UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

The Sitkoh Bay alkalic plutonic suite: Silurian or older alkalic magmatism on eastern Chichagof Island, southeastern Alaska

by

Arthur B. Ford[1], David A. Brew[1], and Robert A. Loney[1]

Open-File Report 90-297

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

[1]U.S. Geological Survey, MS-904
345 Middlefield Road
Menlo Park, CA 94025

CONTENTS

FIGURES

TABLES

The Sitkoh Bay alkalic plutonic suite: Silurian or older alkalic magmatism on eastern Chichagof Island, southeastern Alaska[1]

By A.B. Ford, D.A. Brew, *and* R.A. Loney

Abstract

The Sitkoh Bay alkalic plutonic suite consists of six elongate small plutons totaling about 10 km wide by 45 km long on Chichagof Island near Tenakee Springs, southeastern Alaska. The suite, of Silurian or older age, contains a wide variety of rock types, ranging from nepheline syenite, syenite and trondhjemite to quartz monzonite and granite. This report provides major- and minor-element chemical data, including rare-earth elements (REE), for four bodies of the suite: the Kook Lake, Basket Lake, Point Hayes, and Tenakee Springs plutons. Rocks analyzed are samples typical of units mostly obtained from 1960 reconnaissance mapping. This part of Chichagof Island in the early Paleozoic was probably in or near a continental-margin volcanic arc based on the nature of country rocks of the alkalic suite, but the rocks of the suite lack fingerprints of such arc-related magmatism (for example, strong Nb depletion). The magmatism may be related to a rapid switch from subduction or collision to transcurrent tectonic activity, such as recorded for alkalic rocks from other areas. The analytical data show no evidence of significant REE or other element concentrations as are economic in other bodies of this type, but lack of mineral-resource directed sampling precludes data interpretation in terms of economic significance.

INTRODUCTION

In southeastern Alaska (Fig. 1), alkalic intrusive rocks are unusual (Barker, 1974) and vary widely in age. Alkalic intrusions of Paleozoic age occur in the Paleozoic and older units of the Alexander terrane of Berg and others (1978) on Chichagof Island (Loney and others, 1975) and on Prince of Wales Island near Ketchikan (Gehrels and Saleeby (1986). Alkalic intrusions of Jurassic age (Lanphere and others, 1964; Armstrong, 1985) occur in Paleozoic and older(?) country rocks of the Alexander terrane on southern Prince of Wales Island (Bokan Mountain; MacKevett, 1963; Barker and Mardock, 1988), where they have general peralkalic granitic compositions (Thompson and others, 1982). Alkalic intrusions of middle Tertiary age occur in Mesozoic rocks of the Wrangell area (Brew and others, 1984; Hunt, 1984; Brew, 1988; Douglas and others, 1989).

Alkalic igneous rocks are defined mineralogically as having higher concentrations of alkalis than can be accommodated in feldspars alone and therefore contain feldspathoids, sodic pyroxenes and amphiboles, and other alkali-rich phases (Sorensen, 1974; Fitton and Upton, 1987); or, chemically, "simply to the entire spectrum of rocks whose K + Na contents exceed those defined for calc-alkaline rocks" (Box and Flower, 1989).

This preliminary report provides chemical data to supplement the petrographic studies of Loney and others (1975) from their 1960-1961 reconnaissance mapping of the alkalic intrusive bodies in the area between Point

---

[1]Publication authorized by Director, U.S. Geological Survey; May 11, 1990

Hayes and Tenakee Springs, southeastern Chichagof Island (Fig. 2). The geologic and petrographic descriptions following are based largely on Loney and others' (1975) report. The bodies are significant for their geological setting and implications for the pre-accretionary history of the Alexander terrane, as well as for their potential as hosts for deposits of a variety of economically useful elements. Alkalic plutonic rocks can be economically important for such elements as Nb, Ti, Zr, rare-earth elements (REE), and U (Semenov, 1974; Mariano, 1989); precious metals (Mutschler and others, 1985); and Sn (Bonin, 1986, p. 167). REE in current greatest demand are Nd, Sm, Eu, Tb, and Dy (Mariano, 1989). The Jurassic Bokan Mountain alkalic intrusion of southern Prince of Wales Island (fig. 1) contains actual or potential resources of U, Th, Au, Y, REE, Nb, and Zr (MacKevett, 1963; Warner and Mardock, 1987; Barker and Mardock, 1988; Barker, 1989). At present, the economic potential of the alkalic bodies of southeastern Chichagof Island near Tenakee Springs is unknown.

The syenite and related alkalic intrusive rocks of southeastern Chichagof Island (Loney and others,1975) in the area of Sitkoh Bay and northward to Tenakee Springs (Fig. 2) are here referred to informally as the Sitkoh Bay alkalic plutonic suite. A minimum age of 406 ± 16 Ma for the unit is reported by Lanphere and others (1965). The radiometric and stratigraphic data together indicate an age of Silurian or older for the suite (Loney and others, 1975, p. 27). A striking feature of the Sitkoh Bay suite is the great variability of rock types, both within individual plutons and particularly between plutons, including feldspathoid-bearing syenite, adamellite, trondhjemite, and granite as reported by Loney and others (1975); and as found by the large chemical variations reported in the present study.

Acknowledgments

We thank J.L. Drinkwater for help in various stages of our work, J.P. Calzia for technical review of an early version of the manuscript, and personnel named in the data tables for the analytical work. This study is an outgrowth of a preliminary assessment of mineral resources of the Sitka 1:250,000 quadrangle (NAMRAP program) by the U.S. Geological Survey, in participation with S.M. Karl (Anchorage, AK), D.M. Sutphin (Reston, VA), K.A. Dettweiler (Denver, CO), and C.A. Finn (Denver, CO).

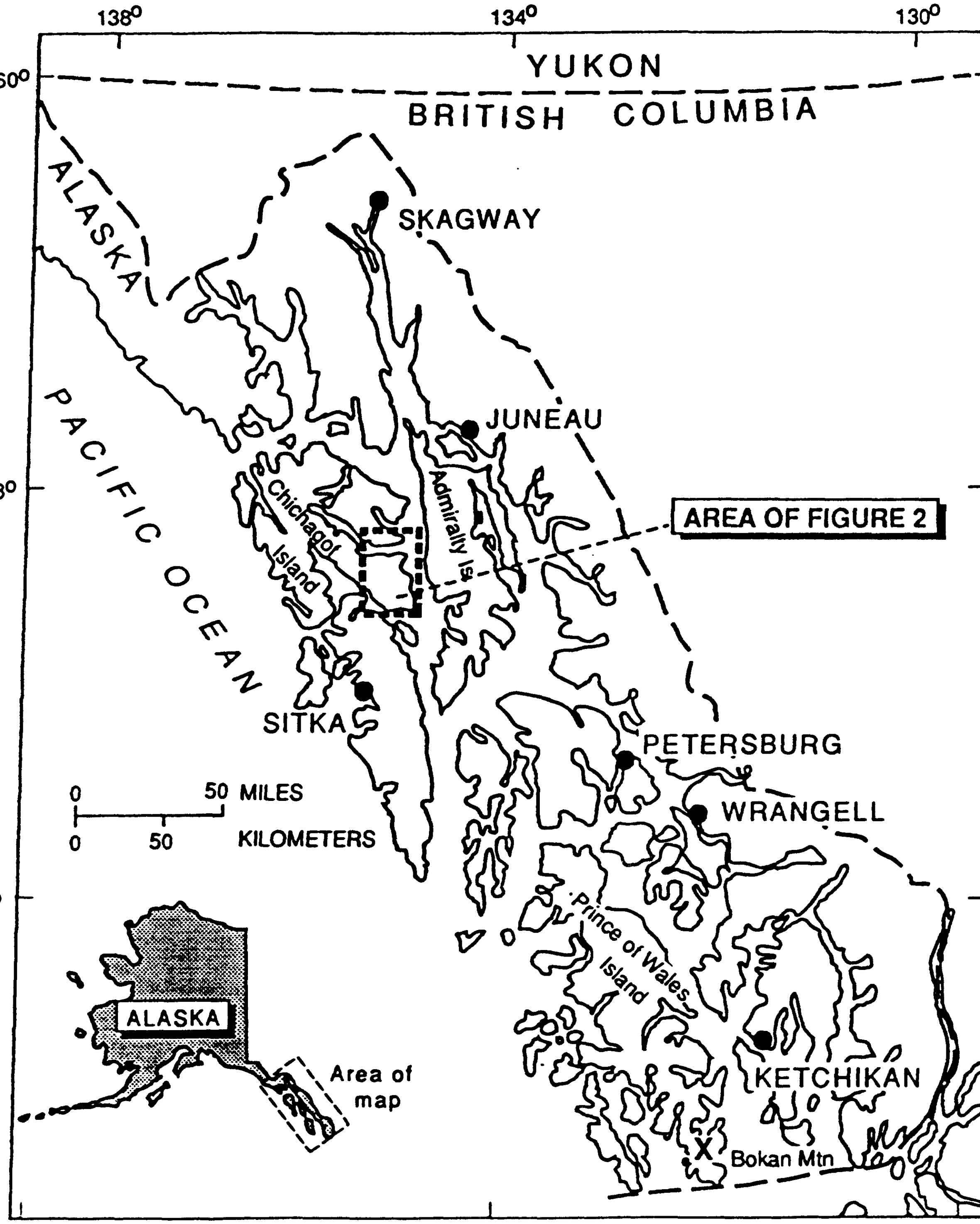

Figure 1. Index map showing location of study area in southeastern Alaska.

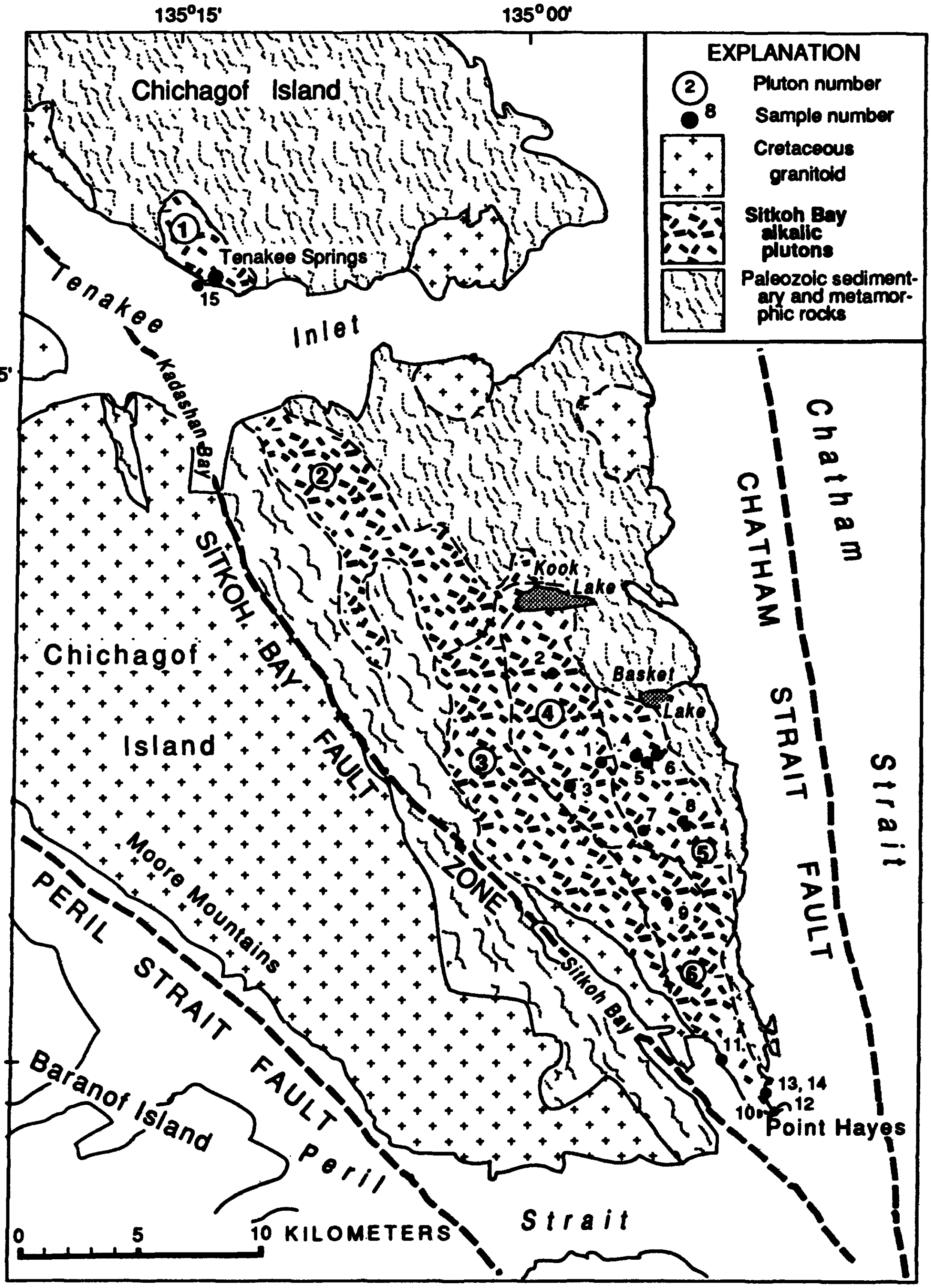

Figure 2. Sketch geologic map of the Sitkoh Bay alkalic plutonic suite, showing plutons and sample localities. Numerous small faults not shown. From Loney and others (1975).

SITKOH BAY ALKALIC PLUTONIC SUITE

Location and general description

The Sitkoh Bay alkalic plutonic suite as mapped by Loney and others (1975) contains six elongate plutons forming an elliptical-shaped composite body approximately 10 km wide at its widest point and 45 km long (about 260 sq km) located on southeastern Chichagof Island (fig. 2). The suite is exposed from Point Hayes, near Sitkoh Bay, northwestward to Kadashan Bay on southeastern Tenakee Inlet. It extends farther northwest beneath Tenakee Inlet to small islands near the village of Tenakee Springs and may extend onshore at the village as shown in fig. 2 and by Loney and others (1975). However, there is a possibility that the pluton numbered one in fig. 2 is a Tertiary body, as discussed below. The rocks are very poorly exposed in the heavily wooded terrain, and the nature of contacts both within the composite body and with the country rocks is therefore generally uncertain (Loney and others, 1975).

Loney and others (1975, p. 27) provisionally divided the alkalic suite into six plutons based on the dominant rock type represented by their available samples that were generally collected from widely scattered localities. The rocks investigated in the present study belong to four of the six plutons. One, at Tenakee Springs, here informally named the Tenakee Springs pluton, is possibly of much younger age (Tertiary?, discussed below) and therefore may be unrelated to the main body of alkalic rock. The other plutons are here named informally the Kook Lake pluton, the Basket Lake pluton, and the Point Hayes pluton, which correspond with plutons 4, 5, and 6 (fig. 2), respectively, of Loney and others (1975).

Geologic setting

The Sitkoh Bay plutonic suite is surrounded by Paleozoic sedimentary and metamorphic rocks of diverse lithology and is intruded by Cretaceous tonalite near Sitkoh Bay (Loney and others, 1975). Lacking known contact exposures, the age relation between the alkalic suite and the surrounding Paleozoic rocks is unknown and at present can only be inferred to be intrusive. Granodiorite and other plutonic rocks of Cretaceous age are widely distributed in the area (fig. 2). Discordant radiometric ages determined for minerals of the Sitkoh Bay suite probably reflect metamorphic effects of the nearby tonalitic batholith (Lanphere and others, 1965). The Paleozoic rocks adjoining the alkalic plutons are mostly interlayered hornfels, schist, and amphibolite that are intensely folded. Other rocks in contact with or near the plutons include the Upper(?) Silurian Point Augusta Formation, the Silurian and (or) Devonian Kennel Creek Limestone, and the Upper Devonian volcanic Freshwater Bay Formation of andesite and basalt. Syenite similar to that in the Sitkoh Bay suite occurs as clasts in the Point Augusta Formation and in other formations of Silurian and Devonian age (Loney and others, 1975, p. 27). Thus, in the absence of known contact relations, the Sitkoh Bay alkalic suite is conceivably older than the surrounding Paleozoic units.

Numerous small faults cut the Sitkoh Bay intrusions and in places separate the individual plutons mapped by Loney and others (1975). The major faults (fig. 2) of the area are (1) the Chatham Strait fault, a dominantly right-lateral strike-slip fault with possibly more than 190 km separation (Ovenshine and Brew, 1972; Hudson and others, 1982; Sonnevil, 1981); (2) the Tenakee fault system, which includes the high-angle Sitkoh Bay fault zone showing right-lateral separation that extends northwest from Sitkoh Bay to 80 km beyond Kadashan Bay at the north end of Chichagof Island; and (3) the Peril Strait fault, which is also a high-angle fault with major right-lateral separation (Loney and others, 1975).

Rocks of the alkalic suite

Each body of the Sitkoh Bay suite is conspicuously heterogeneous, with many rocks showing effects of deuteric alteration and with a tendency for the more alkalic rocks to occur farther from country-rock contacts (Loney and others, 1975). The rocks are locally foliated, altered, and in places cataclastically deformed. The dominant rock types based on thin-section study (Loney and others, 1975) are the following: *pluton 1* (the Tenakee Springs pluton) biotite-bearing trondhjemite; *pluton 2,* biotite syenite; *pluton 3,* hornblende- and biotite-bearing trondhjemite; *pluton 4* (the Kook Lake pluton), sodalite syenite; *pluton 5* (the Basket Lake pluton), hornblende-bearing biotite syenodiorite; and *pluton 6* (the Point Hayes pluton), hornblende syenite. Subordinate rock types consist of hornblende syenite and hornblende-bearing biotite monzonite in pluton 2; biotite- and hornblende-bearing monzonite, biotite granite, hornblende adamellite, and nepheline syenite, in places also containing sodalite, cancrinite, sodic pyroxene, and possibly kalsilite and kaliophyllite in pluton 3; sodalite-nepheline syenite and hornblende syenite in the Kook Lake pluton; hornblende-bearing trondhjemite and biotite-bearing adamellite in the Basket Lake pluton; and biotite syenite and biotite monzonite in the Point Hayes pluton (Loney and others, 1975).

Primary plagioclase, K-feldspar, biotite, hornblende, and apatite occur in varying amounts in all plutons; and secondary biotite, chlorite, and epidote are common (Loney and others, 1975). Minor sphene and opaque minerals occur in nearly all rocks. The Tenakee Springs pluton contains abundant quartz (25-42 percent) and traces of garnet. The Kook Lake pluton generally contains feldspathoids, including cancrinite, nepheline and up to 25(?) mode percent sodalite. The Basket Lake pluton is free of feldspathoids and generally contains quartz, varying up to 35 mode percent. The Point Hayes pluton is generally quartz free and contains minor amounts of nepheline(?) and 2 percent aegerine augite in one sample. Unnamed pluton 2 is quartz and feldspathoid free. Unnamed pluton 3 contains abundant quartz (6-35 percent), except for two samples, one of which contains 15 percent each of nepheline and cancrinite. The Tenakee Springs pluton is lithologically distinctive from the other plutons in containing more abundant quartz and traces of garnet. Elsewhere on Chichagof and Baranof Islands, all plutons associated with thermal springs are of Tertiary age (D.A. Brew, unpublished data) and thus the association of the pluton with the Tenakee thermal springs suggests that it also may be Tertiary and therefore not actually part of the Sitkoh Bay intrusive suite.

CHEMISTRY

Methods

Major-element chemistry, CIPW norms, and chemical ratios for the Kook Lake, Basket Lake, Point Hayes and Tenakee Springs plutons are given in tables 1 and 2, with averages in table 3. Minor-element data for the plutons are given in table 4, except for the Tenakee Springs pluton for which data are unavailable. Analytical methods and accuracy and precision of analysis are given by Baedecker (1987).

Table 1. Major-element content (in weight percent), chemical indexes, and CIPW norms of samples from the Kook Lak Basket Lake, and Point Hayes plutons of the Sitkoh Bay alkalic plutonic suite[1]

[Analysts: J.E. Taggart, A. Bartel, D. Siems, USGS, Denver; except FeO, H_2O and CO_2 by N. Elsheimer, USGS, Men Park. LOI, loss on ignition, 900°C. Chemical ratios and indexes, see text. CIPW norms calculated from analyses normali volatile free]

	Kook Lake pluton			Basket Lake pluton					Point Hayes pluton					
Locality	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sample	61ABD 210	61ABG 181	61APY 131	61ABD 211	61ABD 212	61ABD 213	61APY 134	61APY 153	61APY 152	61ABG 201A	60ABG T24	61ALY 137D	61ALY 138A	61ALY 138B
SiO_2	56.4	56.1	54.6	60.2	59.1	57.3	71.1	67.2	58.4	58.3	59.6	58.6	59.8	52.7
Al_2O_3	21.3	21.7	23.4	18.6	19.8	19.1	15.8	15.3	21.2	19.8	19.5	20.0	18.9	20.3
Fe_2O_3	1.43	1.27	.92	2.42	2.31	2.57	.94	1.47	.69	.93	1.46	1.97	1.70	1.44
FeO	.90	1.14	1.01	2.58	1.57	2.17	.64	1.30	1.03	2.00	.89	1.57	1.49	2.79
MgO	.27	.26	.20	1.74	1.16	1.51	.35	.91	.22	.80	.26	.57	.55	.91
CaO	1.21	1.67	1.15	2.12	3.35	3.73	2.25	1.96	1.76	2.86	2.67	2.74	1.86	5.41
Na_2O	7.77	5.50	9.16	6.27	6.93	5.34	4.86	4.87	4.68	4.39	4.64	4.59	4.15	3.25
K_2O	7.16	6.92	6.72	2.74	2.71	4.73	2.76	4.18	7.70	7.17	7.56	7.07	8.71	7.72
H_2O+	1.25	2.47	.89	1.23	.87	.80	.35	.50	2.55	1.00	.93	.78	.74	1.34
H_2O-	.29	.87	.11	.19	.16	.13	.11	.08	.27	.11	.11	.10	.10	.34
TiO_2	.43	.35	.27	.59	.71	.62	.18	.40	.33	.40	.38	.32	.31	.47
P_2O_5	<.05	<.05	<.05	.34	.35	.46	<.05	.18	<.05	.15	<.05	.11	.10	.18
MnO	.20	.28	.19	.11	.06	.08	.06	.04	.14	.10	.13	.14	.11	.57
CO_2	.13	.65	.37	.25	.08	.39	.18	.09	.41	.73	.78	.17	.46	1.72
Total	98.7	99.2	99.0	99.4	99.2	98.9	99.6	98.5	99.4	98.7	98.9	98.7	99.0	99.1
LOI	1.57	3.63	1.26	1.27	.99	.89	.48	.61	2.92	1.60	1.61	.93	1.16	2.82
K_2O+Na_2O	14.93	12.42	15.88	9.01	9.64	10.07	7.62	9.05	12.38	11.56	12.20	11.66	12.86	10.97
Alkalinity ratio	4.94	3.27	4.66	2.54	2.43	2.58	2.46	3.20	3.34	3.08	3.45	3.10	4.26	2.49
A/CNK	.94	1.11	.96	1.09	.97	.92	1.05	.95	1.10	.98	.94	.99	.96	.86
FeO*	2.19	2.29	1.84	4.76	3.64	4.48	1.48	2.62	1.65	2.83	2.20	3.34	3.02	4.09
FeO*/MgO	8.10	8.79	9.18	2.74	3.14	2.97	4.24	2.88	7.48	3.54	8.48	5.86	5.50	4.49
Mg number	34.8	28.9	26.1	54.6	56.8	55.4	49.3	55.5	27.6	41.6	34.2	39.3	39.7	36.8
Agpaitic index	.96	.76	.96	.71	.72	.73	.69	.82	.76	.76	.81	.76	.86	.68

CIPW Norms

Q	...	...	...	6.32	.51	...	27.25	18.18	...	...	...	...	...	...
C	...	2.36	...	2.33	.22	...	.86	...	2.17	...	...	.08	...	...
or	43.56	42.94	40.77	16.57	16.33	28.64	16.48	25.26	47.30	43.72	45.99	42.77	52.69	47.65
ab	26.50	34.60	19.36	54.30	59.81	46.29	41.54	42.13	35.91	34.91	36.63	36.72	31.78	11.31
an	2.16	8.36	2.96	8.49	14.62	14.52	10.95	7.71	8.74	13.57	10.35	13.18	7.39	18.80
ne	22.31	7.73	32.62	...	...	...	...	...	2.85	1.85	2.05	1.65	2.26	9.43
wo	.62	...	...	...	...	...	...	...	...	...	.42	...	...	...
di	1.75	...	2.18	...	...	1.08	...	.82	...	.06	1.52	...	1.14	6.76
hy	...	...	...	6.45	2.95	.86	1.10	2.54	...	...	...	...	...	...
ol-fo	...	.48	.13	...	...	1.94	...	...	.40	1.43	...	1.02	.76	.82
ol-fa	...	.80	.37	...	...	.56	...	...	.84	1.93	...	.79	.63	1.68
mt	2.14	1.93	.95	3.59	3.26	3.82	1.38	2.17	1.03	1.39	2.18	2.91	2.52	2.18
hm	...	...	...	...	.10	...	...	...	...	...	...	...	...	...
il	.84	.70	.53	1.15	1.38	1.21	.35	.78	.65	.78	.74	.62	.60	.93
ap	.12	.12	.12	.81	.83	1.09	.12	.43	.12	.36	.12	.26	.24	.44
Diff. index	92.7	85.3	92.8	77.2	76.7	74.9	85.3	85.6	86.1	80.5	84.7	81.1	86.7	68.4
Norm.Color index	4.7	3.9	4.2	11.2	7.7	9.5	2.8	6.3	2.9	5.6	4.4	5.3	5.6	12.4
Norm.Plag. An %	3.3	15.0	3.9	13.5	19.6	23.9	20.9	15.5	17.7	26.3	20.5	25.0	17.2	41.0

1. Loney and others' (1975, p. 30) rock names for samples :
   - 61ABD210, sodalite syenite
   - 61ABG181, sodalite syenite
   - 61APY131, biotite-bearing sodalite-nepheline? syenite
   - 61ABD211, biotite-bearing syenodiorite
   - 61ABD212, hornblende-bearing biotite syenodiorite
   - 61APY134, hornblende-bearing trondhjemite
   - 60ABGT24, hornblende syenite
   - 61ABD213, hornblende-bearing biotite syenodiorite
   - 61ALY137D, hornblende syenite
   - 61ALY138A, biotite-bearing syenite
   - 61ALY138B, biotite syenite
   - 61APY153, 61APY152, 61ABG201A (not given)

Table 2. Major-element content (in weight percent), chemical indexes, and CIPW norm of sample from the Tenakee Springs pluton

[Rapid rock analysis by H. Smith and K. Coates, USGS, Reston, VA. Chemical ratios and indexes, see text. CIPW norms calculated from analyses normalized volatile free]

Locality Sample	15 76DB27A
SiO_2	69.7
Al_2O_3	14.3
Fe_2O_3	.88
FeO	1.5
MgO	.33
CaO	2.8
Na_2O	5.3
K_2O	2.4
H_2O+	.81
H_2O-	.26
TiO_2	.17
P_2O_5	.09
MnO	.15
CO_2	.08
Total	98.8
K_2O+Na_2O	7.70
Alkalinity ratio	2.64
A/CNK	.87
FeO*	2.29
FeO*/MgO	6.94
Mg number	28.17
Agpaitic index	.79
	CIPW Norm
Q	24.22
or	14.53
ab	45.94
an	8.34
di	4.51
hy	.62
mt	1.31
il	.33
ap	.21
Diff. index	84.7
Norm.Color index	6.8
Norm.Plag.An %	15.4

Table 3. Average major-element chemistry of plutons of the Sitkoh Bay alkalic intrusion, compared to average syenites

[Data from table 1. Average syenite and average nepheline syenite of Le Maitre (1976). Standard deviation in ( )]

	Kook Lake pluton	Basket Lake pluton	Point Hayes pluton	Average syenite	Average nepheline syenite
Number of samples	3	5	6	517	115
SiO_2	55.7 (1.0)	63.0 (5.9)	57.9 (2.6)	58.58	54.99
Al_2O_3	22.1 (1.1)	17.7 (2.0)	20.0 (.8)	16.64	20.96
Fe_2O_3	1.21 (.26)	1.94 (.74)	1.37 (.48)	3.04	2.25
FeO	1.02 (.12)	1.65 (.76)	1.63 (.69)	3.13	2.05
MgO	.24 (.04)	1.13 (.54)	.55 (.28)	1.87	.77
CaO	1.34 (.28)	2.68 (.80)	2.88 (1.32)	3.53	2.31
Na_2O	7.48 (1.85)	5.65 (.92)	4.28 (.54)	5.24	8.23
K_2O	6.93 (.22)	3.42 (.96)	7.66 (.58)	4.95	5.58
H_2O+	1.54 (.83)	.75 (.34)	1.22 (.68)	.99	1.30
H_2O-	.42 (.40)	.13 (.04)	.17 (.11)	.23	.17
TiO_2	.35 (.08)	.50 (.21)	.38 (.06)	.84	.60
P_2O_5	<.05	.33 (.12)	.14 (.04)	.29	.13
MnO	.22 (.05)	.07 (.03)	.20 (.18)	.13	.15
CO_2	.38 (.26)	.20 (.13)	.71 (.54)	.28	.20
K_2O+Na_2O	14.41 (1.79)	9.08 (.93)	11.94 (.67)	10.19	13.81
Alkali index	4.29 (.89)	2.64 (.32)	3.29 (.58)	3.04	3.92
A/CNK	.99	.99	.95		
FeO*	2.10	3.40	3.10		
FeO*/MgO	8.64	3.00	5.01		
Mg number	29.9	55.0	38.6		
Agpaitic index	.89 (.12)	.73 (.05)	.77 (.06)	.84	.93

Table 4. Minor-element content (in parts per million) of samples from the Kook Lake, Basket Lake, and Point Hayes plutons of the Sitkoh Bay alkalic plutonic suite

[Analysts: (U, Th) R. B. Vaughn, D. M. McKown, J. Budahn, R. Knight, USGS, Denver; (INAA) ; (REE) G. Riddle, USGS, Denver; (EDXRF; Cu, Ni, Cr <20 ppm, all samples.) J. Kent, USGS, Menlo Park]

	Kook Lake pluton			Basket Lake pluton					Point Hayes pluton					
Locality	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sample	61ABD 210	61ABG 181	61APY 131	61ABD 211	61ABD 212	61ABD 213	61APY 134	61APY 153	61APY 152	61ABG 201A	60ABG T24	61ALY 137D	61ALY 138A	61ALY 138B
U	5.49	5.31	6.06	3.98	3.66	1.45	1.62	5.20	1.65	2.14	1.72	1.88	1.03	3.65
Th	9.30	7.65	9.27	8.18	10.5	2.7	3.9	18.5	3.8	3.7	3.5	3.2	2.9	7.30
EDXRF														
Nb	20	18	28	24	30	10	10	40	14	<10.	10	<10	<10	20
Rb	200	250	225	90	72	100	68	128	205	144	134	180	136	168
Sr	40	750	112	580	1100	1500	560	375	1600	1100	440	1200	460	1200
Zr	210	220	225	275	240	122	156	210	108	112	74	112	56	164
Y	32	22	18	22	20	10	12	16	12	14	12	<10	12	34
Ba	38	64	46	1200	1200	2800	1100	820	355	2700	150	3600	560	1200
Ce	90	68	52	102	54	52	<30	82	76	52	68	74	<30	68
La	62	50	<30	68	36	42	<30	56	52	38	38	50	<30	<30
Zn	112	162	98	60	62	64	40	24	72	70	64	98	102	970
INAA														
REE														
La	34	33	36	47	46	42	20	42	27	27	26	23	17	37
Ce	110	110	94	130	130	120	49	88	87	97	94	76	54	120
Pr	7.6	7.6	7.2	8.2	9.0	7.1	3.4	6.0	6.5	5.9	6.5	4.5	3.1	7.0
Nd	31	29	25	29	35	25	13	20	26	24	27	17	13	27
Sm	4.8	4.9	3.3	4.2	4.6	3.1	2.3	3.0	3.6	3.3	4.2	2.5	1.9	4.0
Eu	.93	.70	.68	1.4	1.8	1.2	.66	.93	.78	1.4	1.2	1.1	1.5	1.4
Gd	4.1	3.9	3.0	4.2	3.4	2.8	2.1	2.3	3.5	3.0	3.1	2.5	1.8	3.1
Tb	.64	.57	.46	.63	.56	.39	.32	.41	.55	.46	.47	.37	.22	.48
Dy	4.1	3.9	2.9	3.3	3.4	2.7	2.0	2.5	2.9	2.7	3.0	2.1	1.5	3.0
Ho	.82	.71	.54	.67	.65	.42	.38	.48	.54	.53	.61	.47	.30	.64
Er	2.6	2.0	1.6	1.9	1.8	1.3	1.1	1.7	1.4	1.4	1.4	1.3	.90	1.9
Tm	.37	.40	.22	.29	.30	.23	.20	.24	.19	.20	.20	.17	.11	.32
Yb	2.8	2.3	1.4	2.2	1.9	1.5	1.3	2.1	1.4	1.4	1.2	1.2	.90	2.2

Major-element chemistry

The major-element chemistry of the Kook Lake, Basket Lake, and Point Hayes plutons vary widely (table 1). Some rocks from each of these plutons are peraluminous (oversaturated in Al_2O_3), as shown by molecular ratios $Al_2O_3/(CaO+Na_2O+K_2O) > 1$ (A/CNK, table 1), but average ratios show approximate saturation (.95-.99, table 3) and higher than that of the Tenakee Springs pluton (.87, table 2). As shown by normative mineral contents (table 1), the Kook Lake and Point Hayes plutons are undersaturated in SiO_2 (normative nepheline bearing) in contrast to the Basket Lake pluton: the Kook Lake pluton is markedly more undersaturated (average ne, 21 percent) than the Point Hayes pluton (average ne, 3 percent). The Basket Lake pluton, in contrast, contains large amounts of normative quartz in some samples (up to 27 percent) and is free of normative nepheline. The single sample from the Tenakee Springs pluton also contains high SiO_2 and abundant normative quartz (table 2). The chemical relations are generally in accord with the petrographic descriptions of Loney and others (1975).

The average composition of the three plutons of table 1 varies from quartz monzonite (Basket Lake pluton) to foid-bearing syenite (Point Hayes pluton) and foid syenite (Kook Lake pluton), in Streckeisen and Le Maitre's (1979) chemical approximation of the IUGS modal classification of plutonic rocks (fig. 3). Analyses of most samples lie in fields of nepheline syenite and syenite in Wilson's (1989) chemical classification of plutonic rocks, except chiefly for three that are granite or alkali granite (fig. 4) The compositions of the plutons occupy generally distinct fields in both diagrams. The Tenakee Springs pluton sample, a granite, is compositionally closest to the Basket Lake pluton (figs. 3, 4). The rocks generally classify differently on the chemical basis of figures 3 and 4 than on modes of Loney and others (1975). Trondhjemite, which occurs (based on modes) in some plutons of the Sitkoh Bay alkalic suite (Loney and others, 1975), however, is not included in Streckeisen and Le Maitre's (1979) classification. Only the Tenakee Springs sample is classed as trondhjemite in the Ab-Or-An plot of fig. 5, using Barker's (1979) criteria that trondhjemite contains greater than about 68 percent SiO_2. Other major-element contents of the Tenakee Springs sample are also typically those of trondhjemite (Barker, 1979). Average compositions of the Kook Lake and Point Hayes plutons are similar, respectively, to average nepheline syenite and average syenite (table 3).

The differentiation index (sum of normative salic minerals) is highest for the Kook Lake pluton, generally decreasing progressively in the Point Hayes and Basket Lake plutons (table 1). Normative color index (sum of normative femic minerals) and normative plagioclase An content [100 x an/(an+ab+5/3ne)] are highly variable in the plutons and generally lowest in the Kook Lake pluton (tables 1, 2).

The alkalic to peralkalic character of the Kook Lake, Basket Lake and Point Hayes plutons is shown by covariation of Wright's (1969) alkalinity ratio with SiO_2 content; and the plutons show increasing alkalinity in the order Basket Lake pluton-Point Hayes pluton-Kook Lake pluton (fig. 6), as indicated similarly in figure 3. The sample from Tenakee Springs pluton is calc-alkaline, as is typical of trondhjemite (Barker, 1979). The K_2O contents of the Kook Lake pluton (6.7-7.2 percent, average 6.9 percent) and the Point Hayes pluton (7.1-8.7 percent, average 7.7 percent) are about those of other alkalic rocks classed as K-rich, but are not as high as in ultrapotassic rocks (Sahama, 1974; Miller, 1972). K_2O is markedly lower in the Basket Lake pluton than the Kook Lake pluton and is highest in the Point Hayes pluton (table 3). The three plutons have distinctly different fields of Na_2O/K_2O ratio (fig. 7): the Kook Lake and Basket Lake plutons have average $Na_2O>K_2O$ and the Point Hayes pluton shows $K_2O>Na_2O$. Na_2O/K_2O of the Tenakee Springs pluton compares more closely with ratios of the Basket Lake than the other two plutons (fig. 7), as in other chemical characteristics (figs. 3-6), .

The Sitkoh Bay suite shows iron-depleted compositions in an AFM plot (fig. 8), which is typical of alkaline volcanic suites (Irvine and Baragar, 1971). The fields for the Kook Lake and Point Hayes plutons, and for the Point Hayes and Basket Lake plutons overlap in the plot, with the Kook Lake and Basket Lake plutons occupying distinct fields. The Kook Lake, Basket Lake, and Point Hayes plutons have $(Na_2O + K_2O)/SiO_2$ ratios typical of alkaline-rich suites (Irvine and Baragar, 1971). The Tenakee Springs is the only pluton with calc-alkaline characteristics, though not greatly different from one sample of the alkaline Basket Lake pluton (fig. 6). The Basket Lake pluton shows the largest Fe-enrichment; and rocks from all the plutons are low in MgO (tables 1 and 2), with ratios of total iron, as FeO (FeO*), to MgO greater than 2.5 (fig. 8).

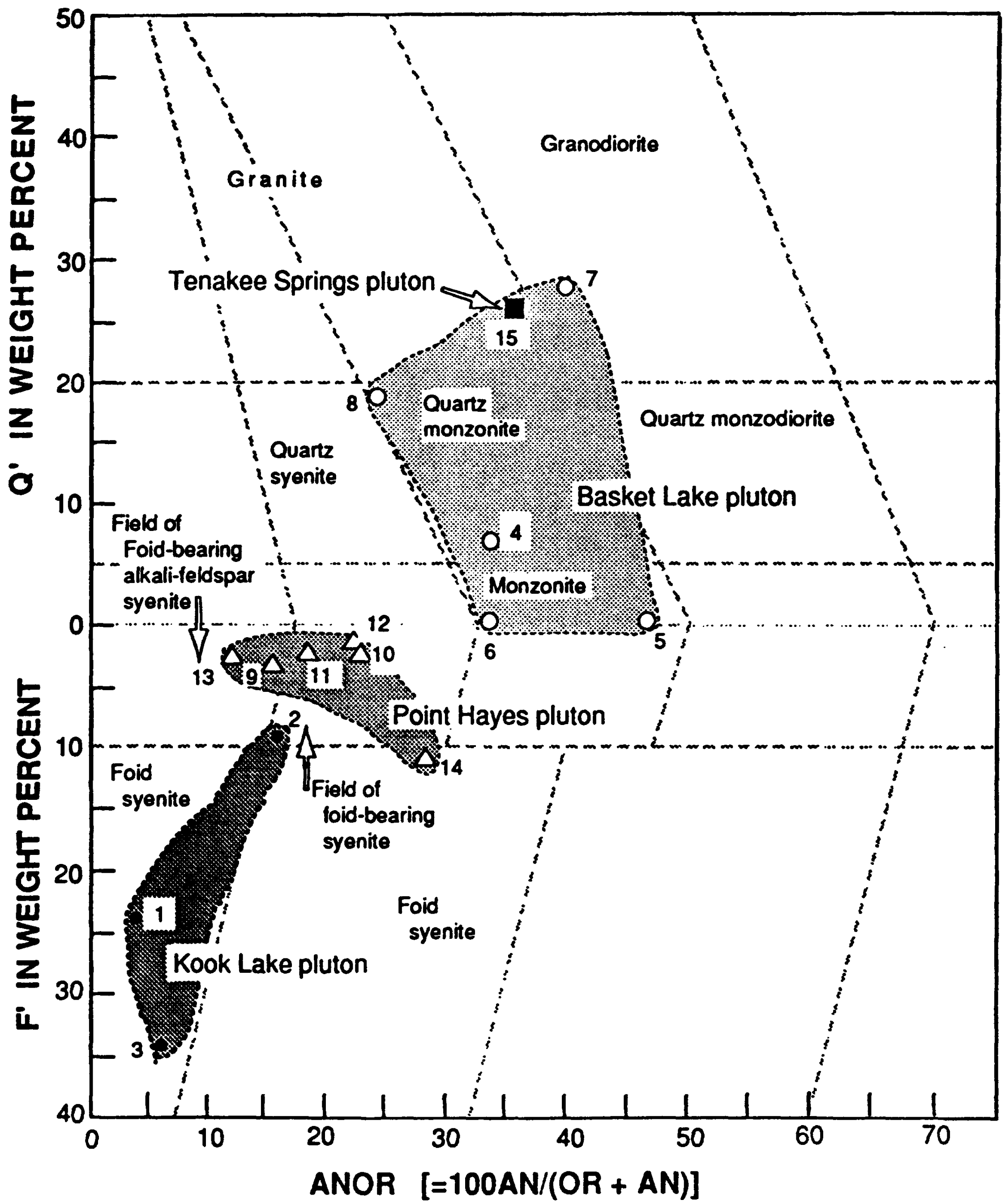

Figure 3. Classification of samples from the Sitkoh Bay alkalic plutonic suite according to the chemical approximation to the IUGS modal QAPF classification (Streckeisen and Le Maitre, 1979). Q', normative Q/(Q+Or+Ab+An); F', normative (Ne+Lc+Kp)/(Ne+Lc+Kp+Or+Ab+An).

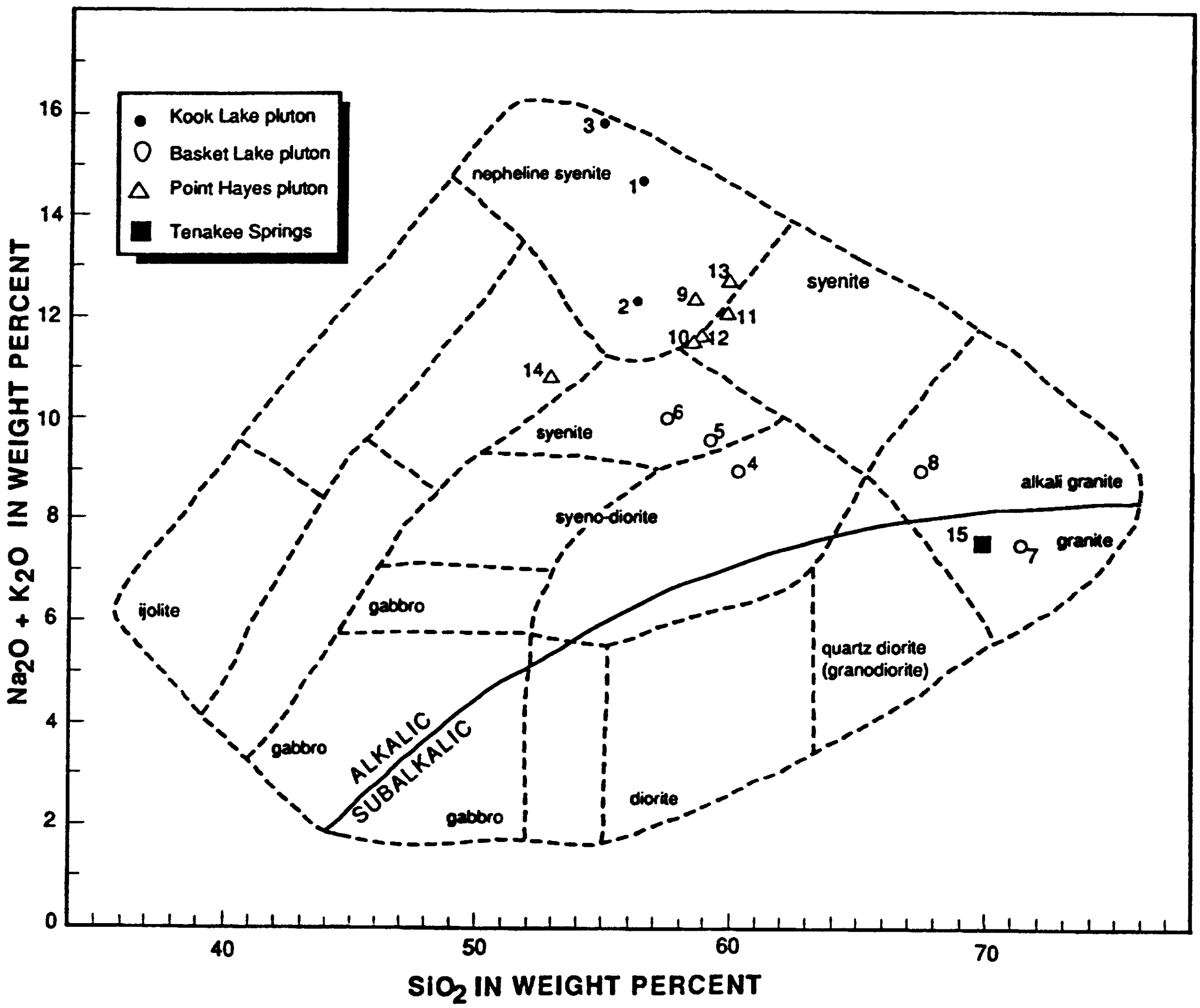

Figure 4. Classification of samples from the Sitkoh Bay alkalic plutonic suite based on diagram of Wilson (1989).

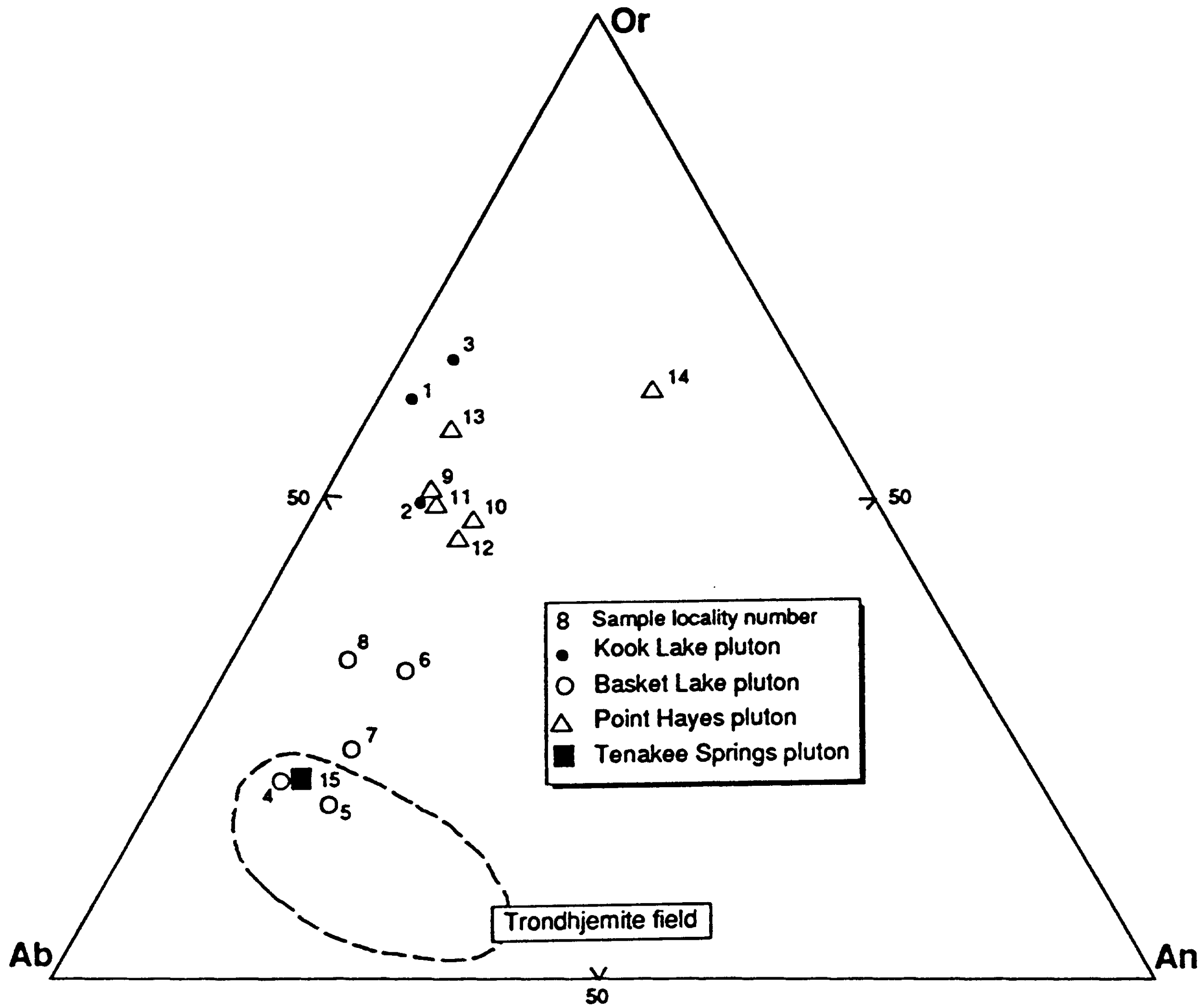

Figure 5. Normative Ab-Or-An diagram of rocks of the Sitkoh Bay alkalic plutonic suite, showing trondhjemite field of Ross (1973). Only sample 15 in the field contains SiO_2 content required for trondhjemite (Barker, 1979).

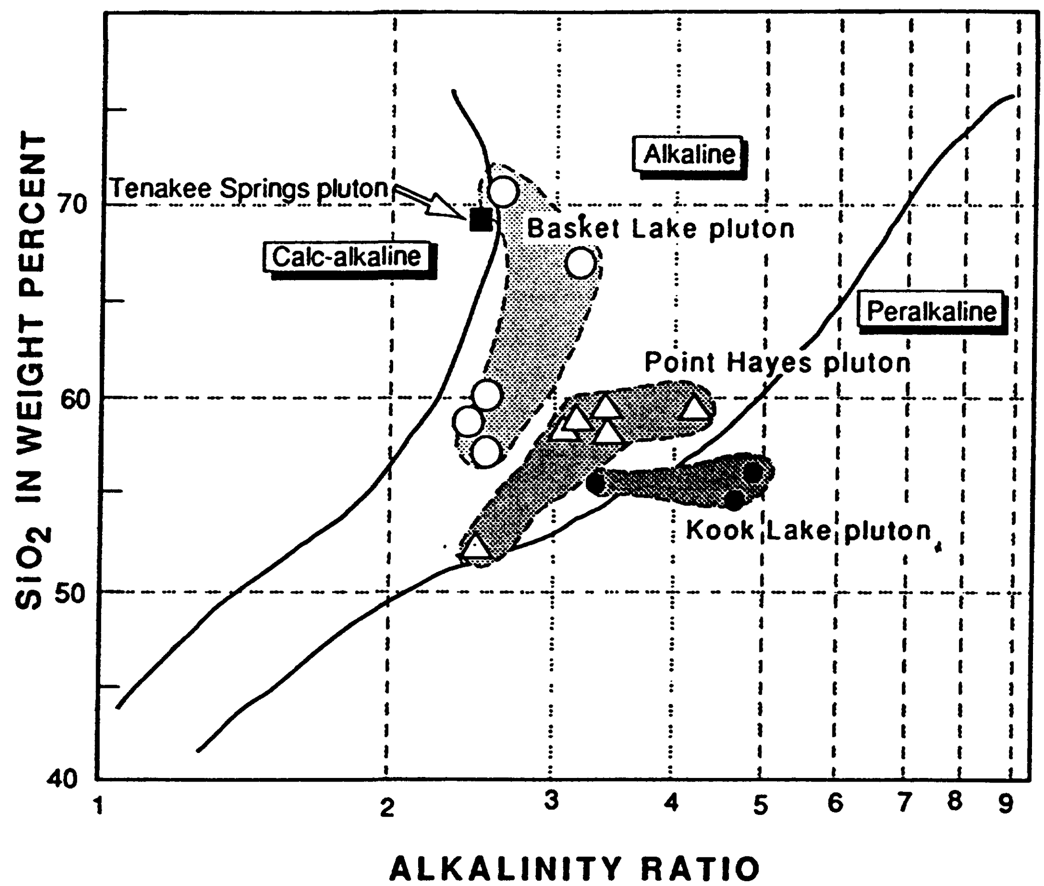

Figure 6. Alkalinity ratio versus SiO_2 diagram of Wright (1969), showing the alkaline nature of rocks of the Sitkoh Bay alkalic plutonic suite. Alkalinity ratio = (Al_2O_3)+CaO+total alkalies)/(Al_2O_3)+CaO-total alkalies).

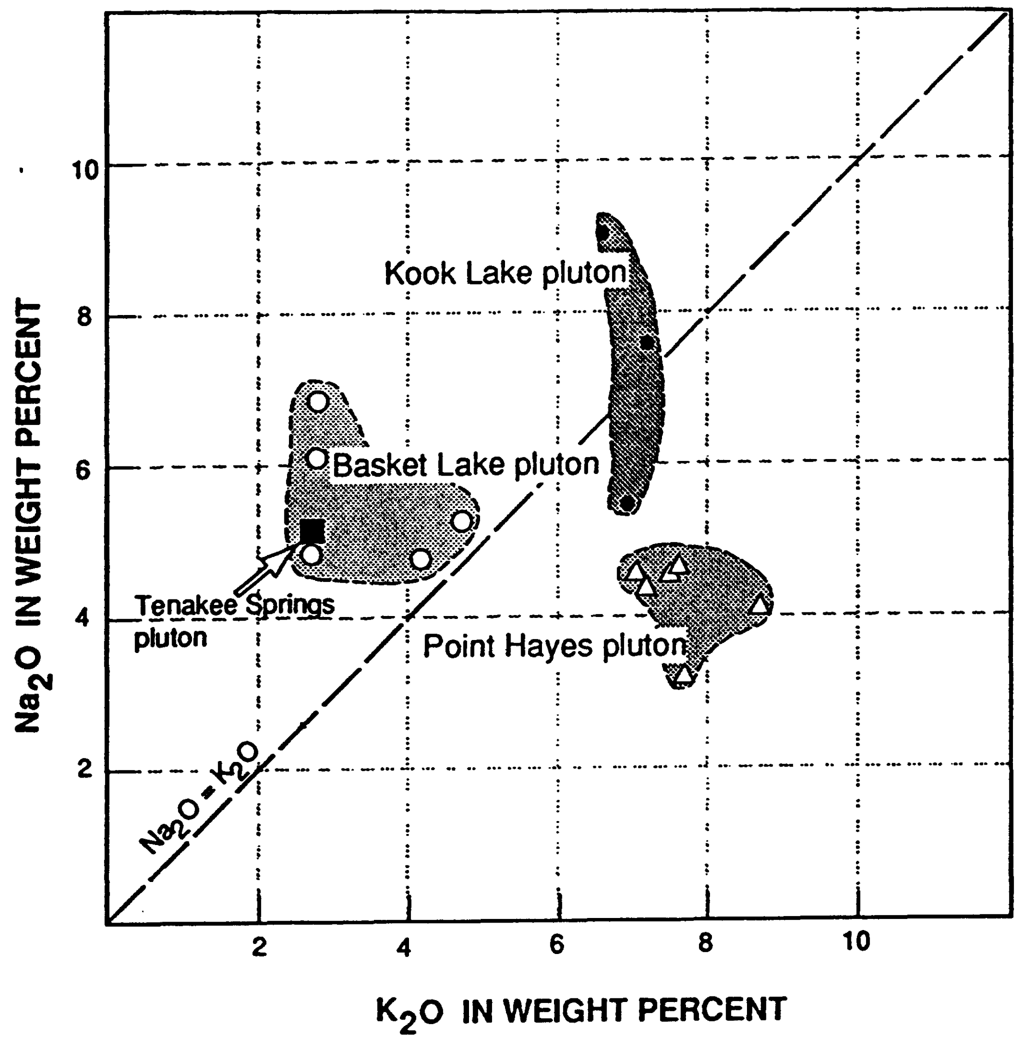

Figure 7. Na_2O versus K_2O diagram of rocks of the Sitkoh Bay alkalic plutonic suite.

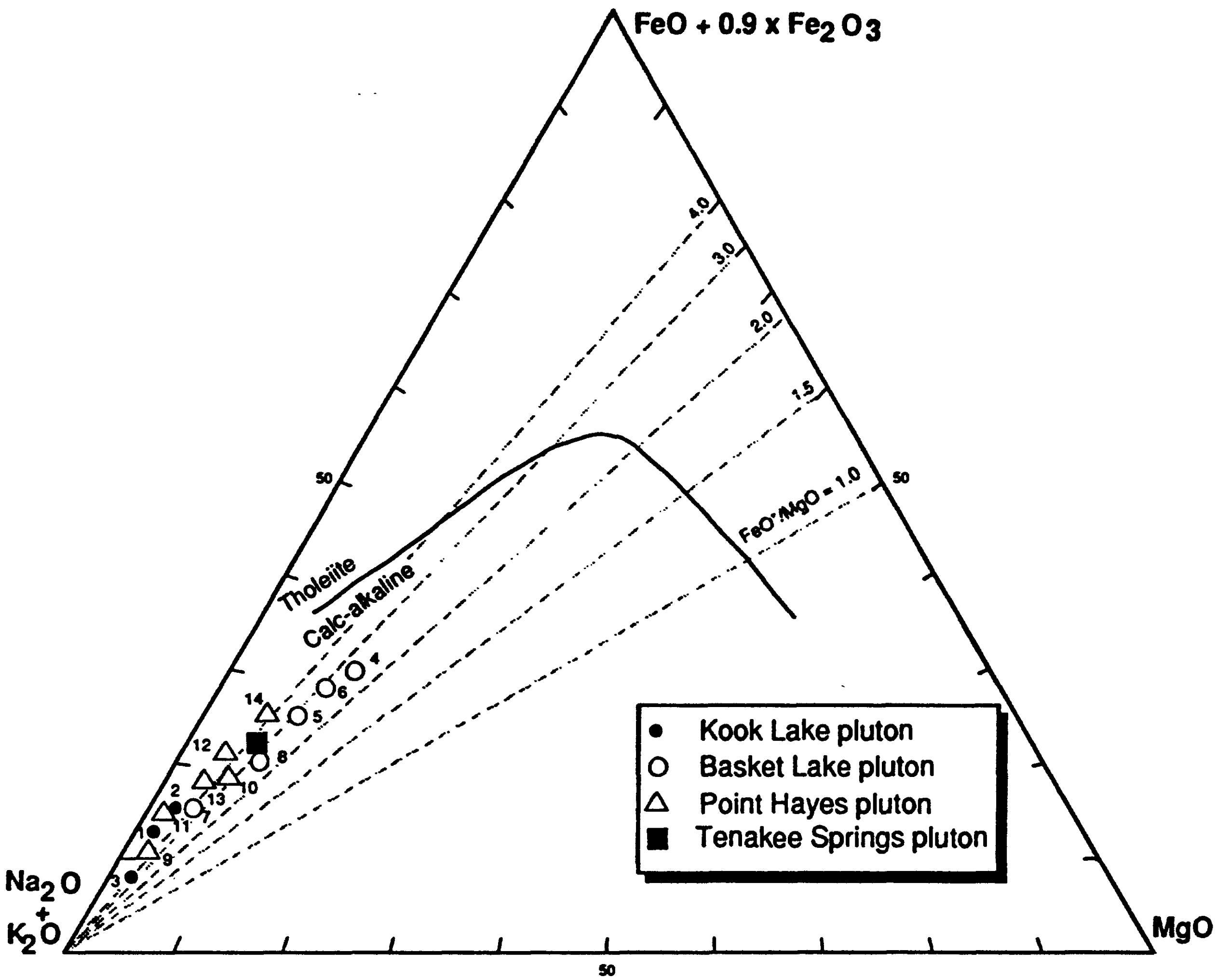

Figure 8. AFM diagram for rocks of the Sitkoh Bay alkalic plutonic suite. Line indicating tholeiite-calcalkaline boundary (Irvine and Baragar (1971) shown for reference: except for Tenakee Springs pluton, all rocks are alkaline (see text).

Representation of the major-element data of table 1 in the bar diagrams of figure 9 shows visual comparison of the many chemical differences between plutons. In general, the Point Hayes pluton has more highly variable major-element content than the Basket Lake and Kook Lake plutons.The Kook Lake pluton is particularly distinct in its generally higher Al_2O_3, K_2O, Na_2O, MnO, and FeO*/MgO and lower Fe_2O_3, FeO, MgO CaO, P_2O_5, and FeO* compared to the Basket Lake and Point Hayes plutons in which abundances are generally more variable. The Basket Lake pluton shows generally higher Fe_2O_3, FeO, MgO, CaO, TiO_2, P_2O_5, and FeO*, and lower Al_2O_3, K_2O, MnO, total alkalis, and FeO*/MgO than the Kook Lake and Point Hayes plutons. Mg numbers [100xMg/(Mg+Fe^2), in molecular amounts] are conspicuously highest in the Basket Lake pluton, which is correspondingly lowest in FeO*/MgO. The Mg numbers for the pluton are much lower than that (> 67) indicative of a primary mantle melt (Gill, 1981).

The Harker diagrams of figure 10 show the wide variation of SiO_2 content in the entire suite (52.7-71.1 percent), due mainly to the unusually high SiO_2 content of three samples (Basket Lake and Tenakee Springs plutons). The correlation coefficients (*r*) between SiO_2 and other oxides in the suite (fig. 10) are generally low, except for Al_2O_3 (r = -0.87) and total alkalies (r = -0.67). Oxide contents of the Kook Lake and Point Hayes plutons are much more clustered than those of the Basket Lake pluton due to Basket Lake's much greater SiO_2 variation. Correlations were determined for all samples of the suite excluding the Tenakee Springs pluton in the possibility it is unrelated to the others. However, individual plutons seem to show somewhat different correlations as is particularly apparent for the Point Hayes and Kook Lake plutons: although oxide contents of the suite overall generally decrease with increasing SiO_2, covariations between Na_2O and SiO_2 of the Point Hayes pluton and between SiO_2 and TiO_2 and Fe_2O_3 of the Kook Lake pluton appear positive. Except possibly the Kook Lake, the plutons lack the positive linear correlation between K_2O and SiO_2 that in other igneous suites implies K activity as an incompatible element (Gill, 1981, p. 105).

Oxides generally show much stronger correlation with MgO than SiO_2 for the suite (excluding Tenakee Springs pluton) and generally have positive rather than negative correlations (compare figs. 11 and 10). Correlations are particularly strong ($r \geq .9$) between MgO and P_2O_5 and FeO*, and moderately strong ($r \geq .8$) between MgO and TiO_2 and FeO. The negative covariation between MgO and K_2O (and total alkalies) of the suite is markedly different (r $\geq$ -.6) from the positive covariations for other elements, though individual plutons show appearance of weakly positive MgO-K_2O covariations different from the overall trend. Trends of other oxides with SiO_2 in individual plutons generally follow the overall trend (fig. 11). Mechanisms such as fractionation that may have controlled most variations may have differed for K_2O, the variations of which may have resulted in part from metasomatism or other secondary processes that produced alterations reported by Loney and others (1975).

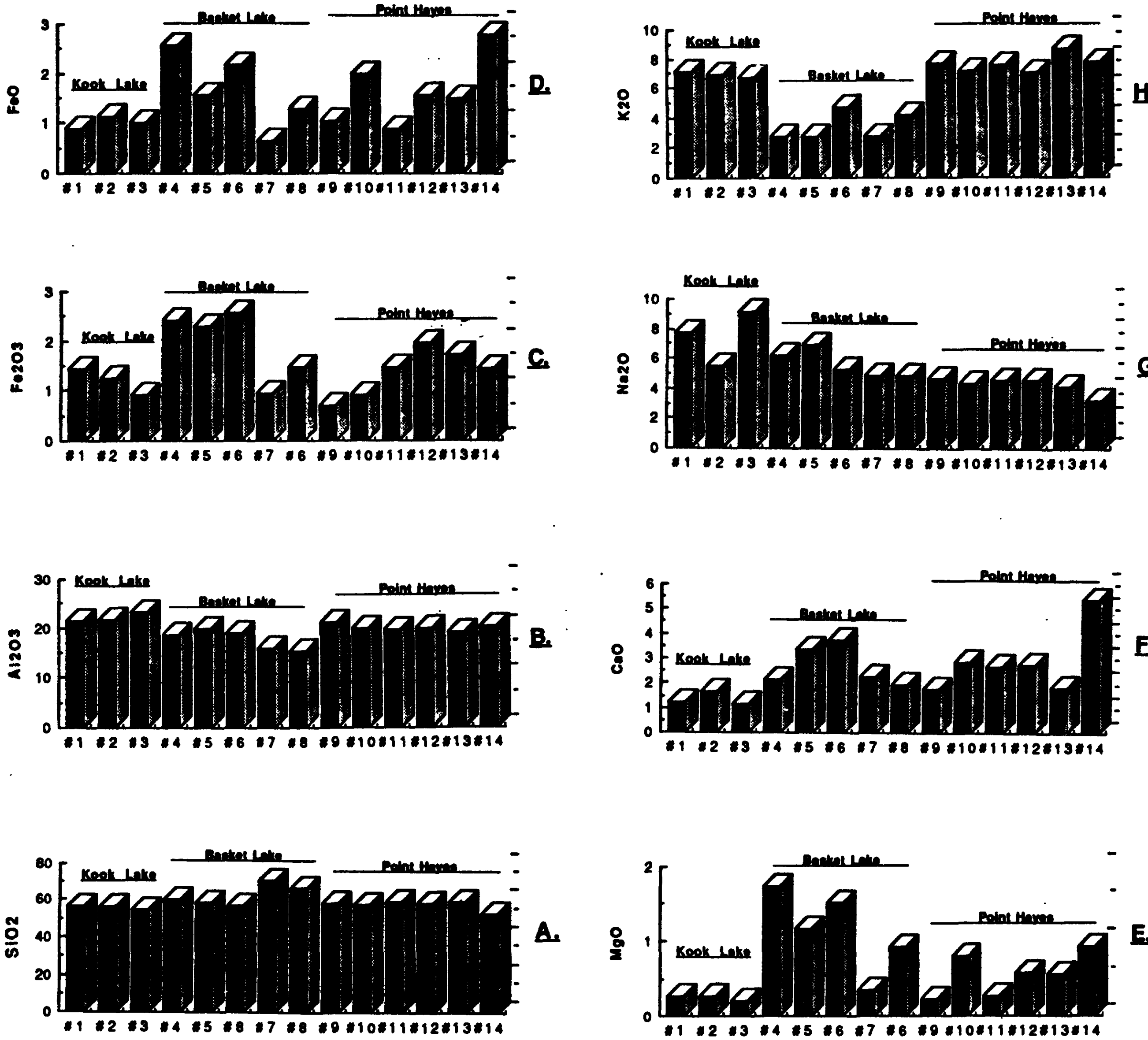

Figure 9. Bar diagrams of major-element data for the Kook Lake, Basket Lake, and Point Hayes plutons of the Sitkoh Bay alkalic plutonic suite.

Continued next page.

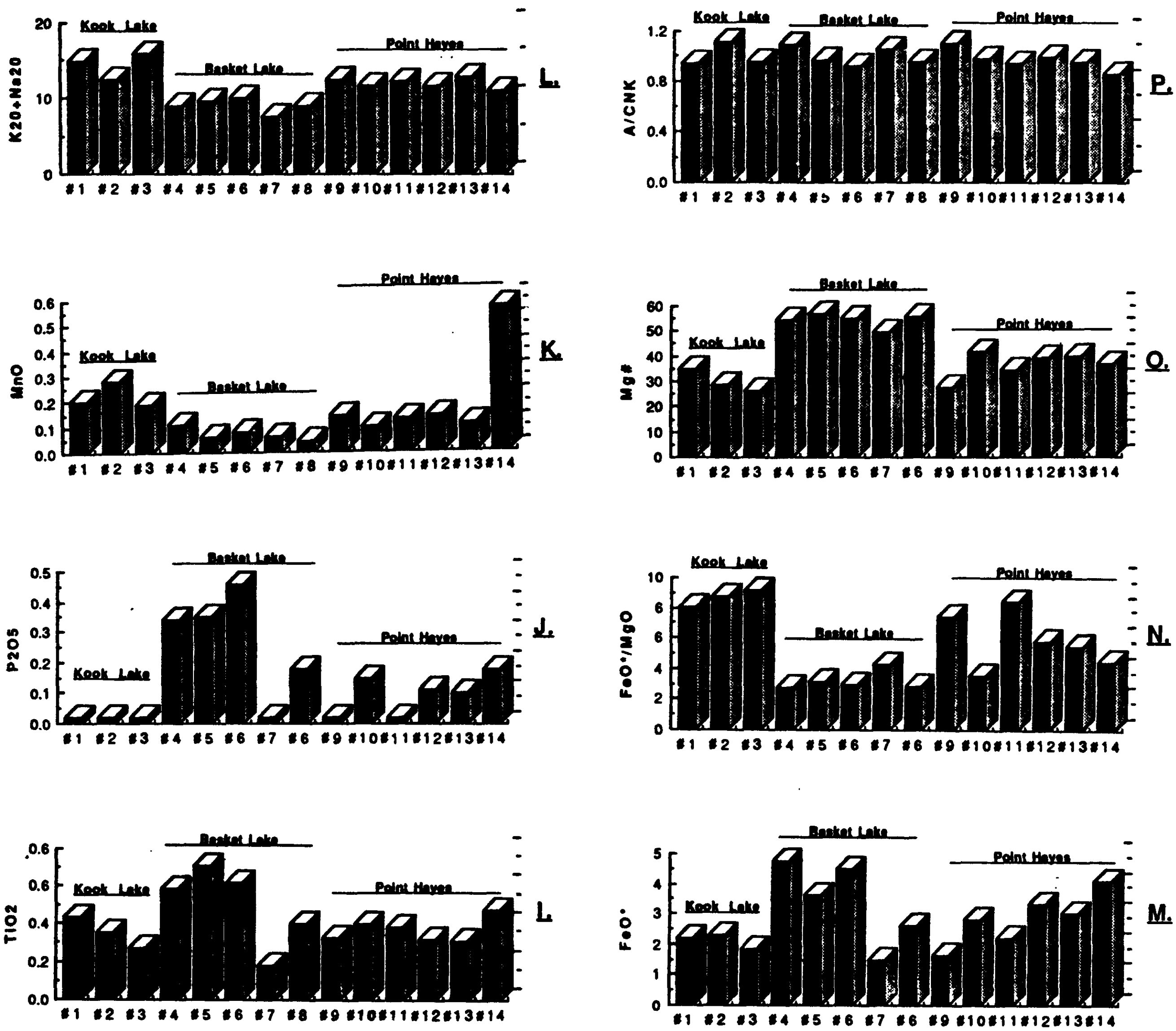

Figure 9. (Continued)

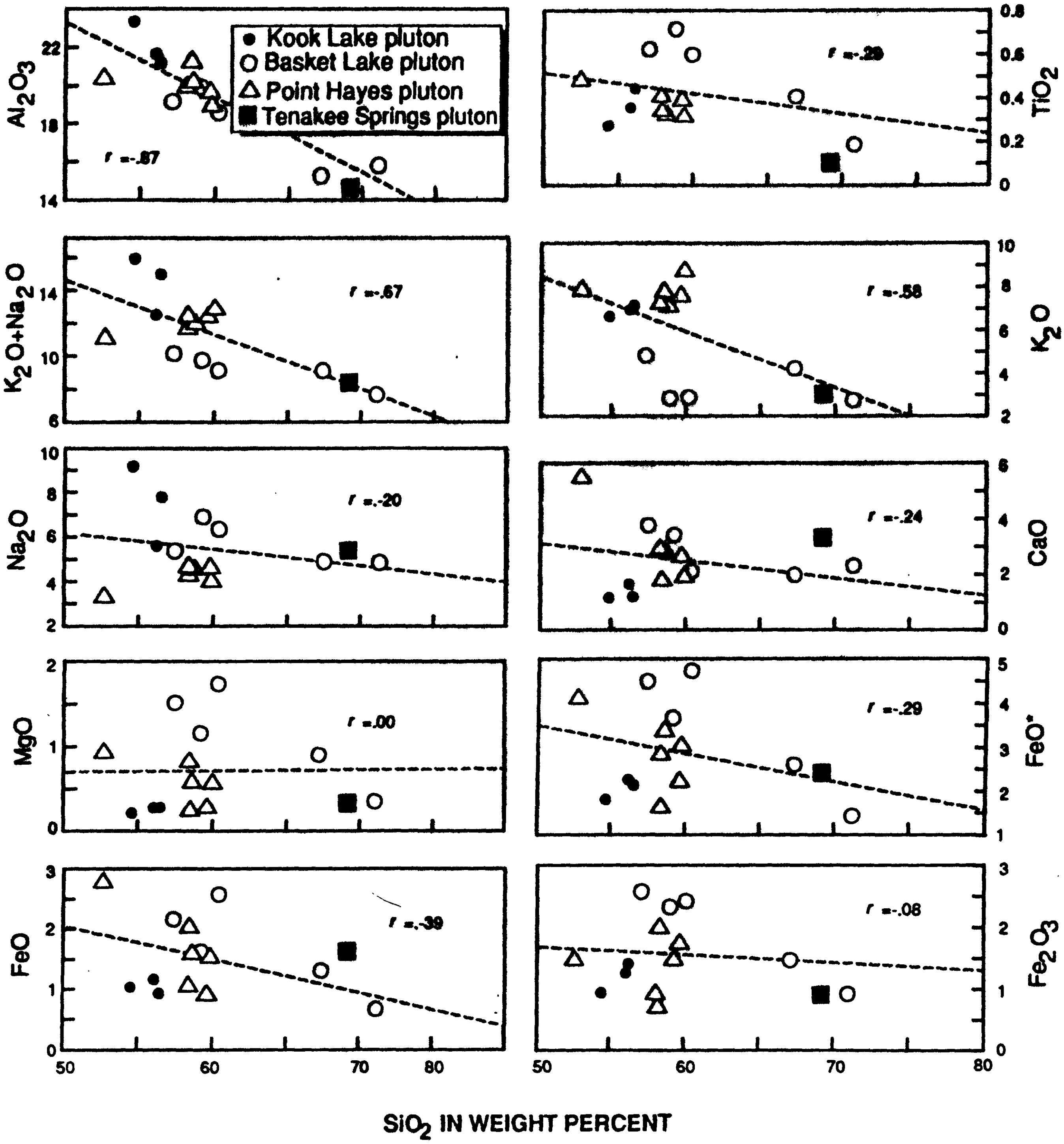

Figure 10. SiO_2 (Harker) variation diagrams, showing least squares line for rocks of the Sitkoh Bay alkalic plutonic suite and correlations (*r*) of oxides with SiO_2. Sample from Tenakee Springs pluton not included in calculations because of possibility that the pluton is unrelated to other bodies (see text).

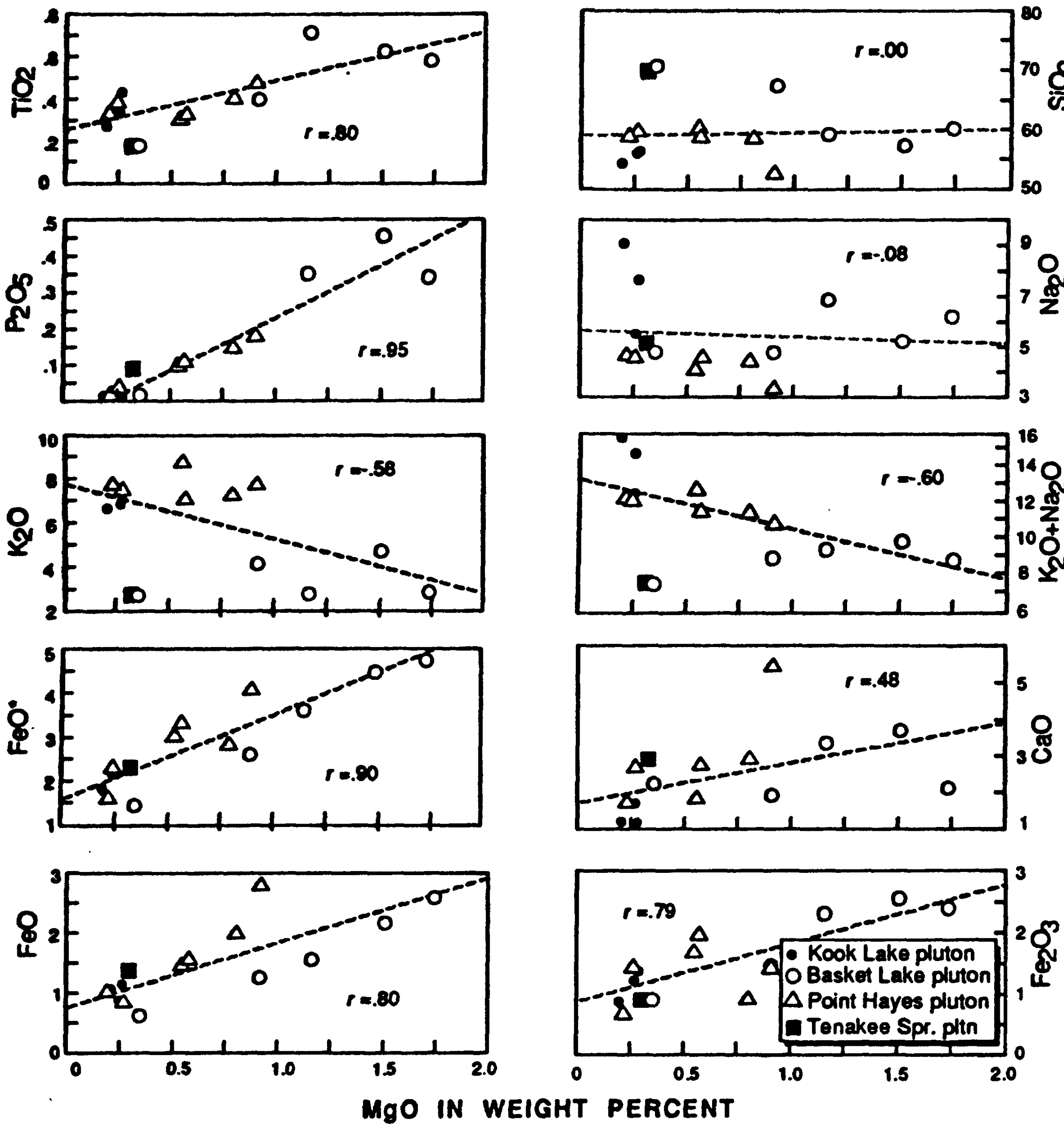

Figure 11. MgO variation diagrams, showing least squares line for rocks of the Sitkoh Bay alkalic plutonic suite and correlations (*r*) of oxides with MgO. Sample from Tenakee Springs pluton not included in calculations because of possibility that the pluton is unrelated to other bodies (see text).

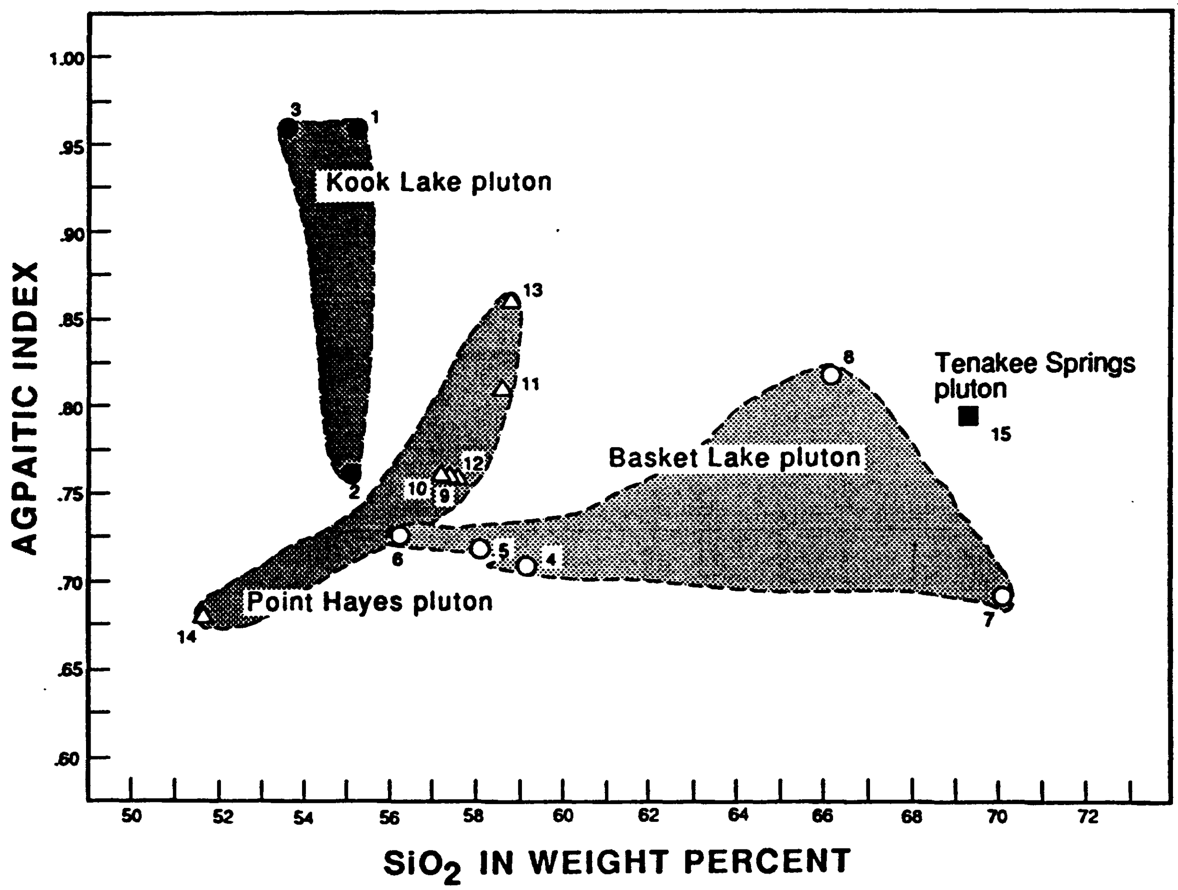

Figure 12. Relation between agpaitic index and SiO_2 for rocks of the Sitkoh Bay alkalic plutonic suite. Agpaitic index = $(Na_2O+K_2O)/Al_2O_3$, in molecular proportions (Sorensen, 1974).

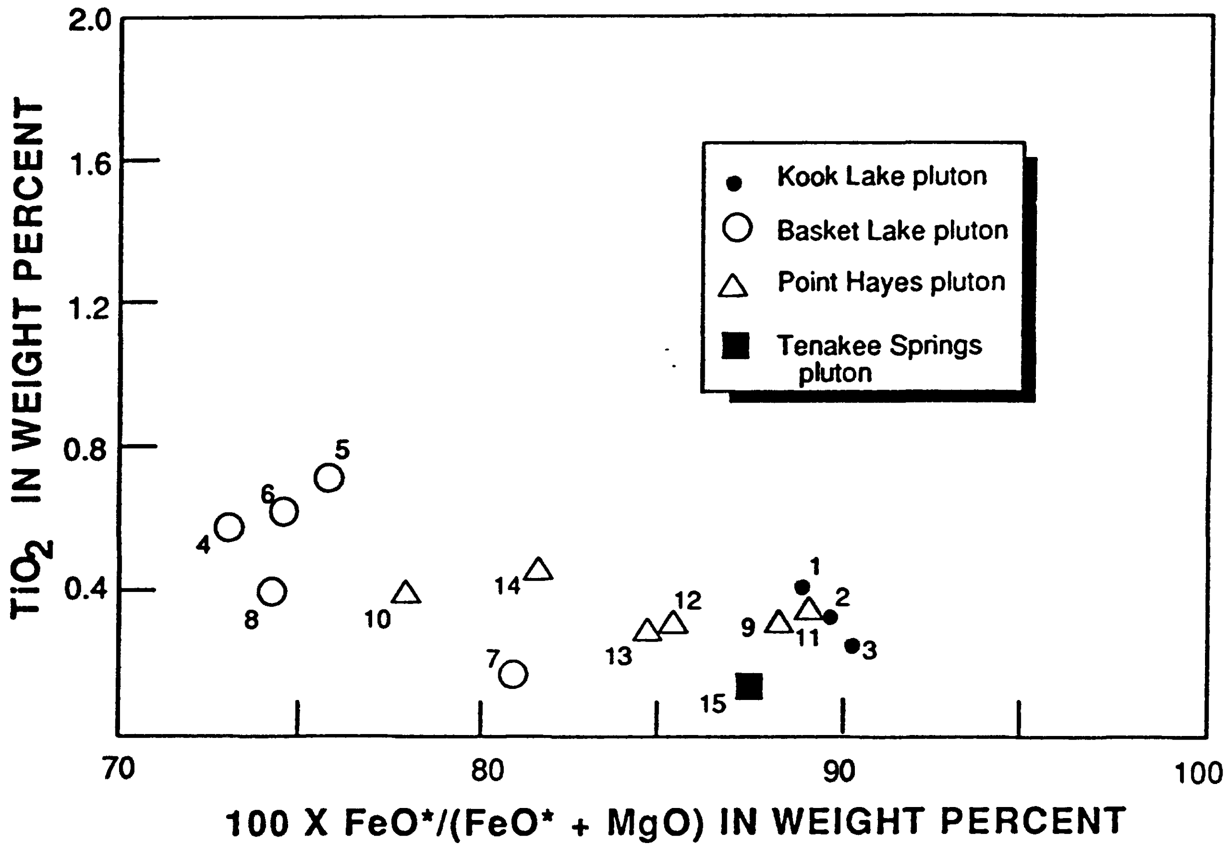

Figure 13. Covariation between TiO_2 and FeO*/(FeO* + MgO) in rocks of the Sitkoh Bay alkalic plutonic suite.

The agpaitic index [(Na_2O + K_2O)/Al_2O_3, in molecular amounts] less than one for all samples (tables 1, 2) indicates that the rocks are undersaturated with respect to alumina and thus are not peralkaline. Note, however, using Wright's (1969) alkalinity ratio, the Kook Lake pluton shows peralkaline characteristics (fig. 6). The agpaitic index < 1 and presence of the the characteristic minerals cancrinite and sodalite (Loney and others, 1975) indicate that the Kook Lake pluton is miaskitic rather than agpaitic nepheline syenite (Sorensen, 1974). Fields of agpaitic indexes for the plutons have little or no overlap (fig. 12).

TiO_2 contents are low, below those typical of syenite (tables 1-3). TiO_2 generally decreases with increasing enrichment of Fe relative to Mg, and fields for the plutons shown in figure 13 generally overlap.

Minor-element chemistry

Rare-earth elements of the Kook Lake, Basket Lake, and Point Hayes plutons (table 4) show moderate light-REE (LREE) enrichment and general similarity in overall REE chondrite-normalized patterns, except for distinct differences in Eu anomalies (fig. 14). The Kook Lake REE patterns are uniformly characterized by small but pronounced negative Eu anomalies suggestive of a plagioclase restite during melt formation or later fractionation (Wilson, 1989). The Basket Lake and Point Hayes plutons, in contrast, have mixed patterns showing smooth variation in some samples and positive (Basket Lake pluton) and positive and negative (Point Hayes pluton) Eu anomalies in others. Lack of consistency in Eu anomalies within individual bodies may reflect alteration differences, whereas regularity (Kook Lake pluton) probably represents primary patterns (Sun and Nesbitt (1978). Heavy REE (HREE) of the Kook Lake and Basket Lake plutons are 10-20 times chondrite values and generally lower in the Point Hayes pluton (fig. 14). The Kook Lake and Basket Lake plutons show closely similar LREE enrichment, generally greater than that of the Point Hayes pluton. Thus, LREE enrichment displays no relation to the alkalinity variation shown in figure 6. The generally higher HREE enrichment and the negative Eu anomalies of the Kook Lake pluton (fig. 14), the most alkalic of the three plutons, are similar to relations of REE patterns in post-tectonic alkaline rocks compared with late-tectonic rocks elsewhere (Liegeois and Black, 1987).

The variation of Ba with Sr in the Kook Lake, Basket Lake, and Point Hayes plutons shows distinctly different trends (fig. 15). Ba increases more or less regularly with Sr, although along different trends, in the Kook Lake and Basket Lake plutons and shows less regularity in the Point Hayes pluton. The positive correlation between these elements (particularly Kook Lake and Basket Lake plutons) is similar to relations for evidence of origin by magmatic fractionation in other alkaline plutons (Bonin, 1986). However, the large differences in trends for the different plutons suggests that different fractionation sequences or other mechanisms are involved.

U and Th contents (table 4) have little overall systematic variation in the Sitkoh Bay alkalic suite and are much lower than Thompson and others (1982) report for aegerine granite of Bokan Mountain (average U: 16 ppm; Th: 50 ppm). The Kook Lake pluton contains higher U than the Basket Lake and Point Hayes plutons but Th contents of the three overlap. U and Th contents of the Kook Lake pluton are much more tightly grouped than in the Basket Lake and Point Hayes plutons, and for all three plutons do not show the strong positive correlation with Rb (figs 16, 17) that characterizes other syenite and related granitic bodies (Bonin, 1986). Rb, however, can be readily susceptible to alteration processes (Whalen and others, 1987, p. 414), which may account for this difference.

Figure 18 shows a plot of covariation between the two incompatible minor elements, Nb and Rb: the Kook Lake and Point Hayes plutons have much higher Rb/Nb ratios (mostly 10->20) compared to the Basket Lake pluton (average, about 5). As in most other chemical relations, the fields for Nb versus Rb of the different plutons are distinct, although Rb/Nb ratios overlap (Kook Lake and Point Hayes plutons). The Kook Lake pluton has generally highest Rb content and the Basket Lake pluton (the most fractionated pluton, figs. 10, 11) has highest Nb content (three samples).

The covariation between Nb and Y is used by Pearce and others (1984) to discriminate the tectonic setting of magmatic rocks. The Sitkoh Bay alkalic suite as now known is overall clearly classed in the field of volcanic-arc and syncollisional granite in their diagram, although showing slight transition into the field of within-plate granite (fig. 19).

Multi-element diagrams ("spidergrams") are also commonly used as a reference format for comparing geochemical variations of rock suites to infer tectonic settings of magmatism (for example, Pearce and others, 1981; 1984). In the MORB-normalized multi-element plot of Pearce (1983), the most conspicuous difference between plutons is a large negative Ba spike of the Kook Lake pluton compared to the Basket Lake and Point Hayes plutons, and a much stronger negative P spike (fig. 20). Except for Ba in the Kook Lake pluton (fig. 20), the suite shows the general enrichment of large-ion-lithophile (LIL) incompatible elements (K, Rb, Ba, and Th) typical of alkalic rocks (Wilson, 1989, p.333). Enrichment of these elements may reflect mantle zone melting rather than crustal melting (Hall, 1987), or derivation from an enriched mantle source (Bailey, 1983). Except for Th, the LIL elements, however, are susceptible to mobility during alteration and thus are subject to some uncertainty in interpretation (Saunders and Tarney, 1984). Patterns for the plutons (fig. 20) significantly lack the strong Nb depletion that characterizes arc magmatism (Gill, 1981; Pearce and others, 1981).

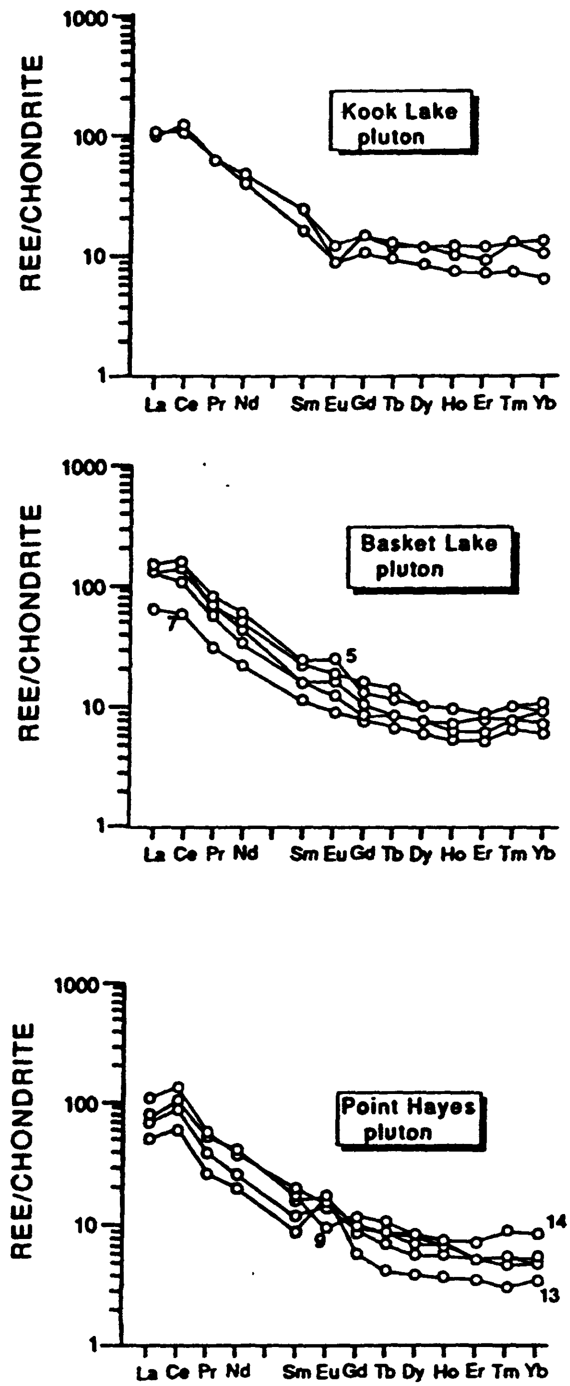

Figure 14. Chondrite normalized rare-earth element plots for *A*, Kook Lake pluton, *B*, Basket Lake pluton and *C*, Point Hayes pluton. From method of Wheatly and Rock (1988).

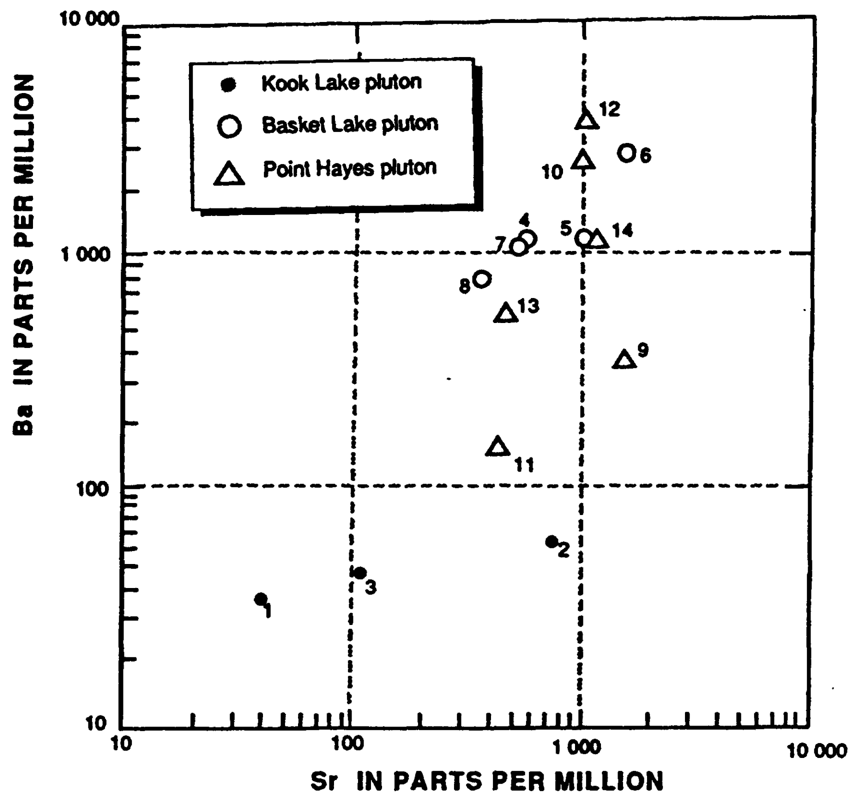

Figure 15. Covariation between Ba and Sr for the Kook Lake, Basket Lake, and Point Hayes plutons.

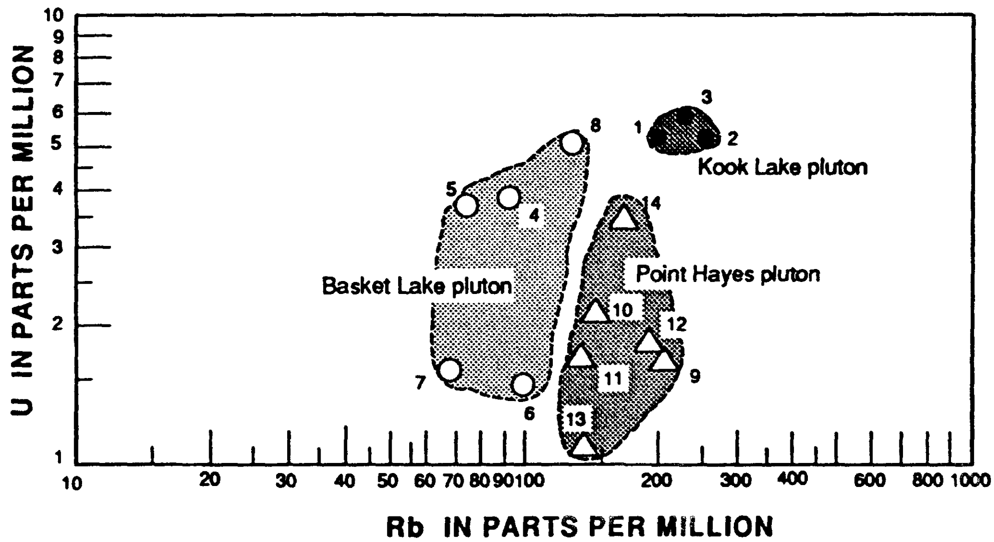

Figure 16. Covariation between U and Rb for the Kook Lake, Basket Lake, and Point Hayes plutons.

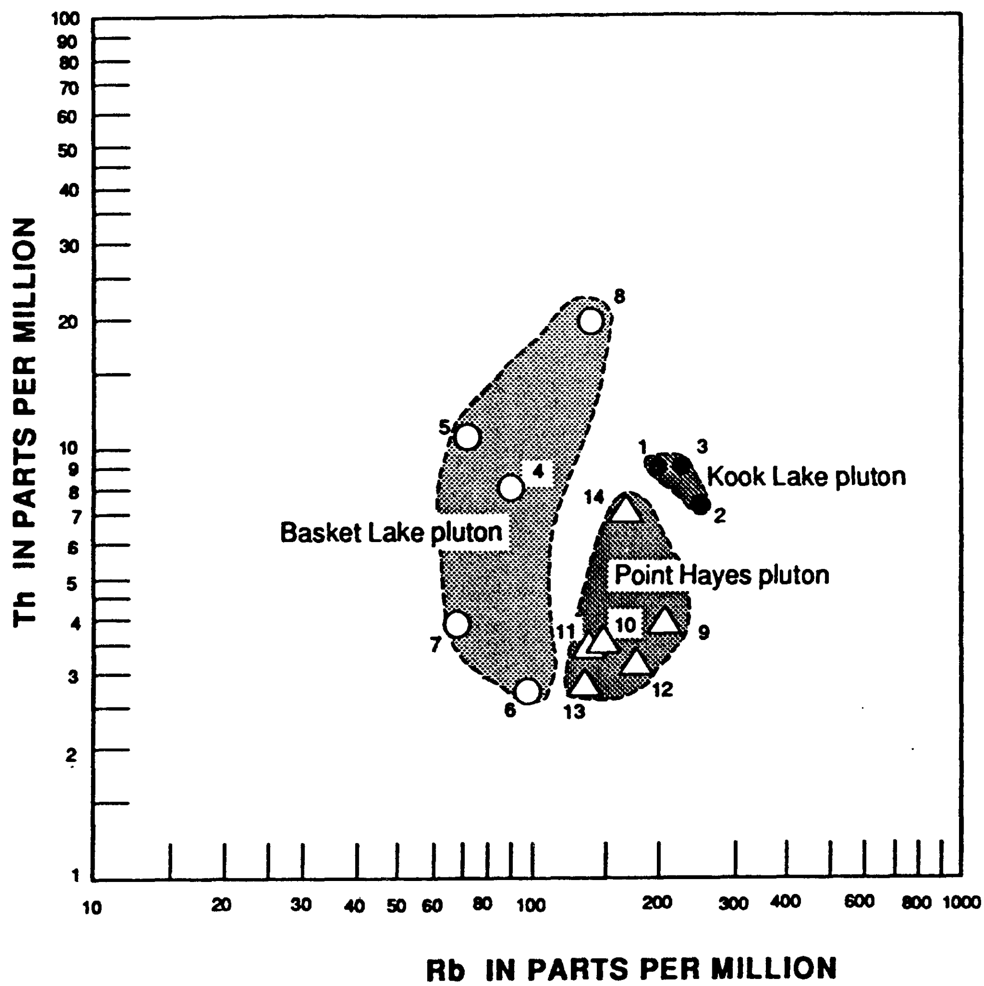

Figure 17. Covariation between Th and Rb for the Kook Lake, Basket Lake, and Point Hayes plutons.

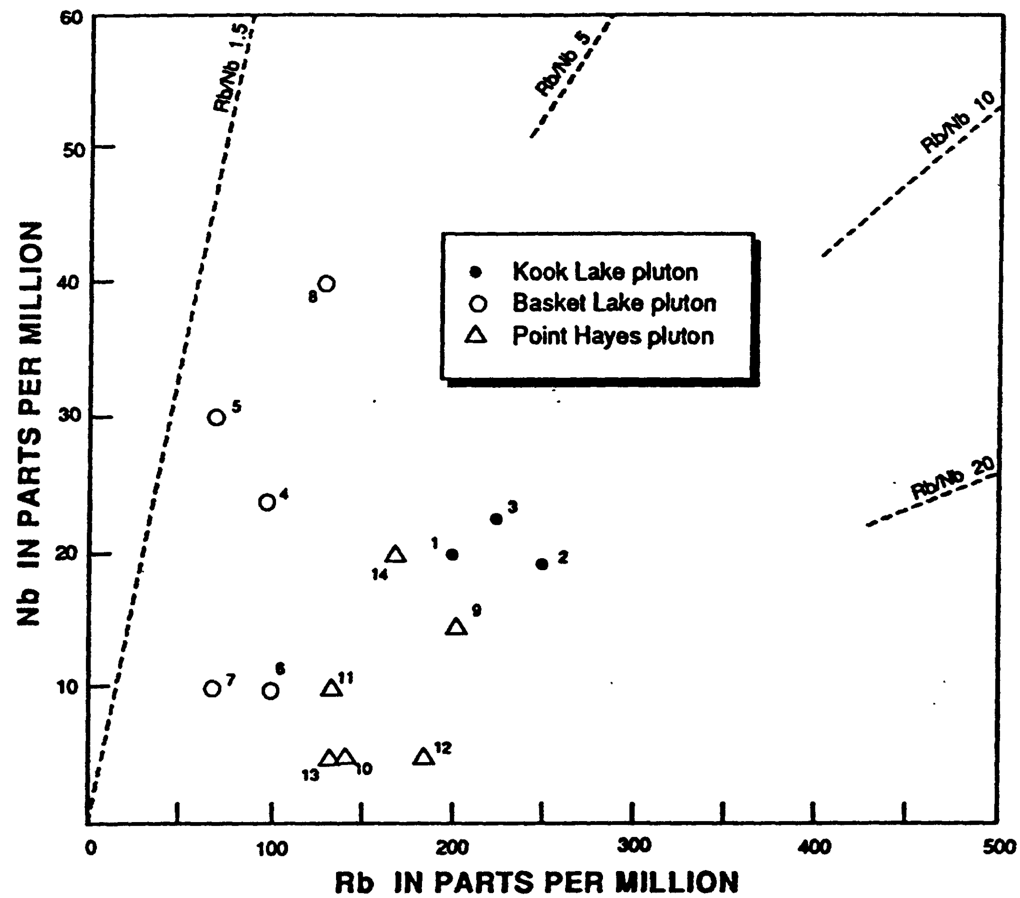

Figure 18. Covariation between Nb and Rb for the Kook Lake, Basket Lake, and Point Hayes plutons.

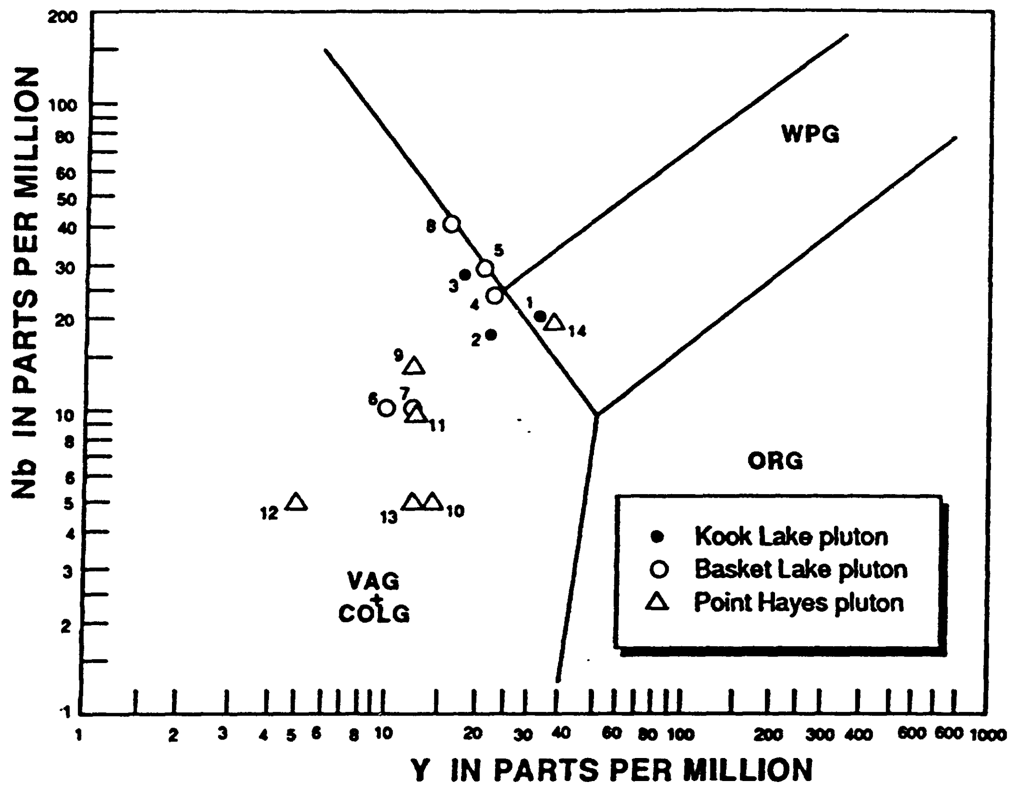

Figure 19. Covariation between Nb and Y for the Kook Lake, Basket Lake, and Point Hayes plutons, showing fields (Pearce and others, 1984) for syncollision and volcanic-arc (VAG+COLG), within-plate (WPG), and ocean-ridge granites (ORG).

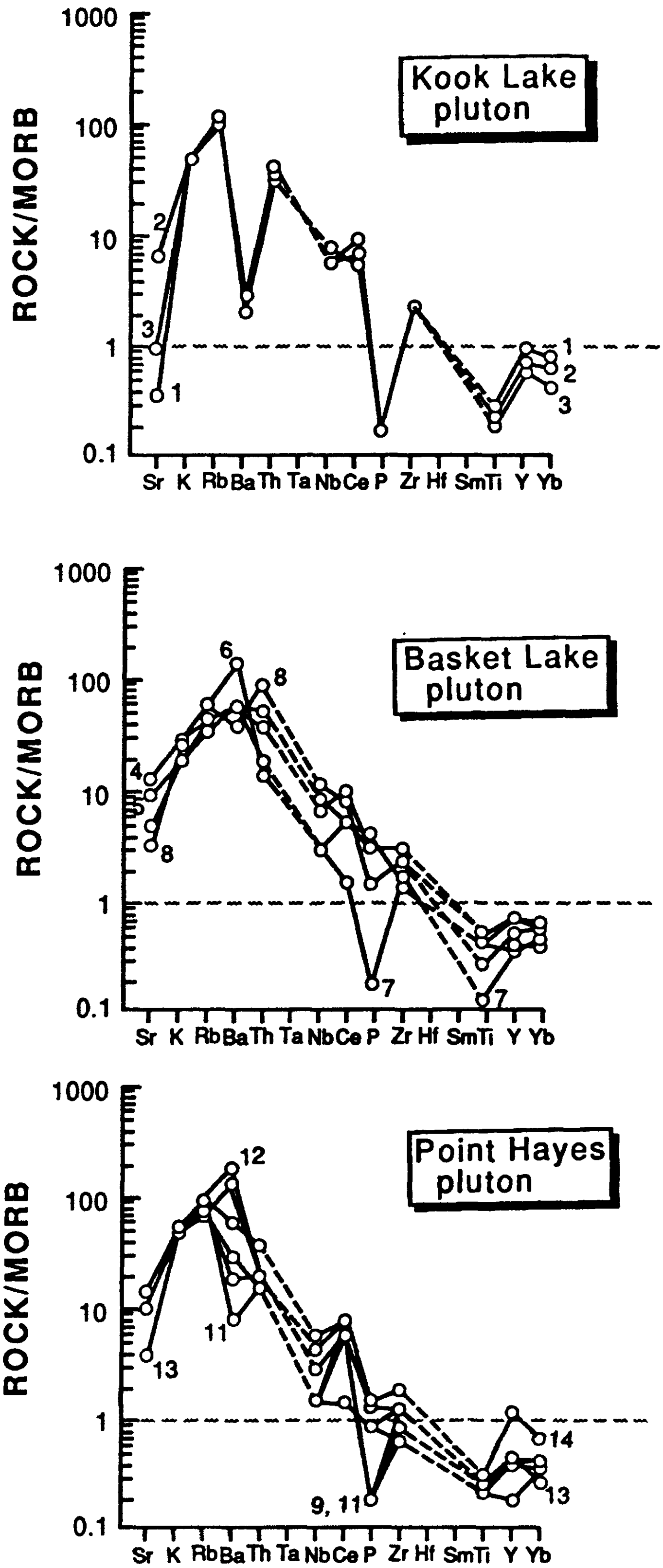

Figure 20. Morb normalized geochemical patterns for the Kook Lake, Basket Lake, and Point Hayes plutons. Method of Pearce (1983) and Wheatley and Rock (1988).

DISCUSSION

Form of the intrusion

The present overall lenticular outline of the Sitkoh Bay alkalic suite contrasts with the more common circular form (ring structures, laccoliths, necks, plugs and stocks) of other syenitic complexes (Sorensen, 1974; Miller, 1972; Thompson and others, 1982; Henderson and others, 1989). However, this may be a factor of depth of erosion, as the Sitkoh Bay suite possibly represents the lower magmatic chamber level beneath an eroded ring structure, as in Bonin's (1986) model for such bodies. Bonin's (1986) model consists of rocks ranging from early gabbro to late granite formed by magmatic differention from mantle-derived gabbro. Evidence such as mafic xenoliths of deeper gabbroic units, however, has not been found in the Sitkoh Bay region.

The original size and shape of the Sitkoh Bay alkalic bodies are highly uncertain. Parts of the suite appear to have been dislocated by the Chatham Strait and Sitkoh Bay fault zones, as well as truncated by a large Cretaceous granitic pluton (fig. 2). In comparison to the about 260 sq km area of the Sitkoh Bay alkalic plutonic suite, syenitic bodies in general vary in size from less than 1 sq km to more than 1,500 sq km (Sorensen, 1974).Widths of alkalic ring complexes average about 15 km across, which is little more than the known width of the Sitkoh Bay suite, but the size of underlying alkalic plutonic bodies associated with them can be considerably greater (Bonin, 1986). The possibility that the Sitkoh Bay alkalic bodies are older than the surrounding rocks makes a much wider distribution beneath superjacent rocks possible.

Relations between plutons

The investigated plutons of the Sitkoh Bay alkalic plutonic suite do not appear to form a simple fractionation sequence as represented by available samples, but instead may reflect differences in magma sources and later history of fractionation combined with varied processes during ascent, emplacement, and later alterations, as suggested by the wide scatter of data in variation diagrams (for example, figs. 10 and 11); the generally distinct chemical fields and differences in trends for different plutons in other diagrams (figs. 3-8, 12-13, 15-18); the inconsistency of REE patterns within plutons (mixed positive and negative Eu anomalies, fig. 14); and differences such as in Ba-Sr trends and inconsistency of Ba/Sr ratios within plutons (fig. 15). The present data are insufficient to evaluate the geochemical relations found in our study owing to the lack of knowledge of field relations between plutons of the suite, the wide sample spacing, and the lack of data for some plutons. Differences in chemical variations may have petrological explanation, but inadequacy of sampling is a limiting factor.

The Tenakee Springs pluton, which is mapped as part of the Sitkoh Bay suite but which may instead be much younger, is chemically distinct from other plutons of our study in being the only calc-alkaline body (and the only trondhjemite, fig. 5), though differing only slightly from the Basket Lake pluton (fig. 6). It also differs from other plutons in its agpaitic index and SiO_2 covariation (fig. 12). However, the major-element chemistry in general does not exclude a possible genetic relation to other plutons of the suite, owing to the generally close similarity with the Basket Lake pluton (figs. 4-8, 10-11).

An interesting aspect of the Sitkoh Bay alkalic suite is the coexistence of nepheline syenites and other undersaturated rocks (such as of the Kook Lake and Point Hayes plutons) with SiO_2-saturated rocks (such as in the Basket Lake pluton). This relation seems to be rather common in other alkalic complexes and poses petrogenetic problems discussed by Henderson and others (1989), Bonin (1986), Woolley and Jones (1987), and Eby (1987) who suggest possible comagmatic derivation by fractionation from a common magma parent but with complexities of varied mantle processes and later histories. The magmas possibly were derived from a heterogeneous mantle source and each of the derived primary magmas may have undergone subsequent fractionation and (or) assimilation in a higher level magma chamber before intrusion to present levels. (Isotopic studies are needed to assess these possibilities.)

The association of the wide range of rock types of the Sitkoh Bay alkalic suite presently cannot be evaluated because of the limited geochemical data for the plutons investigated in this study and the lack of data for some plutons of the suite. In present knowledge lacking known contact relations, the Sitkoh Bay alkalic plutonic suite may even in fact consist of only a single large heterogeneous intrusion, rather than the six plutons as mapped on the basis of geographically scattered lithologies; and the various units (fig. 2) may accordingly represent varied processes of assimilation, fractional crystallization, and other magmatic and postmagmatic processes within a single large intrusive body.

Tectonic setting

Alkaline magmas have generated in a great variety of tectonic settings (Sorensen, 1974; Fitton and Upton, 1987; Box and Flower, 1989) but are typically anorogenic (Bonin, 1986). Martin and Piwinskii (1972) recognize two kinds of magmatism: (1) compressional (orogenic), related to plate convergence and characterized by calc-alkaline magmas; and (2) tensional (anorogenic), characterized by alkaline magmas, such as those of the Sitkoh Bay suite. Fitton and Upton (1987) consider three types of tectonic setting for such alkaline rocks: continental rift valleys, oceanic and continental intraplate setting, and subduction zones. Whalen and others (1987) review the large, contentious literature on metasomatic, differentiation, and partial melting models to explain the origin of alkaline and peralkaline magmas, and show that such magmas can occur in settings as varied as continental (within-plate) rift zones, collisional magmatic arcs, transcurrent fault zones, and active subduction zones.

This part of Chichagof Island in the early Paleozoic was probably a volcanic arc as suggested by the andesitic to basaltic compositions of the Devonian Freshwater Bay Formation and by the abundant turbidites in the Silurian Point Augusta Formation. This apparent continental-margin arc setting for the Sitkoh Bay plutonic suite may be similar to the volcanic arc setting and subduction origin of Cretaceous alkalic rocks of western Alaska proposed by Miller (1972), or may be a subduction-related intra-arc rift. A volcanic arc (or syncollisional) origin of the Sitkoh Bay suite is supported by the Nb-Y tectonic discrimination diagram of figure 19. However, the rocks lack the characteristic trace-element fingerprinting of arc-related magmatism, such as strong Nb depletion, and the strong fractionation of Rb/Th ratios of syncollisional granite (Leat and others, 1987).

The timing of tectonic and magmatic events in this part of Chichagof Island is poorly known. The possibility of an older age of the Sitkoh Bay alkalic plutonic rocks than the Silurian and Devonian arc-related units raises uncertainty about a similarity in tectonic setting. The tectonic-magmatic settings of individual plutons(?) of the suite additionally may have varied in time as in the history of part of the Pan-African orogenic belt reported by Liegeois and Black (1987), during which subduction and collision-related magmatism rapidly switched to alkalic magmatism that accompanied later transurrent shearing. Similarly, different plutons of the Sitkoh Bay suite may represent different settings, as shown by differences in trace-element characteristcs (extents of Nb depletion and differences in tectonic-discrimination fields for Nb and Y covariation). Accordingly, the Tenakee Springs (if related to the suite) and Basket Lake plutons, the least alkaline bodies, were possibly formed during a subduction event that was followed by a switch to a rift or transcurrent-fault setting during which the most alkaline magma formed (Kook Lake pluton).

REFERENCES CITED

Armstrong, R.L., 1985, Rb-Sr dating of the Bokan Mountain granite complex and its country rocks: Canadian Journal of Earth Sciences, v. 22, p. 1233-1236.

Baedecker, P.A., ed., 1987, Methods for geochemical analysis: U.S. Geological Survey Bulletin 1770.

Bailey, D.K, 1983, The chemical and thermal evolution of rifts: Tectonophysics, v. 94, p. 585-597.

Barker, D.S, 1974, Alkaline rocks of North America, *in*, Sorensen, H., ed., The alkaline rocks: New York, John Wiley, p. 160-171.

Barker, Fred, 1979, editor, Trondhjemites, dacites, and related rocks: Elsevier, New York, 659 p.

Barker, J.C., 1989, Geologic setting and deposit-type classification of REE in Alaska, *in* Torma, A.E., and Gundiler, I.H., eds., Precious and rare metal technologies: Elsevier, New York, 702 p.

Barker, J.C., and Mardock, C.L., 1988, Lithphile metal, REE-Y-Nb deposits in southern Prince of Wales Island, Alaska, *in* Carson, D.J.T., and Vassiliou, A.H., eds., Process Mineralogy VIII: The Minerals, Metals & Materials Society, p. 139-157.

Berg, H.C., Jones, D.L., and Coney, P.J., 1978, Pre-Cenozoic tectonostratigraphic terranes of southeastern Alaska and adjacent areas: U.S. Geological Survey Open-File Report 78-1085, 2 sheets.

Bonin, Bernard, 1986, Ring complex granites and anorogenic magmatism: New York, Elsevier, 188 p.

Box, S.E., and Flower, M.F.J., 1989, Introduction to special section on alkaline arc magmatism: Journal of Geophysical Research, v. 94, no. B4, p. 4467-4468.

Brew, D.A., 1988, Latest Mesozoic and Cenozoic igneous rocks of southeastern Alaska--a synopsis: U.S. Geological Survey Open-File Report 88-405, 29 p.

Brew, D.A., Ovenshine, A.T., Karl, S.M., and Hunt, S.J., 1984, Preliminary reconnaissance geologic map of the Petersburg and parts of the Port Alexander and Sumdum 1:250,000 quadrangles, southeastern Alaska: U.S. Geological Survey Open-File Report 84-405, 43 p.

Douglass, S.L., Webster, J.H., Burrell, P.D., Lanphere, M.A., and Brew, D.A., 1989, Major element chemistry, radiometric values, and locations of samples from the Petersburg and parts of the Port Alexander and Sumdum quadrangles, southeastern Alaska: U.S. Geological Survey Open-File Report 89-527, 66 p. Pamphlet, map scale 1:250,000.

Eby, G.N., 1987, The Monteregian Hills and White Mountain alkaline igneous provinces, eastern North America, *in*, Fitton, J.G., and Upton, B.G.J., eds., Alkaline igneous rocks: Geological Society Special Publication, no. 30, p. 433-447.

Fitton, J.G., and Upton, B.G.J., eds, 1987, Alkaline igneous rocks: Geological Society Special Publication, no. 30, 568 p.

Gehrels, G.E., and Saleeby, J.B, 1986, Geologic map of southern Prince of Wales Island: U.S. Geological Survey Open-File Report 86-275, scale 1:63,360, 33 p. pamphlet.

Gill, J.B., 1981, Orogenic andesites and plate tectonics: Springer-Verlag, New York,
390 p.

Hall, Anthony, 1987, Igneous petrology: Longman, New York, 573 p.

Henderson, C.M.B., Pendlebury, Karen, and Foland, K.A., 1989, Mineralogy and petrology of the Red Hill alkaline igneous complex, New Hampshire, U.S.A.: Journal of Petrology, v. 30, Pt. 3, p. 627-666.

Hudson, Travis, Plafker, George, and Dixon, K., 1982, Horizontal offset history of the Chatham Strait fault, *in* Coonrad, W. L., ed. The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 128-132.

Hunt, S., 1984, Preliminary study of a zoned leucocratic-granitic body on central Etolin Island, southeastern Alaska, *in* Coonrad, W.L., and Elliott, R.L., eds., The United States Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular 868, p. 128-131.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, p. 523-548.

Lanphere, M.A., Loney, R.A., and Brew, D.A., 1965, Potassium-argon ages of some plutonic rocks, Tenakee area, Chichagof Island, southeastern Alaska, *in* Geological Survey research 1965: U.S. Geological Survey Professional Paper 525-B, p. B108-B111.

Lanphere, M.A., MacKevett, E.M., Jr., and Stern, T.W., 1964, Potassium-argon and lead-alpha ages of plutonic rocks, Bokan Mountain area, Alaska: Science, v. 145, no. 3633, p. 705-707.[1]

Leat, P.T., Thompson, R.N., Morrison, M.A., Hendry, G.L., and Trayhorn, S.C., 1987, Geodynamic significance of post-Variscan intrusive and extrusive potassic magmatism in SW England: Transactions of the Royal Society of Edinburgh, Earth Sciences, v. 77, p. 349-360.

Le Maitre, R.W., 1976, The chemical variability of some common igneous rocks: Journal of Petrology, v. 17, pt. 4, p. 589-637.

Liegeois, J.P., and Black, R., 1987, Alakaline magmatism subsequent to collision in the Pan-African belt of the Adrar des Iforas (Mali), *in*, Fitton, J.G., and Upton, B.G.J., eds., Alkaline igneous rocks: Geological Society Special Publication, no. 30, p.381-401.

Loney, R.A., Brew, D.A., Muffler, L.J.P., and Pomeroy, J.S., 1975, Reconnaissance Geology of Chichagof, Baranof, and Kruzof Islands, Southeastern Alaska: U.S. Geological Survey Professional Paper 792, 105 p.

MacKevett, E.M., Jr., 1963, Geology and ore deposits of the Bokan Mountain uranium-thorium area, southeastern Alaska: U.S. Geological Survey Bulletin 1154, 125 p.

Mariano, A.N., 1989, Economic geology of rare earth minerals, *in* Lipin, B.R. and McKay, eds., Geochemistry and mineralogy of rare earth elements: Mineralogical Society of America, Reviews in Mineralogy, v. 21, p. 309-337.

Martin, R.F., and Piwinskii, A.J., 1972, Magmatism and tectonic settings: Journal of Geophysical Research, v. 77, no 26, p. 4966-4975.

Miller, T.P., 1972, Potassium-rich alkaline intrusive rocks of western Alaska: Geological Society of America Bulletin, v. 83, p. 2111-2128.

Mutschler, F.E., Griffin, M.E., Stevens, D.S., and Shannon, S.S., Jr., 1985, Precious metal deposits related to alkaline rocks in the North American cordillera---an interpretive review: Transactions of the Geological Society of South Africa, v. 88, p. 355-377.

Ovenshine, A.T., and Brew, D.A., 1972, Separation and history of the Chatham Strait fault, southeast Alaska, North America: 24th International Geological Congress, Section 3, p. 245-254.

Pearce, J.A., 1983, Role of the sub-continental lithosphere in magma genesis at active continental margins, p. 230-249 *in* Hawksworth, C.J., and Norry, M.J., eds., Continental basalts and mantle xenoliths: London, Shiva.

Pearce, J.A., Alabaster, T., Shelton, A.W., and Searle, M.P., 1981, The Oman ophiolite as a Cretaceous arc-basin complex: evidence and implications: Philosophical Transactions, Royal Society of London A, v. 300, p. 299-317.

Pearce, J.A., Harris, N.B.W., and Tindle, A.G., 1984, Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: Journal of Petrology, v. 25, p. 956-983.

Ross, D.C., 1973, Are the rocks of the Salinian block trondhjemitic? U.S. Geological Survey Journal of Research, v. 1, p. 251-254.

Sahama, Th.G., 1974, Potassium-rich alkaline rocks, *in*, Sorensen, H., ed., The alkaline rocks: New York, John Wiley, p. 96-109.

Saunders, A.D., and Tarney, J., 1984, Geochemical characteristics of basaltic volcanism within back-arc basins, in Kokelaar, B.P., and Howells, M.F., Marginal basin geology: The Geological Society, Oxford, p. 59-76.

Semenov, E.I., 1974, Economic mineralogy of alkaline rocks, *in*, Sorensen, ed., The alkaline rocks: New York, John Wiley, p. 543-552.

Sonnevil, R.A., 1981, The Chilkat-Prince of Wales plutonic province, southeastern Alaska, *in* Albert, N.R.D., and Hudson, Travis, eds., The United States Geological Survey in Alaska: Accomplishments during 1979: U.S. Geological Survey Circular 823B, p. B112-B115.

Sorensen, H., 1974, The alkaline rocks: New York, John Wiley, 622 p.

Streckeisen, A., and Le Maitre, R.W., 1979, A chemical approximation to the modal QAPF classification of the igneous rocks: Nues Jahrbuch fur Mineralogie, Abhandlungen, v. 136, p. 169-206.

Sun, Shen-Su, and Nesbitt, 1978, Petrogenesis of Archaean ultrabasic and basic volcanics: evidence from rare earth elements: Contributions to Mineralogy and Petrology, v. 65, p. 301-325.

Thompson, T.B., Pierson, J.R., and Lyttle, Thomas, 1982, Petrology and petrogenesis of the Bokan Granite Complex, southeastern Alaska: Geological Society of America Bulletin, v. 93, p. 898-908.

Warner, J.D., and Mardock, C.L., 1987, Rare earth element-, niobium-, thorium-, and uranium-bearing dikes at Bokan Mountain, southeast Alaska [abs.]: Geological Society of America, Abstracts with Programs, v. 19, no. 6, p. 461.

Whalen, J.B., Currie, K.L., and Chappell, B.W., 1987, A-type granites: geochemical characteristics, discrimination, and petrogenesis: Contributions to Mineralogy and Petrology, v. 95, p. 407-419.

Wheatley, Michael, and Rock, N.M.S., 1988, SPIDER: A Macintosh program to generate normalized multi-element "spidergrams:" American Mineralogist, v. 73 p. 919-921.

Wilson, Marjorie, 1989, Igneous petrogenesis: Boston, Unwin Hyman, 466 p.

Woolley, A.R., and Jones, G.C., 1987, The petrochemistry of the northern part of the Chilwa alkaline province, Malawi, *in*, Fitton, J.G., and Upton, B.G.J., eds., Alkaline igneous rocks: Geological Society Special Publication, no. 30, p. 335-355.

Wright, J.B., 1969, A simple alkalinity ratio and its application to questions of non-orogenic granite genesis: Geological Magazine, v. 106, no. 4, p. 370-384.