. Again, sample 82DNS127 is the exception, plotting in the tholeiitic field. Based on norm values, the syenites are subaluminous, and either metaluminous or subaluminous based on major-oxide values (Shand, 1927). The syenite samples are miaskitic ($K_2O+Na_2O > 1/6SiO_2$) and hence alkaline, except samples 82DNS127, 82DNS195b, and 82AR10, which are plumasitic.

The differentiation index ranges from 75.3 (82AR10) to 84.8 (82DNS195b). The normative color index ranges from 9.8 (82DNS127) to 19.1 (82Ar10), and the average color index is 14.6. The average normative plagioclase composition is $An_{8.7}$, ranging from $An_{0.8}$ (82DNS195b) to An_{24} (82DNS127).

Windy Fork Granite

Along the southeast margin of the Middle Fork plutonic complex is a perthite-arfvedsonite-granite. This distinctive granite, and the mineralogically and lithologically similar peralkaline granite of the nearby Windy Fork pluton, have been informally named the Windy Fork granite. The granite of this rock unit is medium to coarse grained and generally whitish gray. In places the rock has a pinkish or bluish cast due to coloration of the alkali feldspar. Outcrops are generally massive and weather in large blocks. The contact between the Windy Fork granite and syenite appears to be gradational in the Middle Fork plutonic complex.

The Windy Fork granite has a hypidiomorphic-granular texture. The granite consists largely of perthitic alkali feldspar (40-60 percent) and quartz 25-45 percent). Also present are arfvedsonite (5-10 percent) with secondary riebeckite (<2 percent), and minor plagioclase and reddish-brown biotite. Accessory minerals include zircon, apatite, opaque minerals, fluorite, monazite(?), and carbonate. Eudialyte $(Na, Ca, Fe)_6Zr[(Si_3O_9)_2](OH, F, Cl)$, has been noted at two locations in talus within the Middle Fork plutonic complex. This unusual mineral also occurs in the Windy Fork pluton in late-stage dikes related to the granite (Reed and Miller, 1980).

A limited scintillometer survey in the Middle Fork plutonic complex revealed no anomalous radioactivity in the Windy Fork granite. However, local areas of radioactivity (up to 2,500 cps) in the Windy Fork pluton are believed to be due to the presence of uranothorite or thorianite (Reed and Miller, 1980).

Major-oxide analyses of three samples of the Windy Fork granite were obtained (table 1). Two of these samples are from the Middle Fork plutonic complex (82DNS162 and 82DNS193). The third sample is from the Windy Fork pluton (82DNS137). For comparison, data are also presented from Reed and Miller (1980), indicating the average major-oxide composition and CIPW normative minerals of 10 samples from the Windy Fork pluton.

Weight percent SiO_2 in the Windy Fork granite varies from 72.11 to 74.84. The Al_2O_3 content of 11.16 to 11.89 weight-percent is low compared to 14.32 weight-percent of the 'typical' granite (LeMaitre, 1976). The sum of K_2O+Na_2O averages 9.22 weight-percent.

Windy Fork granite samples taken from the Middle Fork plutonic complex are acmite normative, as is the sample from the Windy Fork pluton. Normative quartz ranges from 26.71 to 31.83 weight-percent and the samples contain no normative anorthite.

The Windy Fork granite, plotted as squares on the variation diagrams (fig. 2), is quite homogeneous, and falls at the low end of the ordinate on the $FeTO_3$, TiO_2, CaO, MnO, P_2O_5, and Al_2O_3-vs-SiO_2 diagrams. The Windy Fork granite has about the same low MgO content as the syenite. On the K_2O+Na_2O-vs-SiO_2 plot, the granite falls in the subalkaline field and may be termed a tholeiite according to the classification of Macdonald and Katsura (1964).

By the Shand (1927) definition, the Windy Fork granites of the Middle Fork complex are peralkaline with both oxide and norm values. Of the 10 samples included in the Reed and Miller (1980) average, five are reported as peralkaline.

The two Middle Fork samples have a differentiation index of 89.52 and 90.81. The normative color index of these samples is 4.09 and 3.43, respectively. The normative plagioclase composition of both samples is zero.

Granite, Quartz Monzonite, and Monzodiorite

A heterogeneous unit of various lithologies was mapped in the Middle Fork plutonic complex. These lithologies, including granite, quartz monzonite, and monzodiorite, were combined because of confusing field relationships and internal variability over small areas. Areas of syenite and alkali gabbro were included within this unit as well.

The most abundant lithology of the heterogeneous unit is a biotite-hornblende quartz monzonite, characterized by samples 82DNS75d, 82DNS82, 82DNS197, and 79Ar7 (table 1). These rocks are generally fine to medium grained and have a hypidiomorphic-granular texture. The overall color is gray, characteristically with a 'salt-and-pepper' appearance. The modal composition includes quartz (approximately 15 percent), subequal amounts of andesine and alkali feldspar, clinopyroxene rimmed by green to brown hornblende, biotite, and accessory zircon, apatite, and opaque minerals.

Among the less typical variants included in the unit is sample 82DNS77b, which is a tourmaline-bearing biotite-clinopyroxene-monzodiorite. Samples 82DNS111, 82DNS112b, and 82DNS209, all from near the head of the Middle Fork River, are chemically similar to the alkali gabbros previously described. However, these samples are megascopically different, with a lower color index (30-50), little or no olivine, and more prevalent alkali feldspar (locally as phenocrysts up to 20 percent).

Hornfelsed xenoliths are commonly found within the heterogeneous unit. Contact relationships between this unit and the alkali gabbro are diffuse. The contact of the heterogeneous unit with the syenite appears to be intrusive, but is commonly sutured so that relative ages of the two units are uncertain.

Major-oxide chemistry reveals the heterogeneity of this unit, which falls into two groups on the basis of weight-percent SiO_2. One group ranges from 67.97 to 71.24 weight-percent SiO_2, the other group from 50.64 to 53.00 weight-percent SiO_2. Sample 82DNS125 is a syenite that was included within this map unit.

All four samples in the silica-rich group (quartz monzonites) are quartz normative, with a high of 24.78 weight-percent. Sample 82DNS197 has 1.14 weight-percent corundum in the norm. Among the less silica-saturated group (monzodiorites), three of five samples are quartz normative, with a high of 8.68 weight-percent quartz (82DNS112b). The two silica-undersaturated samples are olivine normative.

On the variation diagrams in figure 2 the two groups are clearly distinguishable as separate coherent clusters of points. The silicic group fills the compositional gap between syenite and Windy Fork granite in each diagram, falling right on trend. The silica-poor group falls to the right of the alkali gabbro group because of slightly higher SiO_2 content, and generally tends to group fairly closely with the gabbroic samples on the vertical scale. The notable exception to this trend is the K_2O+Na_2O-vs-SiO_2 diagram, in which the monzodiorite group has a significantly higher alkali content than the gabbroic group.

All the quartz monzonite samples fall within the tholeiitic field of Macdonald and Katsura (1964). The monzodiorites fall within the alkaline field and may be classed as alkali-olivine, with the exception of 82DNS111, which is tholeiitic because of its lower alkali content.

With oxide values, all nine samples are metaluminous (Shand, 1927). With norm values, all are subaluminous but sample 82DNS197, which is metaluminous.

Differentiation index of the quartz monzonites ranges from 82.76 (82DNS197) to 91.61 (82DNS75d). Normative color index of the quartz monzonites averages 6.8, and the normative plagioclase composition averages $An_{14.3}$. For the monzodiorites, the differentiation index averages 32.2; the normative plagioclase composition averages $An_{41.5}$.

Middle Fork Granite

In the southwest portion of the Middle Fork plutonic complex is a perthite-hornblende-biotite-granite, which is informally named the Middle Fork granite. The Middle Fork granite is lithologically distinct from the Windy Fork granite. The fine- to coarse-grained rocks are characteristically pinkish because of large, pink perthitic alkali feldspar crystals, and weather to whitish. Modal color index is about 25. The Middle Fork granite typically forms rounded, grus-covered hills. Fine-grained pyroxene-rich inclusions are common.

The texture is hypidiomorphic-granular; modal composition is quartz (10-25 percent), hornblende (0-10 percent), biotite (0-5 percent), and clinopyroxene (0-10 percent). Accessories include ubiquitous apatite, zircon, and opaque minerals. Arfvedsonite and riebeckite occur locally. Quartz syenite occurs in places because of variable quartz content of the unit.

Five samples of the Middle Fork granite were analyzed for major-oxide composition (table 1). These analyses show a range of SiO_2 content from 62.22 weight-percent to 66.59 weight-percent. Alkali content of the Middle Fork granite is higher than in the Windy Fork granite.

Normative quartz ranges from 5.85 weight-percent to 15.86 weight-percent. Alkali feldspars account for an average of 35.31 weight-percent of the normative composition, with albite an average of 4.83 weight-percent more abundant than orthoclase.

From the variation diagrams it is seen that the Middle Fork granite is very similar to the syenite in composition.

In the classification of Macdonald and Katsura (1964), the Middle Fork granite is alkali-olivine (82DNS64, 82DNS67a, and 82DNS208) or tholeiitic (82DNS67b and 82AR9). All five samples are metaluminous via oxide values and subaluminous via norm values (Shand, 1927). Sample 82DNS208 is alkali (miaskitic); the other samples are subalkaline (plumasitic).

The average differentiation index for the Middle Fork granite samples is 81.81. Average normative color index is 10.6, and average normative plagioclase composition in $An_{12.92}$.

SUMMARY

The Middle Fork plutonic complex includes alkali gabbro, monzodiorite, quartz syenite, syenite, quartz monzonite, and two varieties of granite, herein called the Windy Fork granite and Middle Fork granite. Relationships between these lithologies is not yet entirely clear, but some preliminary conclusions and speculations can be made.

The complex as a whole has a mildly alkaline character. This is seen most clearly on the K_2O+Na_2O-vs-SiO_2 diagram (fig. 2), and is also suggested by the AFM diagram (fig. 3). On figure 4, which plots Ab'-An-Or, all samples from the complex plot in the potassic series field of Irvine and Baragar (1971).

Linear trends shown in the variation diagrams (fig. 2) suggest possible differentiation from a single source. The wide vertical spread in alkali gabbro compositions reflects inhomogeneity within the unit, perhaps due to localized crystal settling.

An obvious compositional gap can be clearly seen on variation diagrams (fig. 2), in the Na_2O-K_2O-CaO diagram (fig. 5), and in the gap in differentiation index between monzodiorite (average DI = 46.2) and syenite (average DI = 80.1).

A magma chamber differentiating in place is expected to display a continuous compositional range. The compositional gap in the Middle Fork plutonic

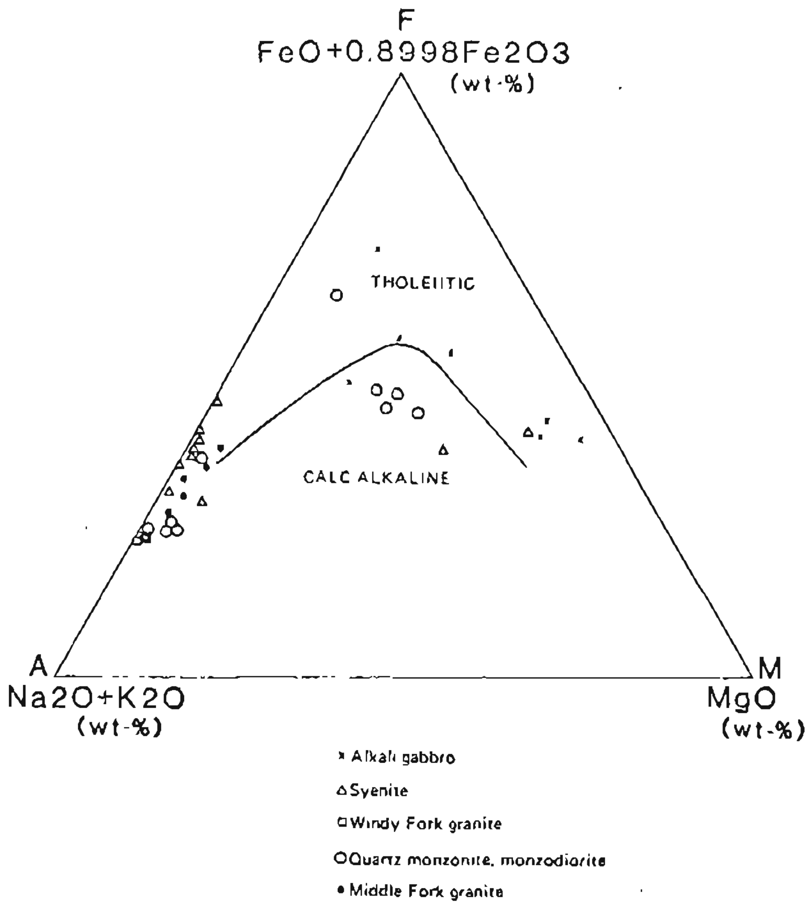

Figure 3. Middle Fork plutonic complex rocks plotted on AFM diagram from Irvine and Baragar (1971).

complex might best be explained by envisioning a large zoned magma chamber at a fairly shallow level. In the felsic upper levels of this chamber, syenite and granite would differentiate. This granite is now exposed as the Windy Fork granite of both the Middle Fork complex and Windy Fork pluton. An upward pulse from the lower reaches of the magma chamber then intruded the syenite to emplace the alkali gabbro, monzodiorite, and quartz monzonite magmas. It is not clear from contact relationships how many pulses may have been involved in the emplacement of these phases. The 'missing' composition remained at a lower level and hence is not exposed in the Middle Fork complex. Diffuse contacts suggest that the syenite was not yet thoroughly solid when intruded by later phases. The so-called Middle Fork granite is perhaps a result of contamination of Windy Fork granite with monzodiorite. This is suggested by the presence of remnant sodic amphiboles, abundant pyroxene-rich inclusions, high color index, and major-oxide composition intermediate between the two lithologies. Magmatic stoping was probably one mechanism of intrusion and xenolith assimilation may account for some of the local lithological variations; in places, mafic inclusions have remnant bedding.

Leucocratic veinlets of alkali feldspar and quartz probably represent the last magmatic activity in the Middle Fork plutonic complex.

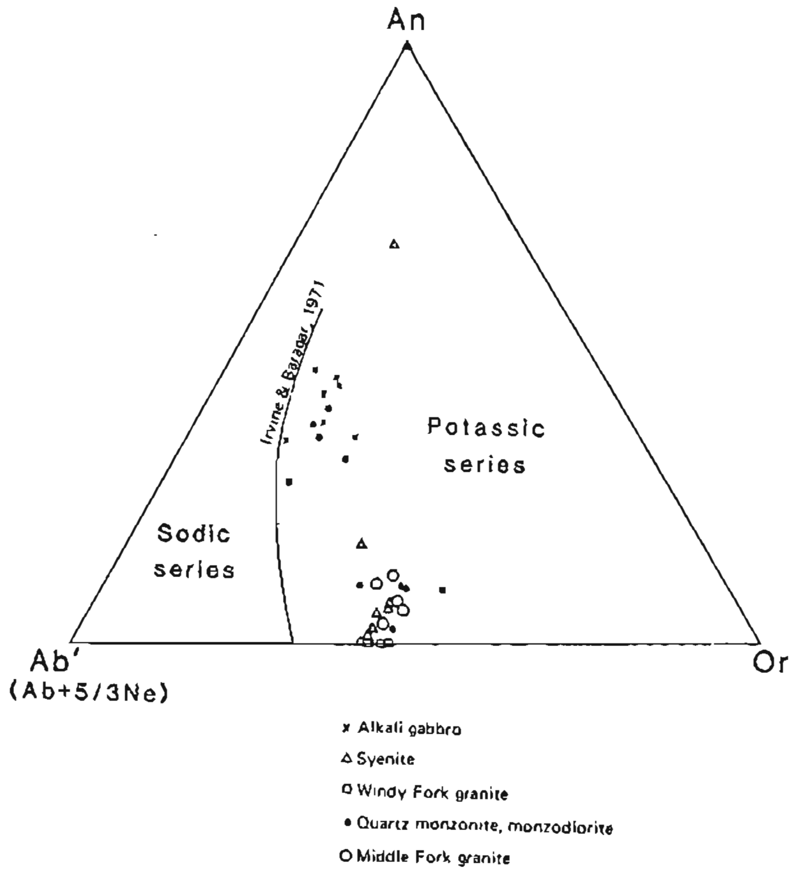

Figure 4. Middle Fork plutonic complex rocks plotted on Ab'-An-Or diagram.

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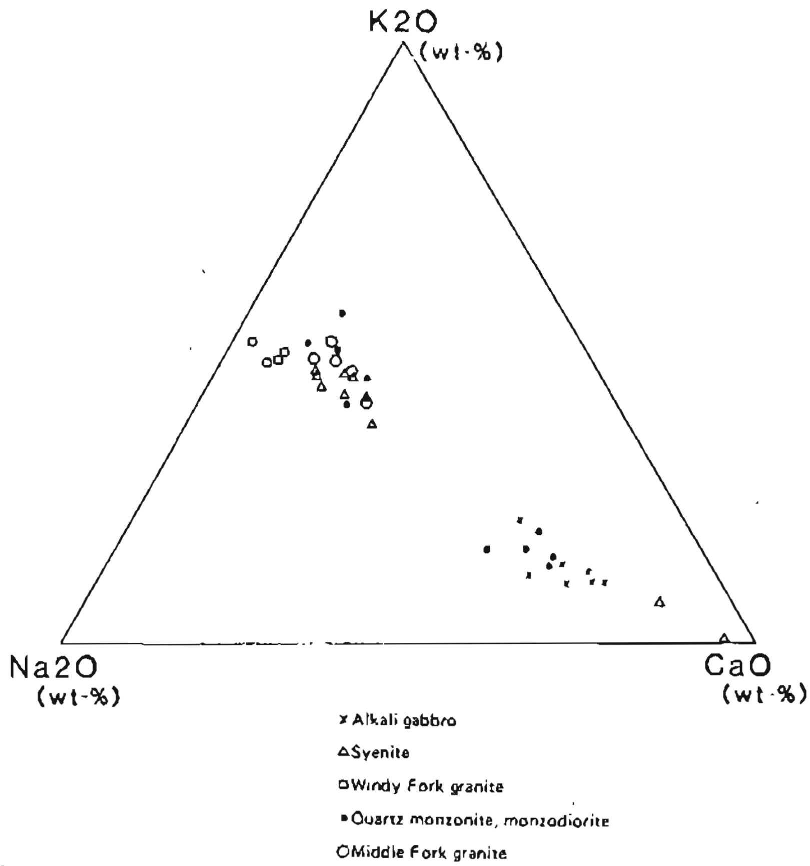

Figure 5. Middle Fork plutonic complex rocks plotted on Na_2O-K_2O-CaO diagram.

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