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GEOLOGICAL SURVEY

Modal compositions, whole-rock chemical data and normative mineralogy, and minor element data for rocks from alkaline intrusive complexes in northwestern Montana

By

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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INTRODUCTION

The purpose of this report is to present mineralogical and chemical analytical data for rock samples collected from five alkaline intrusive complexes in northwestern Montana at Rainy Creek, Bobtail Creek, and Warland Creek in Lincoln County, Haines Point in Sanders County, and Skalkaho in Ravalli County (fig. 1). The major-element data are summarized in a diagram that plots agpaitic index (atomic Na+K/Al) against silica content and the rare-earth-element (REE) data are represented by chondrite-normalized patterns.

These alkaline intrusive complexes are being studied because they appear to represent examples of Rock's (1976, p. 97) gabbroic type of alkaline complex. According to Rock, this type of complex typically contains alkali gabbro, nepheline syenite, oversaturated peralkaline or agpaitic rocks, and other lithologic types; calcic plagioclase should be present in some of the rocks of this type of complex. Rock's (1976, p. 97) other type is the carbonatitic type of alkaline complex. These complexes contain carbonatite, ijolite, pyroxenite, melilitic rocks, nepheline syenite, and other lithologic types; calcic plagioclase is absent from rocks of this type of complex. The distinction between these two types of complexes is important because carbonatitic types such as those at Iron Hill, Colo. (Armbrustmacher, 1979), Magnet Cove, Ark. (Erickson and Blade, 1963), and Mountain Pass, Calif. (Olson and others, 1954) commonly host deposits of rare-earth elements, niobium, thorium, titanium, and other commodities, whereas the gabbroic types do not appear to host such deposits. Cataloging of geochemical and petrologic characteristics of both types of complexes will result in the establishment of a unique set of geochemical parameters so that limited rock samples of remote exposures or drill core from alkaline complexes can be used to determine whether they are gabbroic or carbonatitic and thus to determine the advisability of further exploration of these complexes for the presence of deposits of earlier mentioned commodities.

Carbonate-rich rocks occurring in dikes and thought to resemble carbonatites have been reported at Rainy Creek (R.J. Kujawa, personal commun., 1981) and at Skalkaho (Marti Stomberg, personal commun., 1981). If these complexes were therefore the carbonatitic type, the possible spatial and genetic association of rare-earth elements (REE), niobium, thorium, titanium, and other commodities with these complexes should be considered. However, the "carbonatite dikes" were determined to be hydrothermal carbonate veins on the basis of geochemical composition, and the complexes at Rainy Creek and Skalkaho were determined to be the gabbroic type on the basis of types of lithologies present and their geochemical compositions. Thus, the probability of finding mineral deposits of the kind usually associated with carbonatitic complexes is unlikely at the localities discussed in this report.

PROCEDURE

Rock samples were collected from the five complexes (figs. 2-6) and the intent was to collect unaltered and unweathered samples of each lithologic unit. After petrographic examination of thin sections cut from the rock samples, point counts were made of selected samples in order to determine modal compositions of the rocks (tables 1-8). The same samples were submitted to the Branch of Analytical Chemistry for major and minor element analyses. The major elements (tables 9-11) were determined by X-ray fluorescence spectroscopy (analysts J.S. Wahlberg, J.E. Taggert, and J. Baker). Additional major elements (FeO, H_2O+, H_2O-, and CO_2) were determined by chemical techniques (analysts: H. Neiman and E. Engleman). Normative mineral calculations (tables 9-11) were performed with the technical assistance of Ken Hon. Minor elements (tables 12-14) were partly determined by semiquantitative 6-step DC-arc spectrography (analyst M.J. Malcolm), and partly determined by inductively coupled plasma-optical emission spectroscopy (analyst K. McKowen). Rare-earth elements (tables 12-14) were determined by inductively coupled plasma-optical emission spectroscopy after preconcentration by ion exchange (analyst J.G. Crock) (Crock and others, 1986). Uranium and thorium (tables 12-14) were determined by delayed neutron analysis (analysts: H.T. Millard, Jr., B.A. Keaten, F.M. Luman, R. Bies, M. Coughlin, S. Lasater, J. Storey, S. Danahey, and B. Vaughn).

GEOLOGY

All five of the alkaline intrusive complexes intrude rocks of the Proterozoic Belt Supergroup. In the vicinity of four of the complexes, the Belt rocks consist of fine-grained clastic rocks of low metamorphic grade. In the vicinity of the complex at Skalkaho, the host rocks are chiefly calc-silicate rocks, presumably belonging to the contact-metasomatic aureole surrounding the Idaho batholith. The Belt rocks show evidence of fenitization adjacent to contacts with the alkaline complexes.

The complex at Rainy Creek (fig. 2) contains the largest known vermiculite deposit and the largest vermiculite mining and milling operation in the world. The complex comprises a bimodal suite of rocks, with an ultramafic component consisting of pyroxenite and biotitite and a younger leucocratic component consisting of small separate intrusions of quartz-bearing syenite and nepheline syenite. The ultramafic rocks are intruded by syenite dikes that are probably related to the rocks of the quartz-bearing syenite intrusion, and sparse carbonate veins. Tables 1-3 list modal compositions of rock samples from the complex at Rainy Creek.

The complex at Skalkaho (fig. 3) also comprises a bimodal suite of rocks, an ultramafic component consisting of several types of pyroxenite and mafic pegmatite, and a leucocratic component consisting chiefly of alkali-feldspar syenite. Some of the pyroxenites have cumulus textures. Trachyte dikes and carbonate veins intersect many of the rocks. The ultramafic rocks contain vermiculite. Tables 4 and 5 list modal compositions of rock samples from the complex at Skalkaho.

Quartz alkali-feldspar syenite, alkali-feldspar syenite, and nepheline-bearing alkali-feldspar syenite are exposed in road cuts through the complex at Haines Point (fig. 4) and are the principal lithologies of cores drilled in the complex as part of a base- and precious-metal exploration program conducted by Burlington Northern in 1981. No ultramafic rocks are exposed at Haines Point, but an aeromagnetic map prepared by Kleinkopf and others (1972) shows a 400- to 500-gamma anomaly directly over the complex suggesting the possibility that ultramafic rocks occur beneath the syenite. Table 6 lists modal compositions of Haines Point syenite samples.

The complex at Bobtail Creek (fig. 5) consists chiefly of coarse-grained, trachytoid-textured leucocratic rocks with compositions ranging from syenitic to monzodioritic. Subordinate amounts of biotite shonkinite are found along the southwestern part of the syenite intrusion. Table 7 lists modal compositions of syenite and shonkinite samples from the complex at Bobtail Creek.

A wide variety of leucocratic rocks occur in the complex at Warland Creek (fig. 6), including syenite, quartz syenite, quartz monzonite, granite, and alkali-feldspar granite. Some of the rocks contain crystals of augitic clinopyroxene that are zoned outward to aegirine-augite. The presence of the alkali pyroxene qualifies these rocks as alkaline (Sorensen, 1974, p. 7). These rocks are cut by dikes of similar rock types and by small gold- and silver-bearing quartz veins. Table 8 lists modal compositions of leucocratic rock samples from the complex at Warland Creek.

GEOCHEMISTRY

Two aspects of the geochemical compositions of the rocks from the northwestern Montana alkaline complexes are illustrated, the plots of agpaitic index against weight percent SiO_2 (fig. 7) and plots of chondrite-normalized rare-earth-element (REE) data (figs. 8-17).

The plots of agpaitic index (Na+K/Al) against weight percent SiO_2 for all the analyzed rocks (tables 9-11) mostly fall in the alkali basalt family field. The major exceptions are the Rainy Creek pyroxenites and most of the Skalkaho pyroxenite cumulates, which fall in the nephelinite family field, and the quartz-rich leucocratic rocks from the complex at Warland Creek, which fall in the subalkaline rocks field.

Figures 8-17 illustrate chondrite-normalized patterns of the REE data contained in tables 12-14. The chondrite values used for normalizing the REE data are those given in Boynton (1984, p. 91). Certain elements, terbium, dysprosium, thalium, and ytterblum are not included in the patterns because of the difficulties in producing accurate analytical results for these elements at the low end of their detection intervals (J.G. Crock, personal commun., 1986).

Further interpretation of the analytical data will be presented in future publications. Future papers will also discuss the implications of radium/strontium (Rb/Sr) and samarium/neodymium (Sm/Nd) studies on the origins of these same complexes; these isotopic results stem from cooperative studies with Kiyoto Futa of the Branch of Isotopic Geology.

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The following people provided access to mining properties and to drill core: R.J. Kujawa, consulting for Zonolite Division of W.R. Grace and Company at Rainy Creek, Marti Stomberg of Western Vermiculite at Skalkaho, R.E. Harris, formerly of Burlington Northern's Energy and Minerals Department, at Haines Point, and Mrs. Elizabeth Daniels of Victor, Mont., holder of claims adjacent to the Zonolite property at Rainy Creek.

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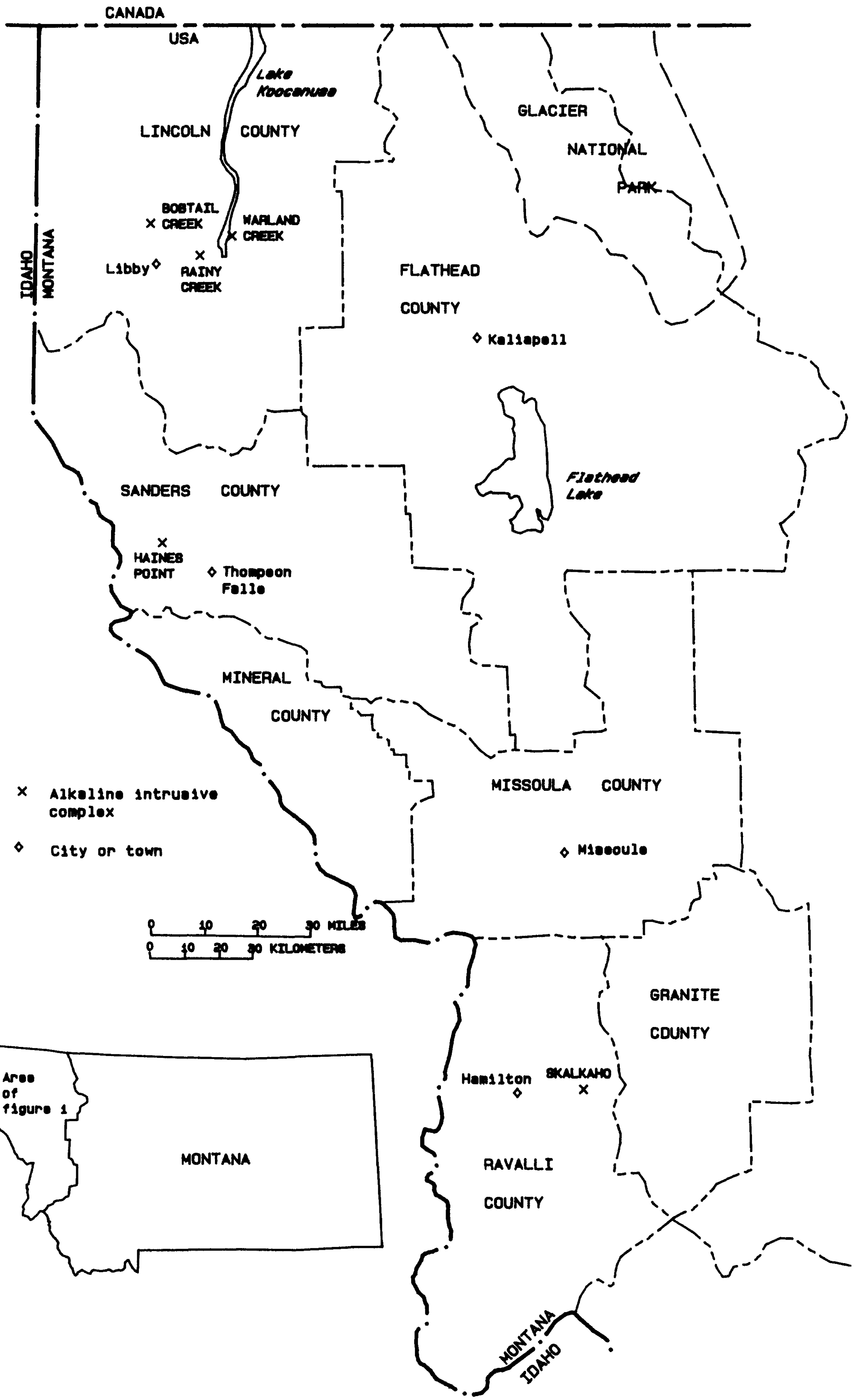

Figure 1. Map showing the locations of alkaline intrusive complexes in northwestern Montana.

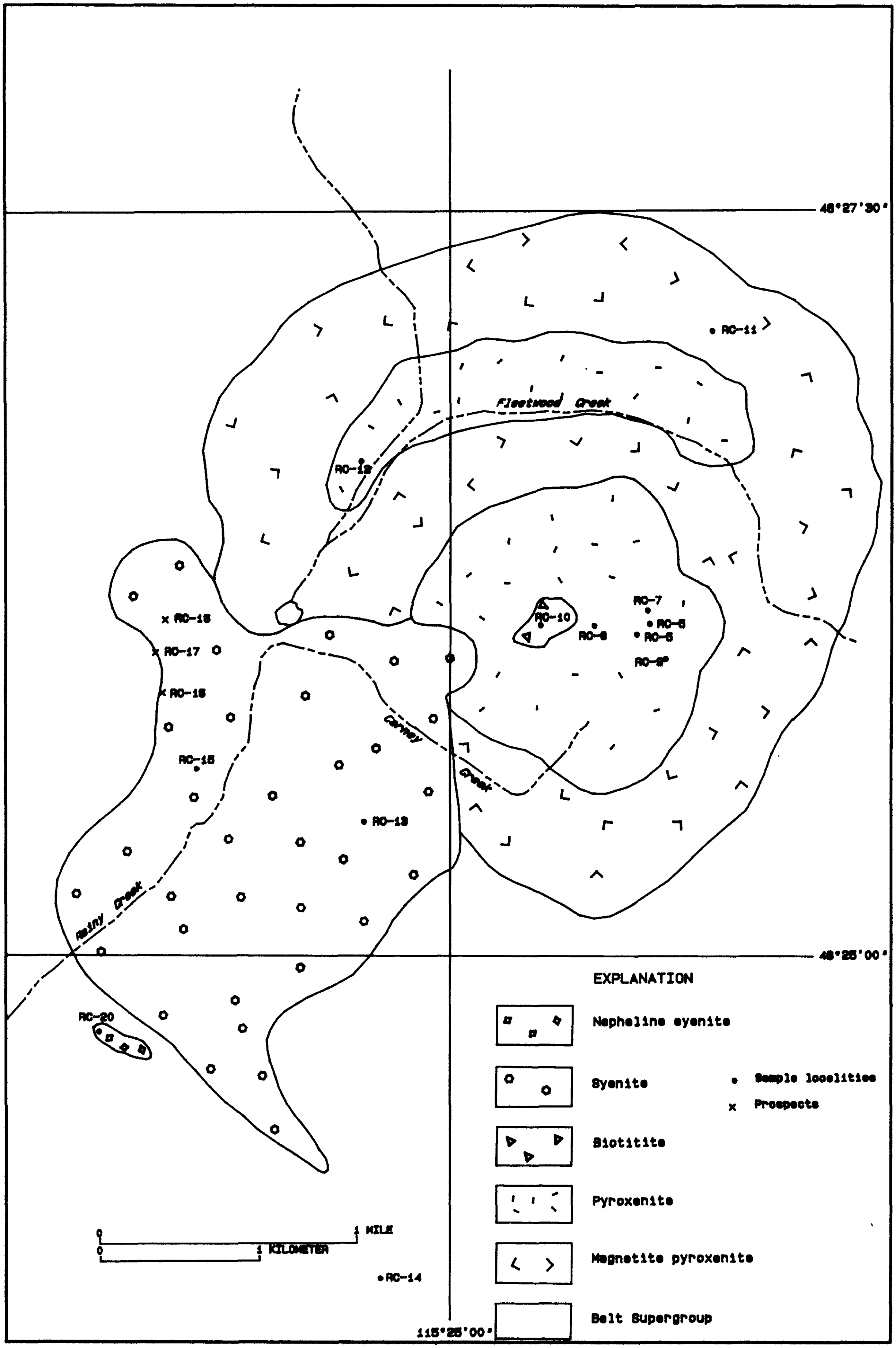

Figure 2. Geologic map of the alkaline intrusive complex at Rainy Creek, Lincoln County, Montana, modified from Boettcher (1966).

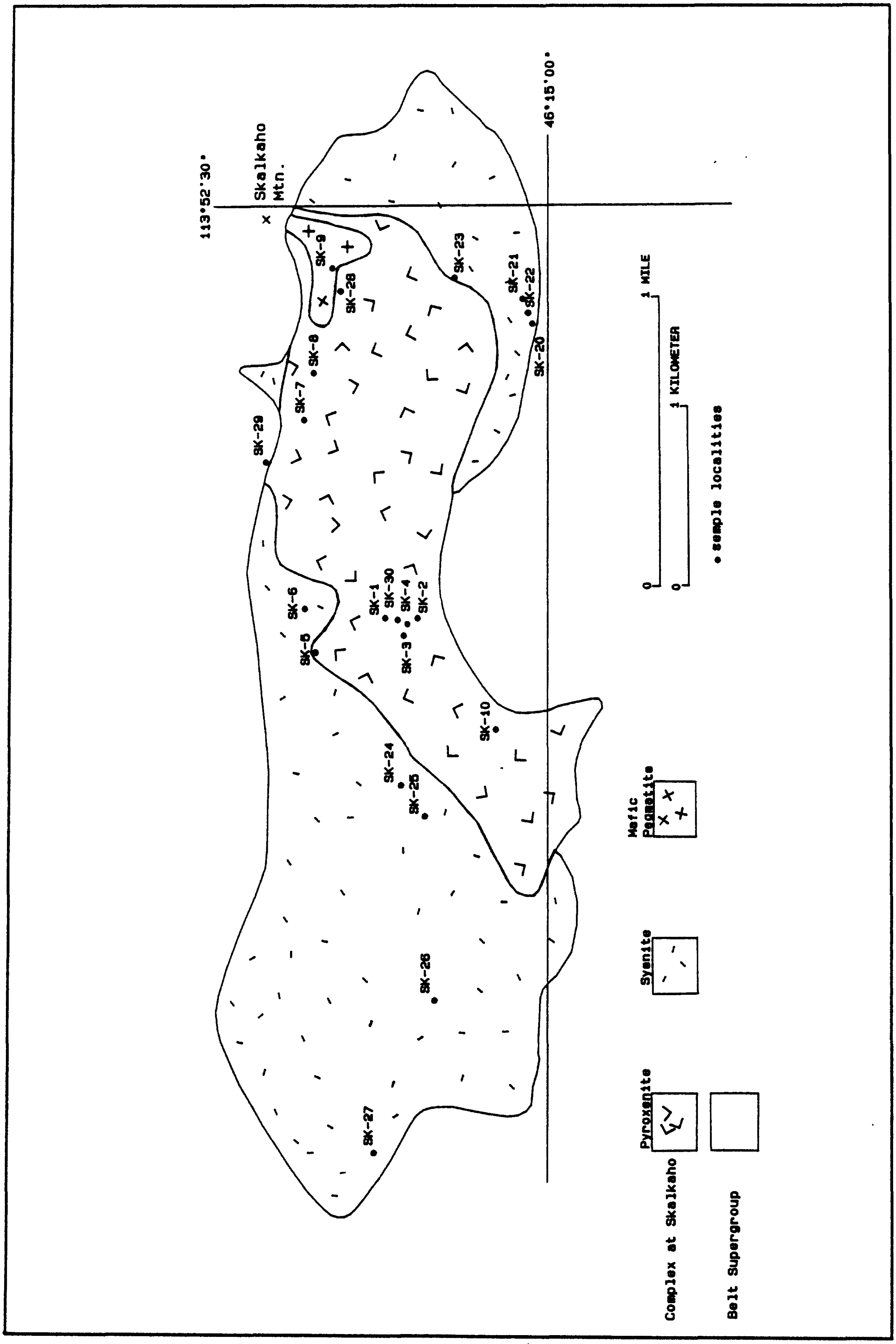

Figure 3. Geologic map of the alkaline intrusive complex at Akalkaho, Ravalli County, Montana, modified from Lelek (1979, p. 11).

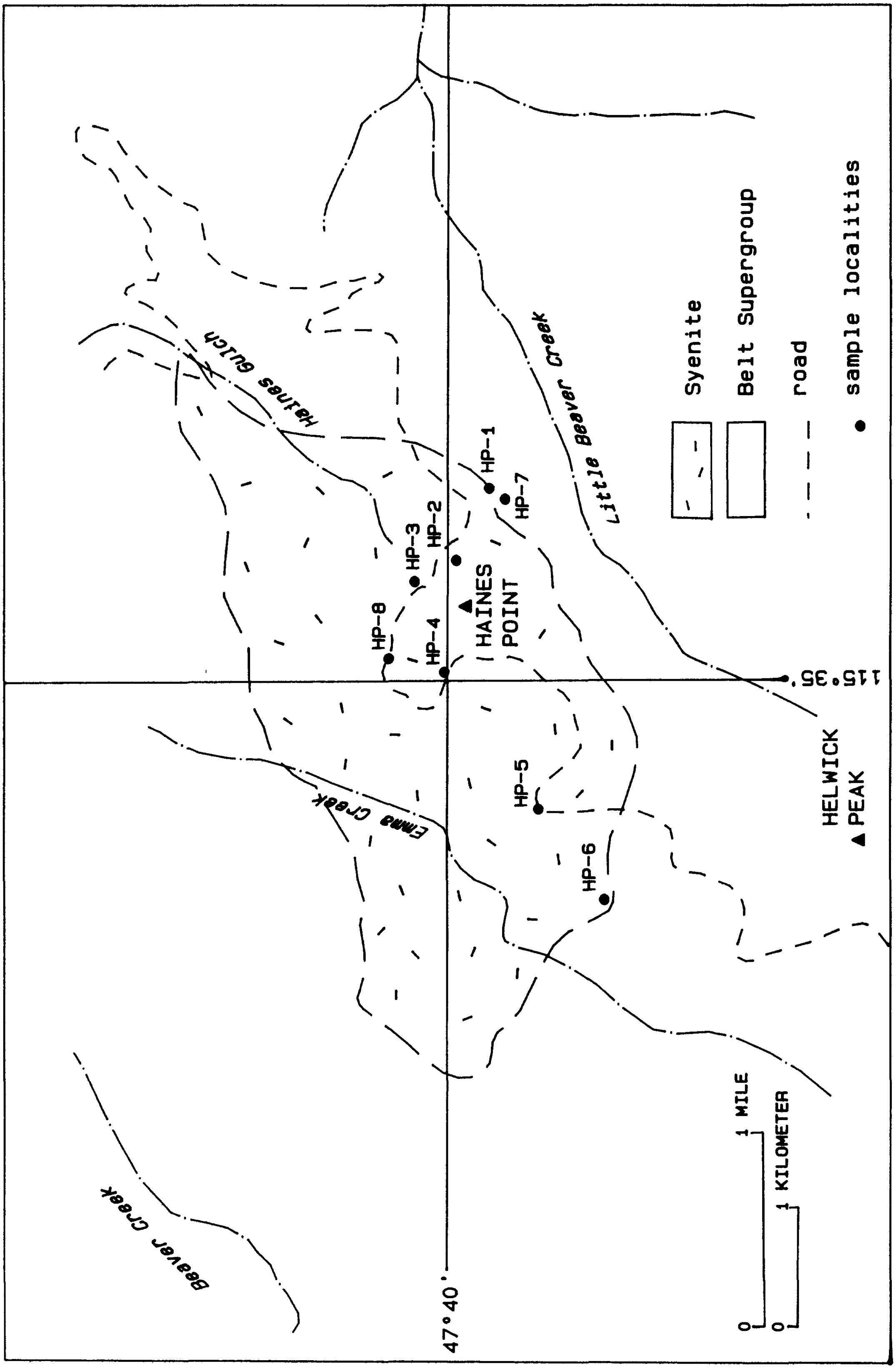

Figure 4. Geologic map of the alkaline intrusive complex at Haines Point, Sanders County, Montana, modified from Harrison and others (1986).

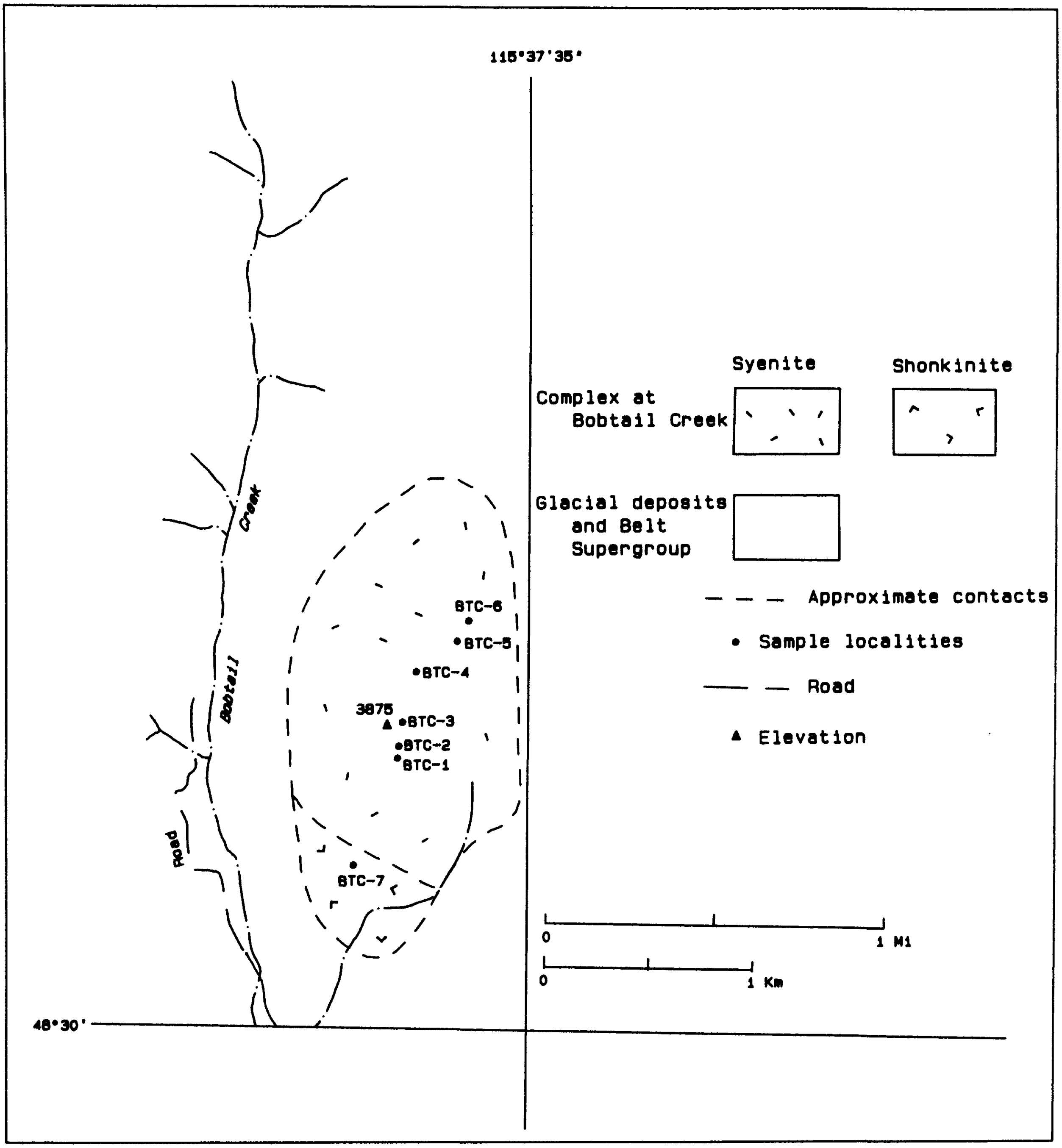

Figure 5. Geologic sketch map of the alkaline intrusive complex at Bobtail Creek, Lincoln County, Montana.

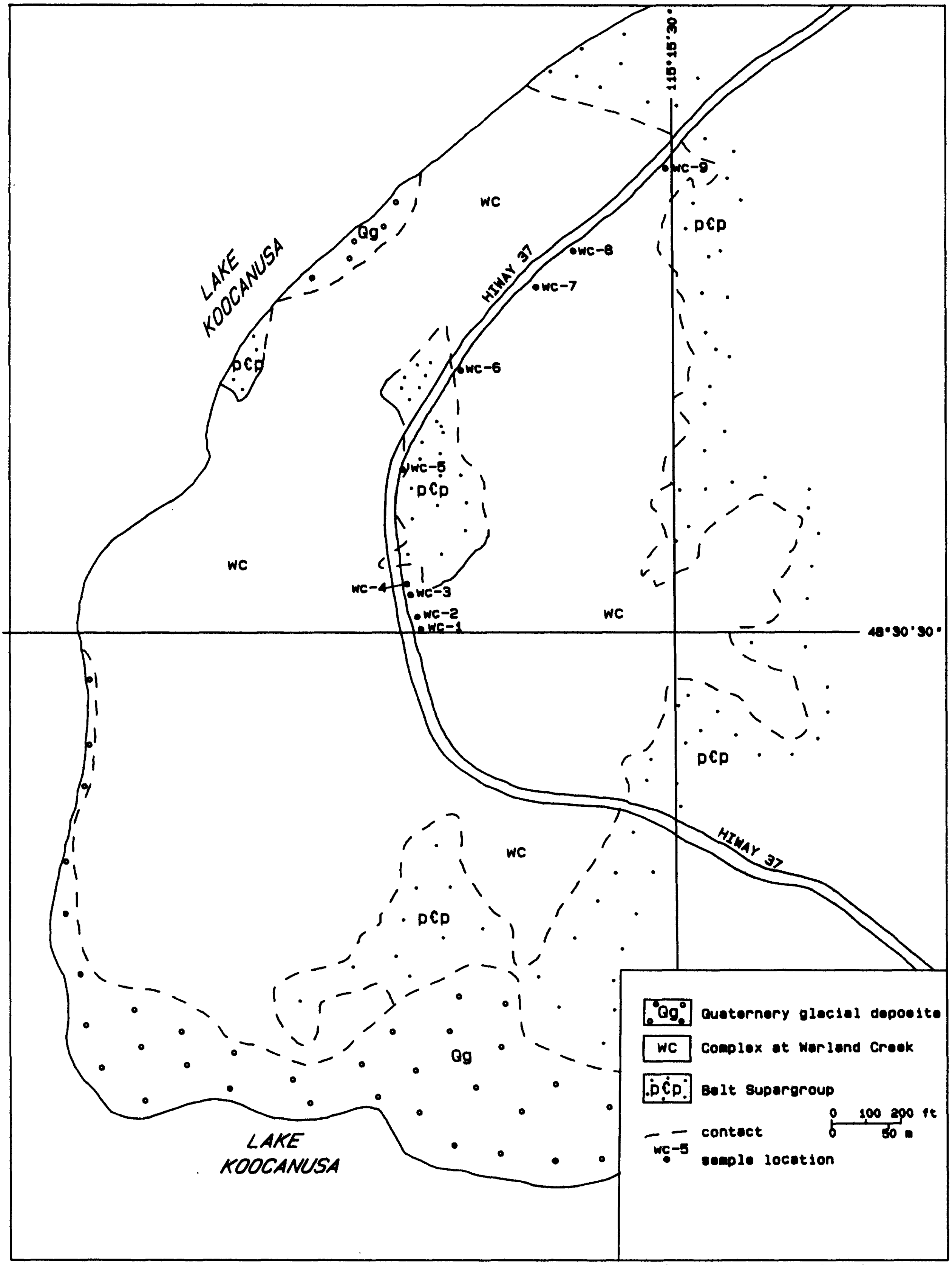

Figure 6. Geologic map of the complex of leucocratic rocks at Warland Creek. Modified from Fleshman and Siegman (1982, plate 11).

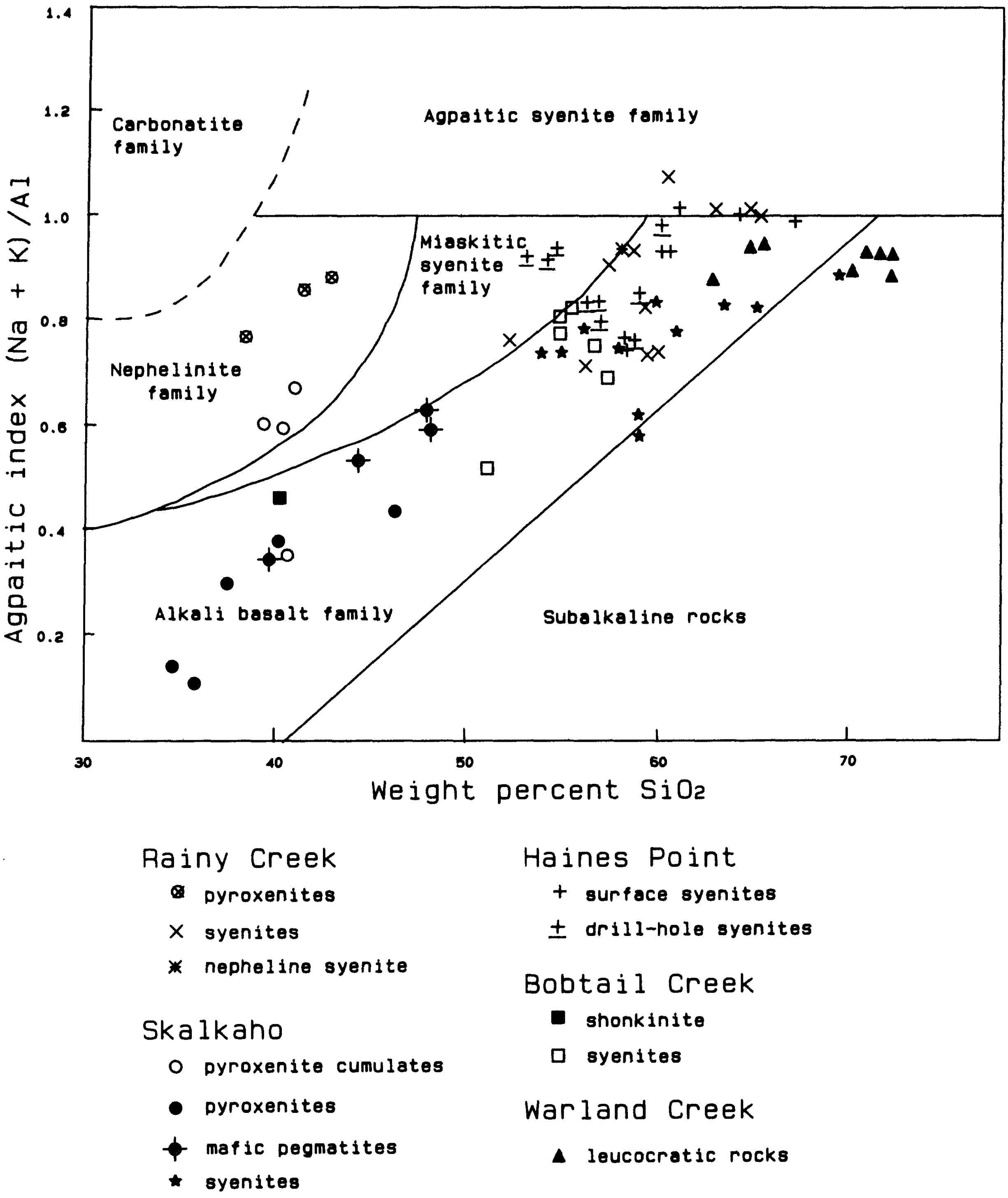

Figure 7. Agpaitic index-silica diagram for alkaline rocks; modified from Currie (1976, p. 7).

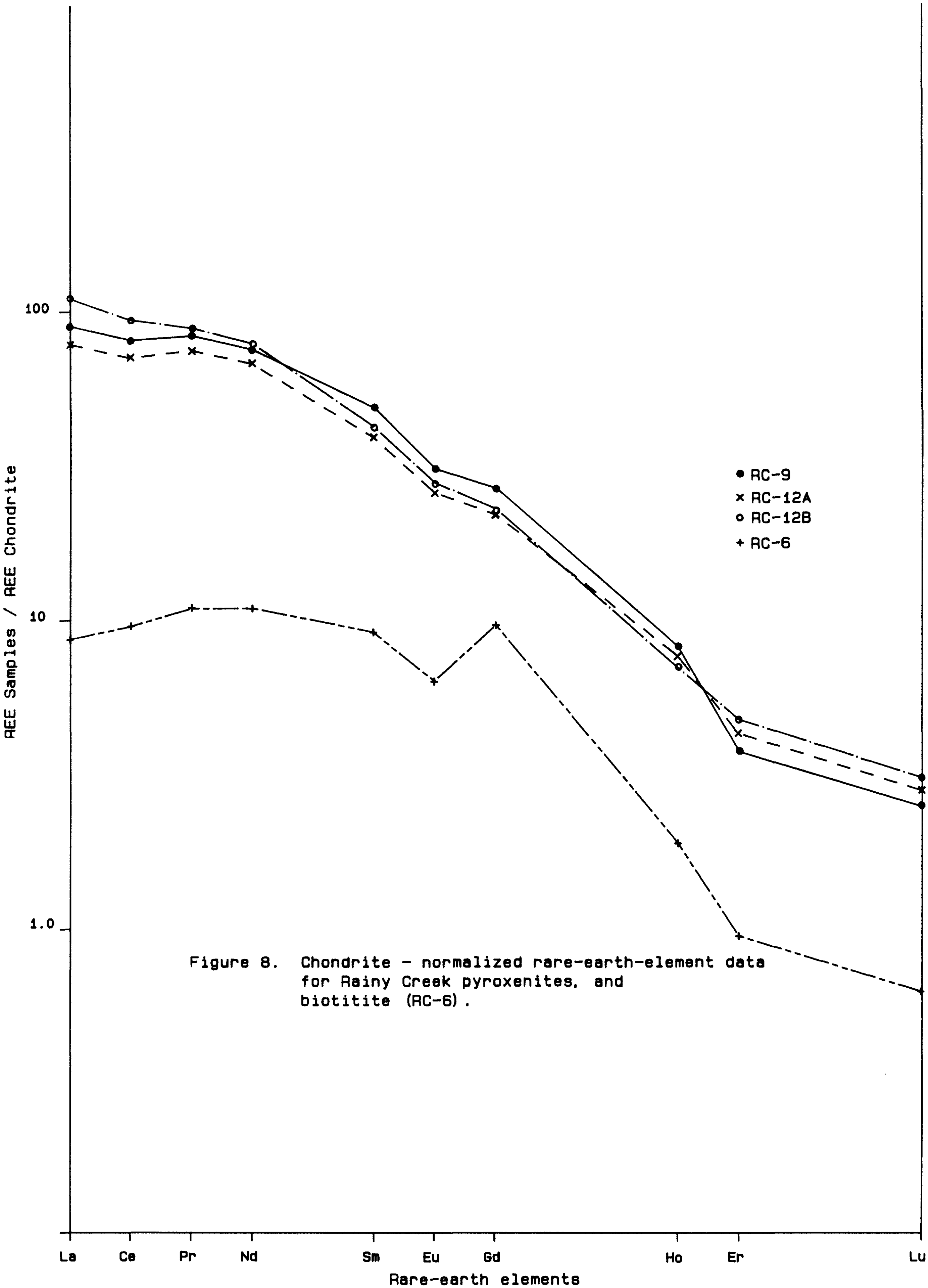

Figure 8. Chondrite - normalized rare-earth-element data for Rainy Creek pyroxenites, and biotitite (RC-6).

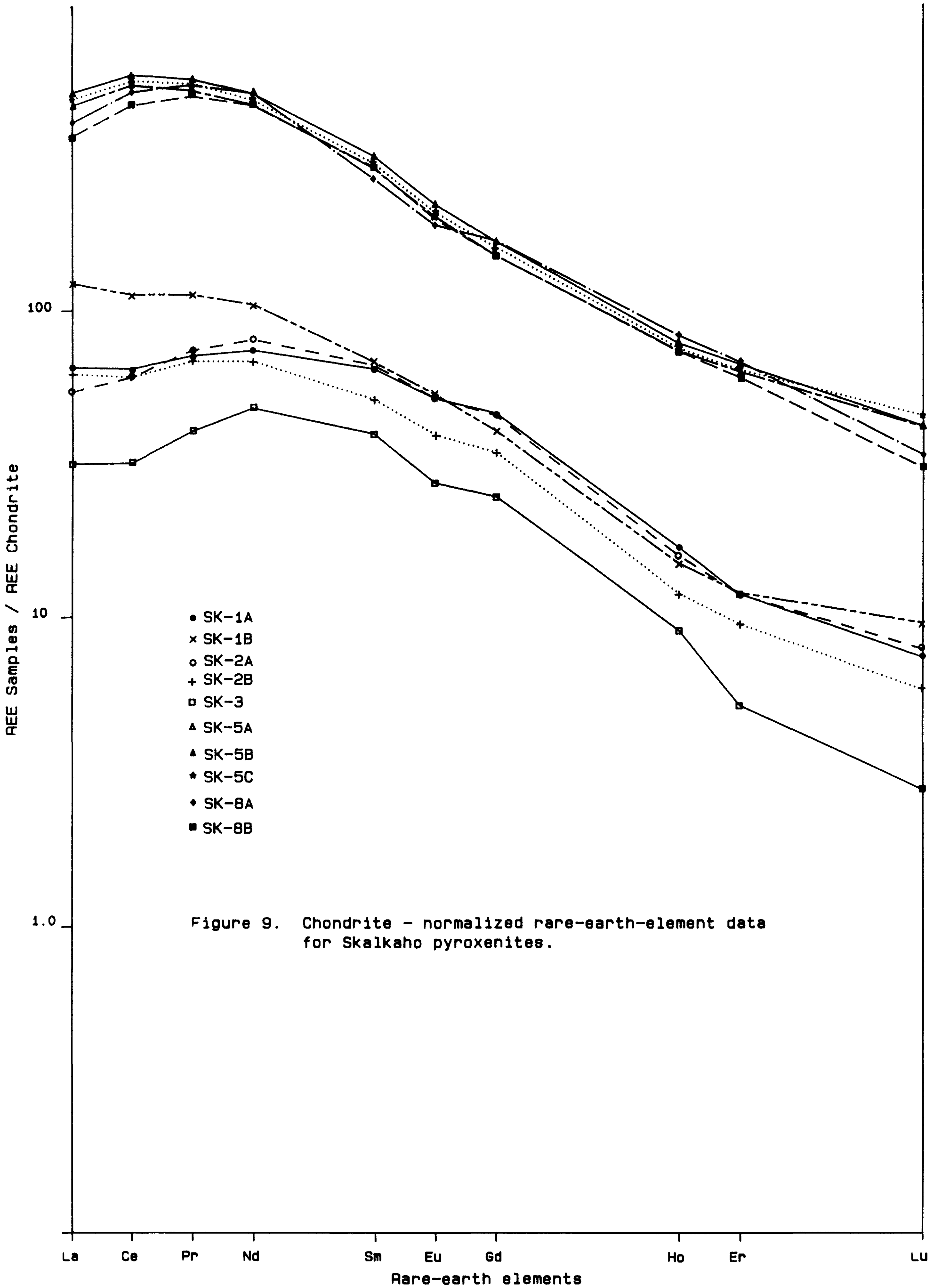

Figure 9. Chondrite - normalized rare-earth-element data for Skalkaho pyroxenites.

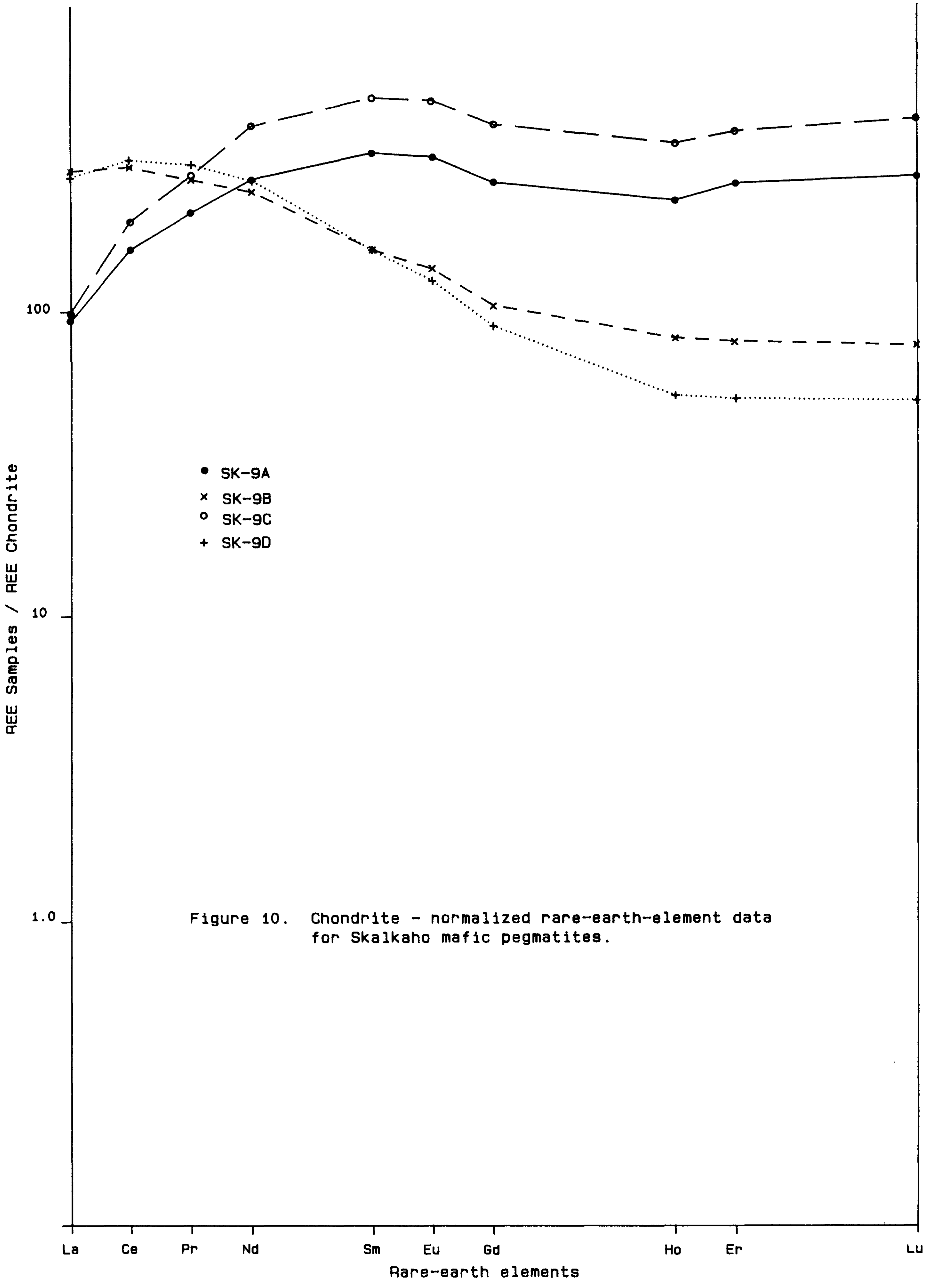

Figure 10. Chondrite - normalized rare-earth-element data for Skalkaho mafic pegmatites.

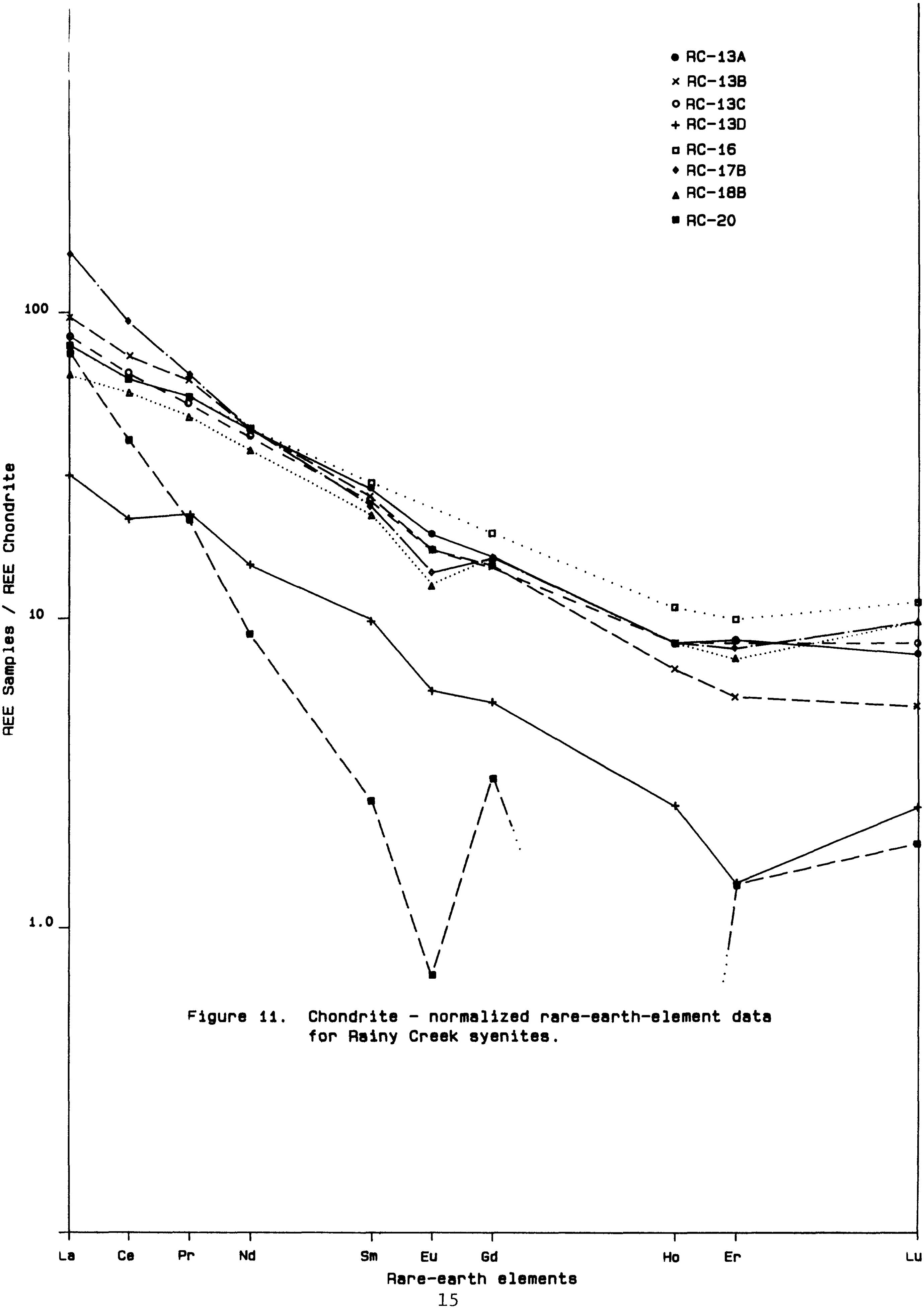

Figure 11. Chondrite - normalized rare-earth-element data for Rainy Creek syenites.

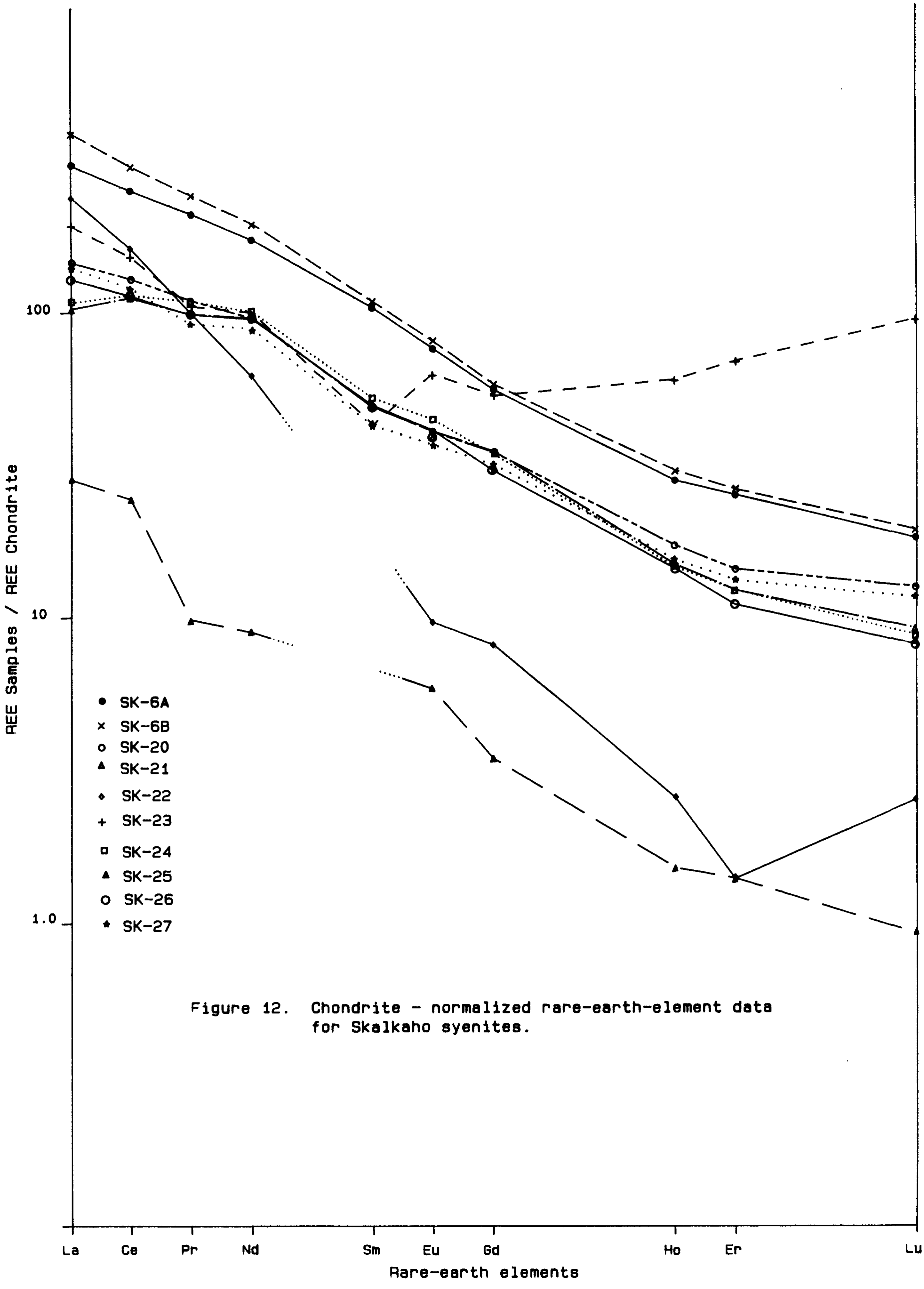

Figure 12. Chondrite - normalized rare-earth-element data for Skalkaho syenites.

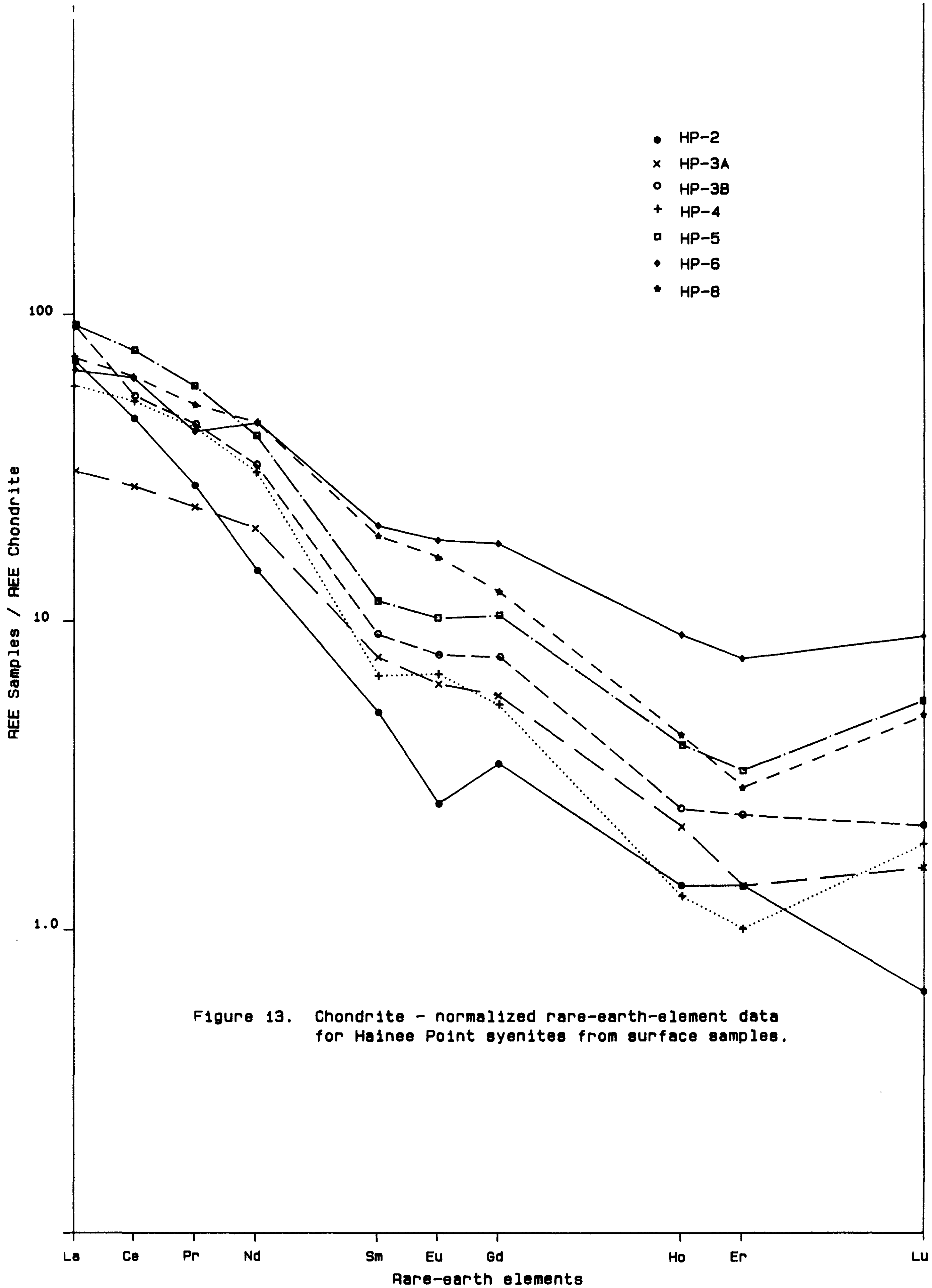

Figure 13. Chondrite - normalized rare-earth-element data for Hainee Point syenites from surface samples.

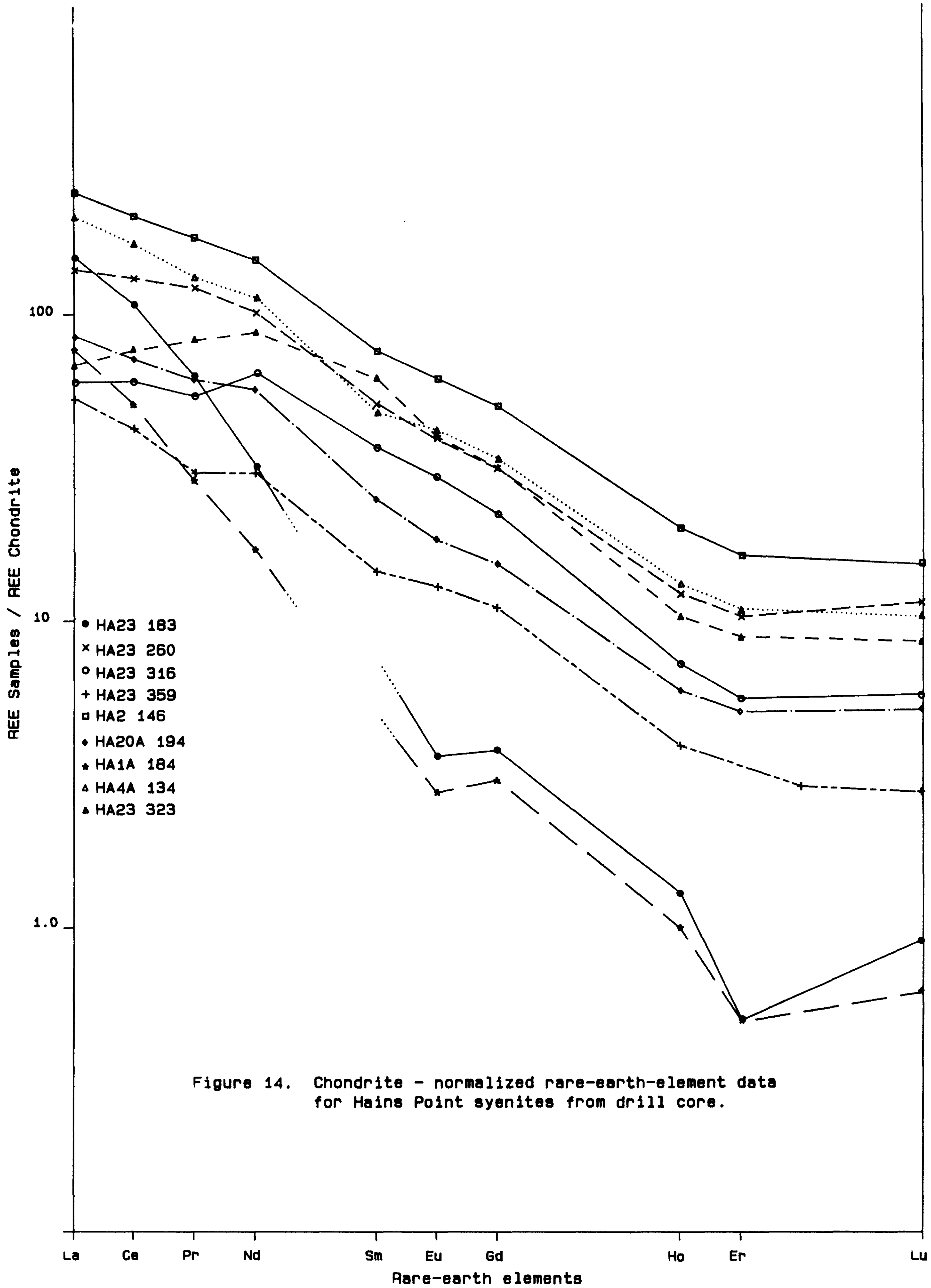

Figure 14. Chondrite - normalized rare-earth-element data for Hains Point syenites from drill core.

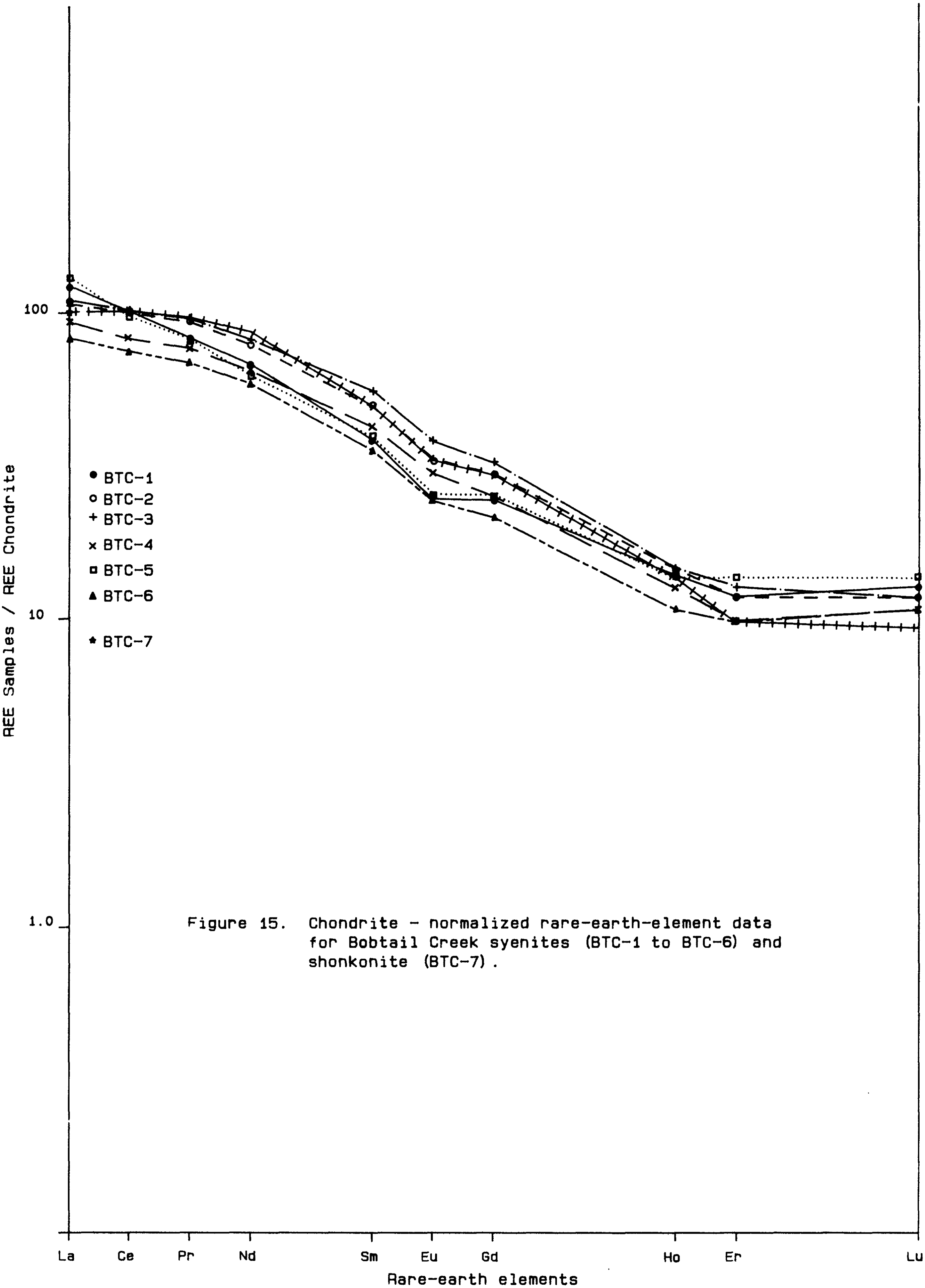

Figure 15. Chondrite - normalized rare-earth-element data for Bobtail Creek syenites (BTC-1 to BTC-6) and shonkonite (BTC-7).

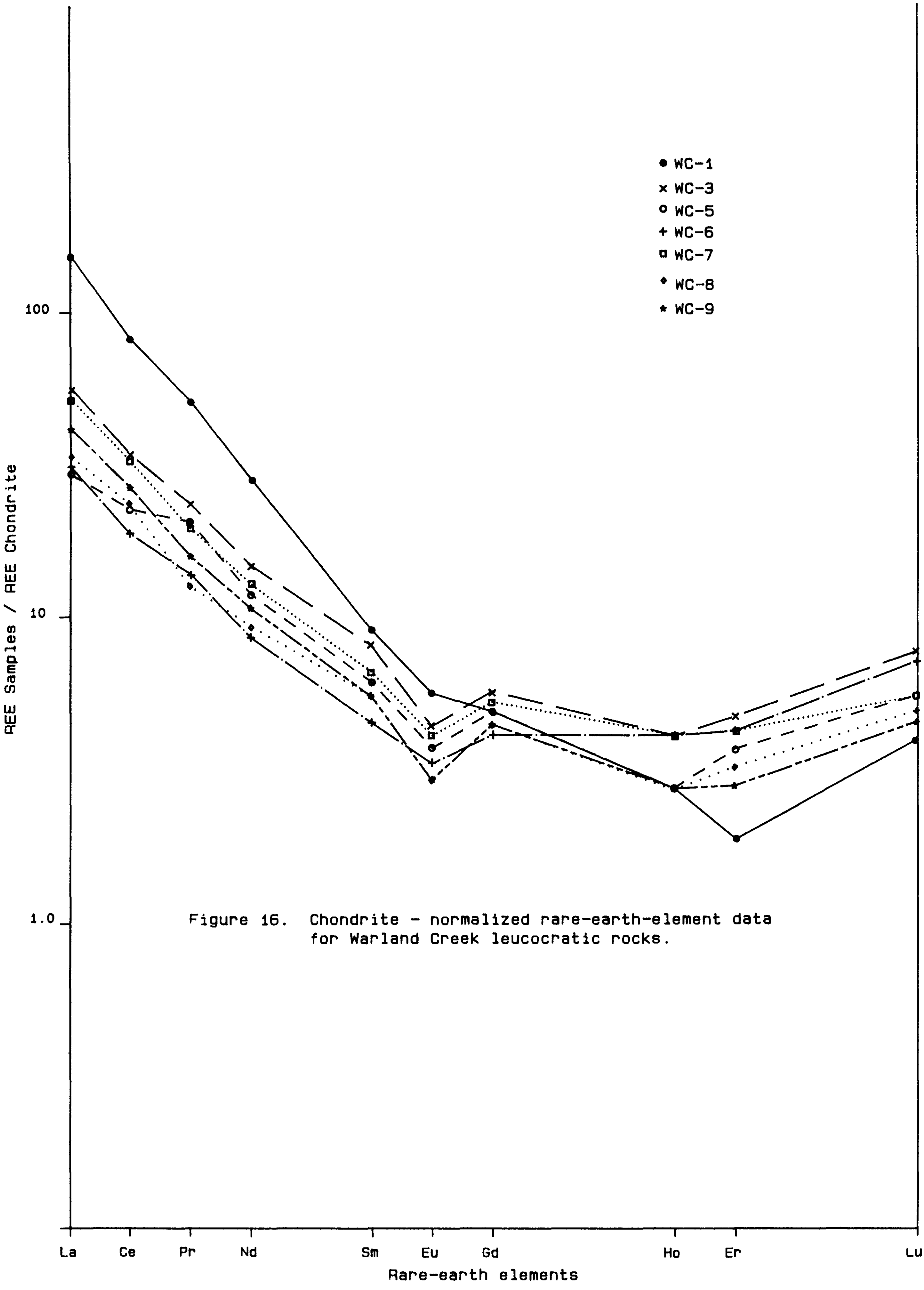

Figure 16. Chondrite - normalized rare-earth-element data for Warland Creek leucocratic rocks.

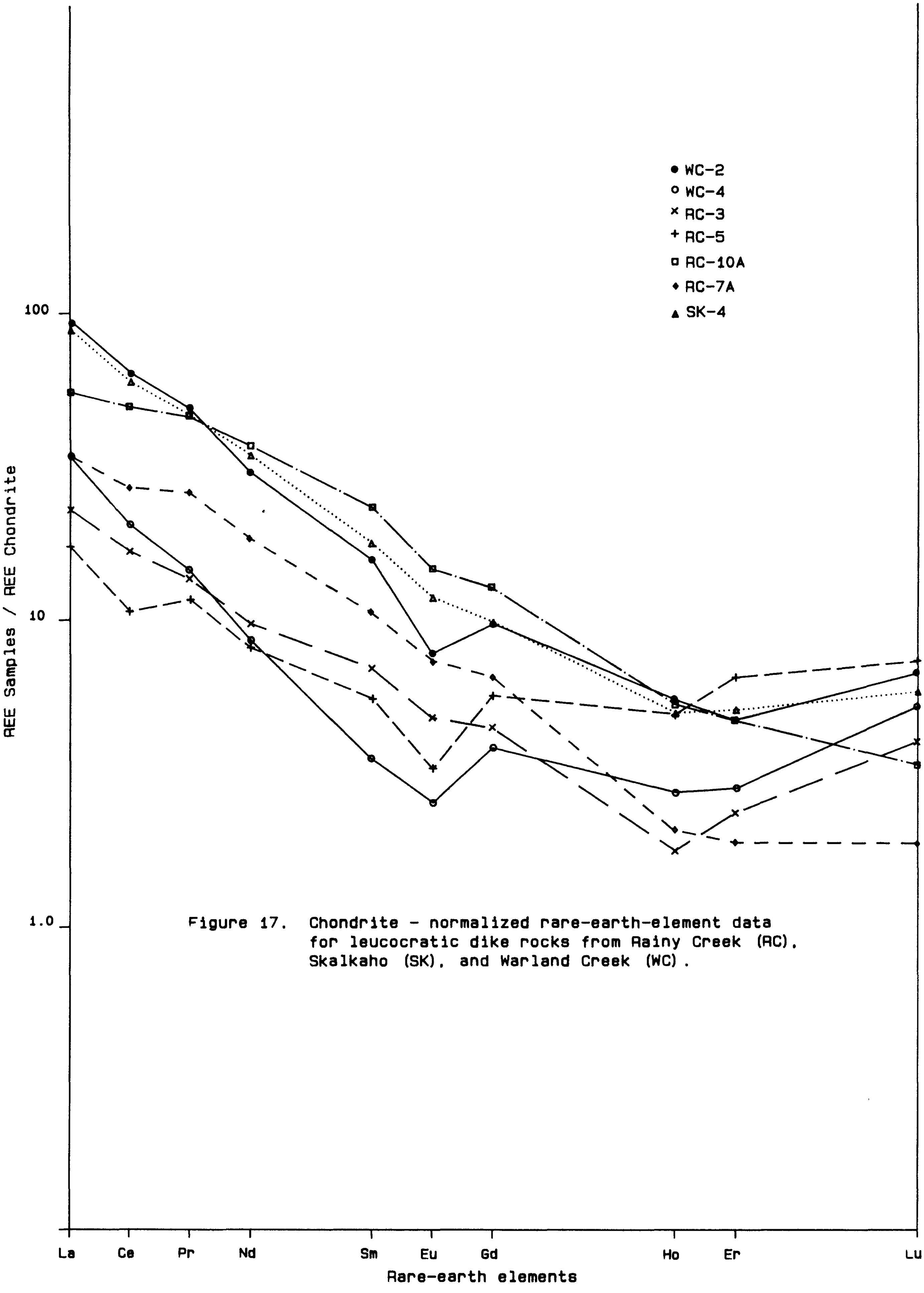

Figure 17. Chondrite - normalized rare-earth-element data for leucocratic dike rocks from Rainy Creek (RC), Skalkaho (SK), and Warland Creek (WC).

Table 1.--Modal composition, in volume percent, of pyroxenites from the complex at Rainy Creek

[---, not detected; tr, <0.1 percent]

	RC-9	RC-12A	RC-12B	Pyroxenite[1]
Clinopyroxene	90.6	46.6	56.7	36.8-71.5
Biotite	7.6	30.8	33.8	0.3-28.8
Fluorapatite	0.2	10.9	6.1	1.4- 9.0
Sphene	---	1.5	0.3	0.1- 2.3
Magnetite	---	10.2	3.1	4.2-29.5
Vermiculite(?)	1.6	---	---	(incl. in biotite)
Carbonate	---	tr	---	---
Sulfides	---	tr	---	---
Total counts	1034	964	1119	16 samples

[1]Magnetite pyroxenites, Boettcher (1967, Table 5, p. 538); 3 samples contain 2.8-10.0 percent garnet, 1 sample contains 1.4 percent plagioclase, and 1 sample contains 35.9 percent orthoclase.

Table 2.--Modal composition, in volume percent, of syenite samples from the complex at Rainy Creek

[---, not detected; tr, <0.1 percent]

	RC-10B	RC-13B	RC-13C	RC-13D	RC-20
Potassic feldspar	93.9	82.9	68.3	83.0	17.9
Nepheline	---	---	---	---	30.0
Clinopyroxene	3.9	---	11.8	15.0	2.1
Plagioclase	0.9	0.8	0.6	1.9	49.3
Sphene	1.0	-	1.1	tr	0.1
Fluorapatite	0.2	0.2	0.5	0.1	---
Magnetite	0.1	2.9	1.2	---	0.2
Cancrinite	---	---	---	---	0.4
Zircon	---	---	---	---	---
Muscovite	---	12.8	---	---	---
Biotite	---	0.4	0.7	tr	tr
Garnet-	---	---	1.6	---	---
Amphilbole	---	---	0.5	---	---
Carbonate	---	---	0.2	---	---
Total counts	1048	516	1079	1063	1035

Table 3.--Modal composition, in volume percent, of samples from syenite dikes from the complex at Rainy Creek

[---, not detected; tr, <0.1 percent]

	RC-3	RC-5	RC-7A	RC-7B	RC-10A
Quartz	0.2	---	---	---	---
Plagioclase	19.1	---	8.6	7.2	5.5
Potassic feldspar	66.0	84.4	82.6	79.9	80.8
Clinopyroxene	3.1	---	7.6	12.7	11.1
Magnetite	1.0	---	---	---	0.1
Sphene	0.1	---	0.8	tr	2.1
Apatite	---	---	0.1	0.2	0.3
Carbonate	0.5	---	---	---	---
Biotite	---	---	0.3	---	---
Muscovite	---	15.3	---	---	---
Zircon	---	---	---	tr	0.1
Ferric oxide aggregate	---	0.3	---	---	---
Total counts	959	531	1165	1087	1026

Table 4.--Modal composition, in volume percent, of pyroxenite samples from the complex at Skalkaho

[---, not detected; tr, <0.1 percent]

	SK-1A	SK-1B	SK-2A	SK-2B	SK-5A	SK-5B	SK-5C	SK-8A	Anhydrous[1] pyroxenite	Mica[1] pyroxenite	Amphibole[1] pyroxenite
Clinopyroxene	66.2	57.1	69.5	63.2	59.2	62.7	65.0	58.0	98-99	65-90	4-86
Plagioclase	9.0	---	---	---	---	tr	---	---	---	3-8	2-5
Potassic feldspar	---	---	---	---	5.8	8.1	5.8	---	---	---	
Amphibole	7.7	28.1	7.1	1.4	14.5	9.1	10.4	19.9	---	---	0-45
Biotite	1.2	---	5.0	22.4	---	---	0.2	---	---	5-30	0-2
Sphene	1.4	1.4	0.9	0.4	9.7	9.2	10.4	12.3	0-1	tr	0-15
Apatite	2.9	4.6	1.5	4.0	3.7	2.2	3.2	2.8	1	tr	tr-5
Magnetite	5.15	8.8	15.7	8.6	6.9	8.4	5.0	7.0	tr	tr	tr-5
Epidote	6.5	---	0.3	---	tr	0.3	---	---	tr	tr	0-45
Garnet	---	---	---	---	---	---	---	---	tr	---	0-4
Sulfide	---	---	tr	---	---	---	---	---	---	---	---
Total counts	829	1041	868	1037	1291	782	618	1005	2 samples	4 samples	18 samples

[1]Data from Lelek (1979, table 1a, p. 21).

Table 5.--Modal composition, in volume percent, of syenite samples from the complex at Skalkaho

[---, not detected; tr, <0.1 percent]

	SK-6A	SK-6B	SK-20	SK-24	SK-25	Syenites[1]
Microperthite feldspar	68.9	62.4	75.3	70.7	76.5	40-89
Clinopyroxene	19.8	22.1	3.7	18.3	7.5	0-7
Amphibole	4.3	5.7	9.5	1.9	3.3	0-9
Biotite	---	---	0.3	---	---	tr
Plagioclase	0.1	3.8	6.9	1.7	9.6	0-30
Epidote	0.7	0.2	1.0	1.1	0.9	tr-4
Sphene	3.4	3.3	0.6	2.6	1.5	0-2
Apatite	0.7	1.2	0.6	0.7	0.3	0-1
Zircon	---	---	tr	---	---	tr
Sulfides	2.1	---	---	---	---	---
Garnet	---	---	1.7	---	tr	0-tr
Magnetite	---	1.3	0.4	3.0	0.4	tr-1
Total counts	995	912	1084	1107	1166	4 samples

[1]Data from Lelek (1979, table 1b, p. 21).

Table 6.--Modal composition, in volume percent, of syenite samples from the complex at Haines Point

[---, not detected; tr, <0.1 percent; ?, uncertain]

	HP-2[1]	HP-3A	HP-3B	HP-4	HP-5	HP-6	HP-8	HA1A-184	HA2-146.7	HA20A-194	HA4A-134	HA23-183.5	HA23-260	HA23-316	HA23-323	HA23-359.4
Potassic feldspar	80.9	95.2	86.8	81.1	75.2	42.8	85.5	86.2	65.1	78.8	73.6	70.6	81.9	92.6	85.9	81.8
Quartz	---	---	---	---	0.4	10.1	---	---	---	---	---	---	---	---	---	---
Plagioclase	0.8	2.0	6.8	2.4	19.3	28.3	1.4	0.6	0.9	0.7	0.5	0.2	1.1	0.6	tr	0.4
Garnet	---	---	---	0.2?	---	---	---	---	12.7	0.3	8.5	7.2	2.9	2.0	5.7	4.2
Biotite	tr	1.8	3.1	0.1	---	0.1	0.1	7.1	15.7	17.6	11.8	4.8	2.9	1.7	1.2	7.3
Nepheline	---	---	---	---	---	---	---	---	---	---	---	---	---	---	6.7	---
Muscovite	16.5	0.1	1.3	0.2	---	0.2	0.6	2.0	1.0	0.4	1.4	15.7	6.2	2.1	---	4.0
Magnetite	1.8	0.8	1.9	2.8	0.1	0.3	0.3	2.6	1.6	1.0	1.2	1.2	4.4	0.4	tr	1.4
Apatite	tr	0.1	0.1	tr	tr	tr	0.1	tr	0.7	0.2	0.5	tr	---	tr	0.3	tr
Sphene	---	---	---	1.1	0.1	0.6	0.6	0.3	0.7	0.1	0.6	---	0.1	0.6	0.2	0.2
Aegirine-augite	---	---	tr	12.1	4.9	7.6	11.4	1.2	1.6	0.9	1.9	0.3	---	---	tr	---
Carbonate	---	---	---	---	---	---	---	---	---	---	---	0.5	0.5	tr	tr	0.7
Epidote	---	---	tr	---	---	---	---	---	---	---	tr	---	---	---	---	---
Total counts	1070	1017	1116	1134	1027	1032	1086	1038	1065	1040	1071	1032	1030	1027	1050	1053

[1]HP- samples are surface sample, HA samples are drill-core samples.

Table 7.--Modal composition, in volume percent, of syenite (BTC-1 TO BTC-6) and shonkinite (BTC-7) from the complex at Bobtail Creek

[---, not detected; tr, <0.1 percent]

	BTC-1	BTC-2	BTC-3	BTC-4	BTC-5	BTC-6	BTC-7
Potassic feldspar	54.0	69.8	62.2	64.5	48.2	20.5	15.8
Plagioclase	26.3	6.6	7.4	4.3	35.8	45.3	---
Clinopyroxene	13.0	17.5	21.9	12.0	5.0	12.5	66.1
Amphibole	1.6	0.2	0.2	11.9	7.6	8.4	---
Epidote	---	---	0.1	---		0.3	---
Biotite	0.2	0.1	0.2	0.2	0.4	7.7	0.8
Magnetite	2.5	4.4	4.8	3.0	2.4	3.9	13.3
Sphene	1.4	1.1	2.0	0.3	0.6	0.9	0.6
Apatite	1.0	0.2	1.2	0.8	tr	0.5	3.4
Chlorite	---	tr	---	---	tr	---	---
Zircon	tr	0.1	tr	---	tr	---	---
Mermykite	tr	---	---	---	tr	---	---
Total counts	1157	903	1007	992	843	766	959

Table 8.--Modal composition, in volume percent, of leucocratic rocks from the complex at Warland Creek

[---, not detected; tr, <0.1 percent]

	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6	WC-7	WC-8	WC-9
Quartz	---	30.0	0.9	-	5.0	16.6	16.7	14.4	22.4
Microcline	66.4	57.7	78.0	49.1	63.7	37.2	36.5	41.1	34.2
Plagioclase	27.3	3.6	17.2	48.2	26.8	43.4	43.3	41.8	39.8
Biotite	0.6	0.2	0.1	---	0.5	1.2	1.0	0.6	0.8
Garnet	3.4	---	0.8	---	tr	0.6	1.6	0.5	---
Amphibole	0.2	8.2	2.3	---	---	---	tr	---	---
Clinopyroxene	---	---	---	2.3	3.3	0.9		1.5	2.4
Sphene	tr	tr	0.3	0.2	0.2	---	0.2	0.1	0.2
Zircon	0.2	---	tr	0.1	tr	tr	---	---	---
Magnetite	0.1	0.3	0.3	0.1	0.3	tr	0.4	---	0.2
Apatite	tr	---	0.1	tr	tr	0.1	---	---	tr
Carbonate	0.8	---	---	0.2	---	---	---	---	---
Epidote	0.4	---	---	---	tr	---	---	---	---
Chlorite	0.2	---	---	---	---	---	---	---	---
Muscovite	0.4	---	---	---	tr	---	0.3	---	---
Total counts	1024	1017	1075	1031	1015	1033	1028	1032	1035

Table 9.—Whole-rock chemical analyses (in percent) and normative calculations of ultramafic rocks and mafic pegmatites from alkaline complexes in northwestern Montana

[—, not detected]

	Rainy Creek pyroxenites					Skalkaho pyroxenites									Skalkaho mafic pegmatites				Bobtail Creek shonkinite
	RC-9	RC-12A	RC-12B	RCPY-64[1]	Pyroxenite[3]	SK-1A	SK-1B	SK-2A	SK-2B	SK-3	SK-5A	SK-5B	SK-5C	SK-8B	SK-9A	SK-9B	SK-9C	SK-9D	BTC-7
								Whole-rock chemical analyses											
SiO_2	42.8	38.5	41.5	44.87	37.47	37.4	46.3	35.7	39.3	34.6	40.7	39.3	39.9	39.4	44.2	47.5	38.8	47.8	40.0
Al_2O_3	3.2	3.0	3.4	6.35	2.86	7.46	7.4	6.87	6.61	4.3	5.51	5.29	5.76	5.84	6.61	7.87	5.93	6.78	6.47
Fe_2O_3	8.15	12.09	10.45	4.96	11.77	11.55	6.60	15.02	9.74	17.00	14.50	13.59	12.02	9.94	14.0	8.24	17.74	7.88	13.9
FeO	5.71	7.84	7.78	2.79	7.83	8.77	6.39	8.71	7.97	9.36	7.65	10.0	9.25	7.25	4.95	4.46	3.20	6.41	9.45
MgO	13.3	11.7	11.2	17.26	10.12	8.79	8.24	8.35	10.6	9.71	5.43	5.56	5.37	6.29	2.80	5.74	1.40	5.03	6.81
CaO	20.1	20.1	19.6	13.61	21.68	19.2	20.0	19.9	19.5	19.6	17.2	18.0	18.1	19.3	22.0	18.4	26.9	19.1	16.7
Na_2O	.7	.5	.8	.35	.47	.9	1.8	.4	.6	.3	1.4	1.4	1.4	.9	1.8	2.5	1.1	2.3	.87
K_2O	1.58	1.37	1.45	3.26	.93	.68	.32	.17	1.36	.11	1.14	.72	.92	.49	.44	.42	.13	.45	1.46
H_2O	.90	.66	.69	4.06	1.00	.84	1.0	.56	.93	.50	1.07	.61	.66	2.28	.43	.62	.28	.48	1.21
TiO_2	.91	1.02	.89	.88	1.07	2.02	1.04	2.96	1.70	2.07	4.28	4.17	4.64	5.14	2.38	1.95	2.87	2.25	1.49
P_2O_5	2.5	3.2	2.5	1.05	4.33	2.1	1.3	1.5	2.2	2.2	1.0	.97	1.0	1.4	.20	1.1	.30	.69	1.24
MnO	.15	.18	.22	.09	.16	.30	.36	.44	.25	.22	.50	.60	.59	.37	1.17	.47	1.44	.96	.37
CO_2	.34	.18	.24	—	.36	.03	.09	.02	.03	.02	.01	.01	.01	.01	.01	.07	.01	.11	—
Total	100.34	100.34	100.72	99.93[2]	100.77[4]	100.04	100.84	100.60	100.79	99.99	100.30	100.22	99.62	98.61	100.09	99.34	100.10	100.24	99.97
								Normative calculations											
100 $Mg/Mg+Fe^{+2}$	64.4	53.7	52.7			43.7	50.0	4.27	50.8	44.6	35.5	30.1	31.1	40.2	34.9	49.9	25.2	37.8	35.9
D.I.[5]	11.1	8.7	11.4	19.8	6.6	7.3	15.2	2.6	9.1	1.9	20.7	16.5	18.1	13.0	20.6	26.8	9.2	25.0	15.3
Q											1.95	.29	.60	2.04	2.74	2.82		2.87	
Or	2.37		4.58	11.34			1.89				6.78	4.27	5.29	3.01	2.61	2.51	.77	2.67	8.74
Ab							11.01				11.93	11.89	11.97	7.91	15.28	21.43	7.33	19.51	5.59
An	.93	1.90	1.40	6.40	3.06	14.42	11.19	16.44	11.34	10.11	5.42	6.05	6.79	10.85	8.69	9.13	10.88	6.86	9.56
Lc	5.51	6.37	3.13	6.85	4.36	3.18		.79	6.31	.51									
Ne	3.23	2.30	3.67	1.65	2.27	4.16	2.30	1.83	2.75	1.38			1.08		1.01				
Wo	33.72	30.29	32.55	24.20		25.51	33.04	27.55	25.67	27.74	30.84	32.22	32.27	32.98	41.53	31.57	50.43	34.62	27.61
En	27.54	24.24	25.00	20.92	59.81	19.48	20.56	20.79	19.76	23.88	13.62	13.90	13.52	16.26	7.00	14.48	3.49	12.56	17.17
Fs	2.10	2.54	4.12			3.37	5.24		3.18	.13		1.37	.50					3.34	4.15
Fo	4.04	3.50	2.02	16.71		1.81			4.68	.30									
Fa	.34	.40	.37			.34			.83	<.01									
Cs		1.08				2.01		1.96	2.93	2.04									
Mt	11.88	17.59	15.15	7.02	17.40	16.88	9.59	20.92	1.14	24.78	13.98	19.78	17.61	10.05	10.01	10.39	6.71	11.45	20.41
Hm				.15				.59			4.96			3.39	7.14	1.18	13.15		
Il	1.74	1.94	1.69	1.75	1.98	3.87	1.98	5.62	3.23	3.95	8.18	7.95	8.90	10.13	4.54	3.75	5.46	4.28	2.86
Ap	5.96	7.60	5.92	2.54	10.42	5.01	3.08	3.55	5.22	5.24	2.38	2.31	2.39	3.44	.48	2.64	.71	1.64	2.97
Cc	.78	.41	.55		.90	.07	.20	.04	.07	.05	.02	.02	.02	.02	.02	.16	.02	.25	
DI Wo	33.72	30.29	32.55	24.20		25.51	28.40	24.05	25.67	27.74	15.76	17.29	16.07	18.82	8.10	16.76	4.04	17.47	23.52
DI En	27.54	24.24	25.00	20.92		19.48	20.56	20.79	19.76	23.88	13.62	13.90	13.52	16.26	7.00	14.48	3.49	12.56	17.17
DI Fs	2.10	2.54	4.12			3.37	5.24		3.18	.13		1.37	.50					3.34	4.15
OL Fo	4.04	3.50	2.02			1.81			4.68	.30									
OL Fa	.34	.40	.37			.34			.83	<.01									
WOL								3.50			15.08	14.93	16.20	14.16	33.43	14.82	9.18	17.15	4.09

[1]Boettcher, 1966, p. 25.

[2]Includes 0.03 Cr_2O_3, 0.11 CuO, 0.05 ZnO, 0.05 SrO, 0.17 BaO.

[3]Larsen and Pardee, 1929, p. 103, 104.

[4]Includes 0.04 S, 0.36 F, 0.12 V_2O_3, 0.06 BaO, 0.14 SrO.

[5]Differentiation Index: normative quartz + orthoclase + albite + nepheline + leucite.

Table 10.—Whole-rock chemical analyses (in percent) and normative calculations for samples of leucocratic rocks from alkaline complexes in northwestern Montana

[—, means not detected]

	Rainy Creek syenites								Skalkaho syenites									
	RC-13A	RC-13B	RC-13C	RC-13D	RC-16	RC-17B	RC-18B	RC-20	SK-6A	SK-6B	SK-20	SK-21	SK-22	SK-23	SK-24	SK-25	SK-26	SK-27
								Whole-rock chemical analyses										
SiO_2	58.8	60.0	56.1	61.6	64.2	63.2	65.1	58.2	53.7	52.4	56.2	65.8	62.9	56.6	58.0	61.5	60.9	57.5
Al_2O_3	18.9	20.1	17.8	16.2	17.2	17.0	15.3	22.6	15.2	14.5	15.2	20.5	19.1	20.9	16.6	18.2	18.0	17.2
Fe_2O_3	4.06	2.37	2.81	2.42	1.83	2.12	1.45	1.18	4.92	5.27	3.21	.26	1.19	2.43	3.55	2.21	1.72	2.77
FeO	.30	.16	1.22	.54	.92	.05	.92	.23	3.53	4.17	3.13	.20	.38	.54	1.83	1.61	1.39	3.88
MgO	.30	.20	1.3	.91	.66	.48	.76	.11	1.8	2.0	2.6	.2	.3	.2	1.1	.92	.71	2.3
CaO	.88	.17	3.57	1.68	2.58	1.53	2.25	.47	6.16	7.08	7.23	.70	1.93	5.56	3.41	3.72	2.39	5.83
Na_2O	2.1	.9	2.6	2.2	4.51	4.62	3.32	9.85	2.3	2.1	3.2	5.4	3.9	3.8	2.3	3.0	2.9	3.6
K_2O	11.6	14.0	9.43	11.8	5.21	7.92	8.85	4.38	7.15	6.83	6.02	7.73	8.87	5.68	9.49	8.88	9.91	4.39
H_2O	.83	.98	2.18	.24	.69	.49	.30	.71	.55	.49	.55	.35	.27	.51	.38	.21	.29	.84
TiO_2	.68	.56	.54	.15	.36	.37	.37	.05	1.33	1.52	.81	.04	.21	.30	.77	.66	.62	.76
P_2O_5	0.10	.20	<0.1	<0.1	.13	.15	.12	<0.1	.30	.40	.30	<0.1	<0.1	<0.1	.20	.10	<0.1	.40
MnO	.09	<0.02	.11	.03	.05	.12	.06	.05	.25	.28	.18	<0.01	.05	.21	.12	.10	.07	.15
CO_2	.31	.03	.02	.01	<0.01	.01	<0.01	.03	.01	.01	.01	<0.01	<0.01	<0.01	.01	.01	.01	<0.01
Total	98.95	99.67	97.68	97.78	98.34	98.06	98.80	97.86	97.20	97.05	98.64	101.18	99.10	96.73	97.76	101.12	98.91	99.62
								Normative calculations										
D.I.	89.0	92.5	78.5	90.3	82.9	91.5	90.1	95.1	65.5	61.6	64.3	93.6	88.4	69.9	79.4	79.7	85.2	62.2
Q	1.01	.94		.75	12.31	3.49	8.52		1.69	1.35	.40	2.95	1.96	1.55	1.86	2.58	.93	5.11
C	2.29	3.51						.90				1.96						
Or	69.86	83.83	58.35	71.49.	31.53	47.94	53.09	26.64	43.72	41.80	36.27	45.30	53.04	34.88	57.59	52.00	59.38	26.26
Ab	18.11	7.72	16.74	18.08	39.03	40.07	28.52	47.92	20.14	18.40	27.61	45.32	33.39	33.42	19.99	25.16	24.88	30.84
An	1.79		9.48		11.47	2.31	.72	2.20	10.38	10.32	9.51	3.44	8.51	24.11	7.13	9.88	6.93	18.03
Ne			3.41					20.52										
Ac				.89														
Wo			3.73	3.54	.28	1.57	4.10		7.99	9.72	10.44		.49	1.90	3.69	3.22	2.10	3.59
En	.76	.44	3.22	2.32	1.68	1.22	1.92		4.64	5.16	6.60	.49	.76	.52	2.81	2.27	1.79	5.80
Fs									.71	1.36	2.13	.09				.22	.24	3.91
Fo			.12					.20										
Fa																		
Cs																		
Mt			2.85	1.44	2.14		2.12	.78	.7.38	7.91	4.74	.37	.79	1.62	4.17	3.18	2.53	4.07
Hm	4.14	2.40	.97	1.18	.40	2.17	.01	.68					.66	1.41	.77			
Il	.84	.34	1.07	.29	.70	.37	.71	.10	2.61	2.99	1.57	.08	.40	.59	1.50	1.24	1.19	1.46
Tn						.45												
Ru	.25	.39																
Ap	.24	.31			.32	.36	.29		.74	.98	.72.				49	.24		.96
Cc	.72		.05	.02		.02		.07	.02	.02	.02				.02	.02	.02	
Mg		.06																
DI Wo			3.73	2.69	.28	1.42	2.22		5.99	7.17	9.52		.49	.60	6.07	2.82	2.10	3.59
DI En			3.22	2.32	.24	1.22	1.92		4.64	5.16	6.60		.42	.52	3.26	2.27	1.65	2.05
DI Fs									.71	1.36	2.13				2.81	.22	.22	1.38
HY En					1.44							.49	.33				.14	3.75
HY Fs												.09					.02	2.52
HO Fo			.12					.20										
HO Fa																		
WOL				.85		.15	1.88		2.00	2.55	.92			1.30	.43	.39		

Table 10.—Whole-rock chemical analyses (in percent) and normative calculations for samples of leucocratic rocks from alkaline complexes in northwestern Montana—Continued

	Haines Point (surface samples)							Haines Point (drill-core samples)								
	HP-2	HP-3A	HP-3B	HP-4	HP-5	HP-6	HP-8	HA-23 183.5-184.5	HA-23 260-261	HA-23 316-317	HA-23 323-324	HA-23 359.4-360.4	HA-2 146.7-148	HA-20A 194-195	HA-1A 184-185.2	HA-4A 134.135.5
								Whole-rock chemical analyses								
SiO_2	58.2	60.4	60.2	58.9	64.3	67.2	61.3	58.7	56.3	57.1	56.6	59.1	53.2	54.7	59.9	54.3
Al_2O_3	21.6	18.1	18.2	16.2	17.4	15.5	16.3	21.7	18.2	18.0	17.3	19.3	14.6	16.0	17.6	15.5
Fe_2O_3	2.29	2.24	6.86	5.66	1.54	2.09	3.10	2.16	4.30	2.95	3.97	1.58	5.92	3.90	2.06	5.18
FeO	.40	1.26	1.14	1.69	.28	.27	.79	1.21	1.47	.94	.57	.91	2.94	4.66	2.25	3.00
MgO	.12	.28	.30	.24	.19	.46	.42	.18	.58	.40	.25	.31	1.25	1.94	.94	1.39
CaO	.11	.06	.07	1.05	.47	1.03	1.37	.19	2.02	3.0	4.41	1.04	6.24	2.07	.32	4.33
Na_2O	.72	1.51	1.73	2.45	4.33	5.18	2.33	3.07	1.13	1.13	1.48	1.42	1.14	1.21	1.36	1.28
K_2O	14.1	13.4	13.0	11.3	9.52	6.24	12.0	10.5	12.2	11.7	11.0	13.0	10.7	12.1	13.7	11.2
H_2O	1.33	.55	.52	.46	.50	.48	.39	1.12	.91	.85	.65	.62	.54	.77	.45	.67
TiO_2	.12	.26	.25	.39	.16	.28	.41	.24	.80	.55	.73	.27	1.18	.84	.34	.95
P_2O_5	<0.05	<0.05	<0.05	<0.05	<0.05	.08	<0.05	<0.05	.11	.06	.07	<0.05	.41	.06	.07	.34
MnO	.03	.07	.08	.12	.06	.09	.09	.13	.20	.07	.08	.04	.19	.25	.11	.20
CO_2	.02	.01	.02	.01	.01	.01	.03	.70	.36	.28	.04	.43	.21	.26	.16	.11
Total	99.04	98.14	102.37	98.47	98.76	98.91	98.53	99.90	98.58	97.03	97.15	98.02	98.52	98.76	99.26	98.45
								Normative calculations								
D.I.	91.3	94.2	89.8	89.0	96.4	93.6	90.0	89.8	83.2	82.2		91.0	71.6	79.3	91.9	75.8
Q				.01	1.98	11.58	.39	.67		.37						
C	5.12	1.05	1.18					5.35	.57			2.05			.50	
Or	85.27	81.14	75.42	68.13	57.25	37.46	72.26	62.81	73.81	71.88		78.87	64.53	72.97	81.93	67.69
Ab	5.75	13.07	14.37	20.83	27.14	44.53	17.36	26.30	8.83	9.94		11.90	3.75	1.47	7.97	4.71
An	.43	.24	.22			.62			7.19	9.87		2.51	3.18	2.54	.12	3.55
Ne	.26	.01							.52			.24	3.3	4.86	1.99	3.45
Ac				.28	.13		2.41									
Wo				2.19	.96	1.66	2.81			1.40			10.16	2.45		6.44
En			.22	.61	.48	1.16	1.07			1.04			3.18	1.25		3.54
Fs															1.14	.03
Fo	.21	.50	.36						1.04	1.40		.56		2.58	1.66	
Fa		.13												2.60	1.62	
Cs																
Mt	1.06	3.33	3.15	4.80	.65	.36	1.68	1.79	3.14	1.73		2.34	6.81	5.77	3.02	7.68
Hm	1.61		4.56	2.36	1.08	1.88	1.17	.96	2.23	1.87		.01	1.34			
Il	.23	.51	.47	.76	.31	.54	.79	.46	1.56	1.09		.53	2.29	1.63	.65	1.84
In																
Ru																
Ap						.19			.27	.15			.99	.14	.17	.82
Cc	.05	.02	.04	.02	.02	.02	.07	.34	.84	.66		1.00	.49	.60	.37	.26
Mg								.38								
DI Wo				.71	.56	1.35	1.23						3.68	2.45		4.13
DI En				.61	.48	1.16	1.07			1.20			3.18	1.25	3.54	
DI Fs										1.04				1.14		.03
HY En			.22													
HY Fs																
OL Fo	.21	.50	.36						1.04			.56		2.58	1.66	
OL Fa		.13												2.60	1.62	
WOL				1.49	.41	.31	1.58			.20			6.48			2.32

Table 10.—Whole-rock chemical analyses (in percent) and normative calculations for samples of leucocratic rocks from alkaline complexes in northwestern Montana—Continued

	Bobtail Creek syenites						Warland Creek leucocratic rocks						
	BTC-1	BTC-2	BTC-3	BTC-4	BTC-5	BTC-6	WC-1	WC-3	WC-5	WC-6	WC-7	WC-8	WC-9
							Whole-rock chemical analyses						
SiO_2	56.2	54.5	55.0	54.6	56.9	50.8	62.2	64.9	64.6	70.4	70.9	69.7	71.5
Al_2O_3	16.0	14.5	14.6	15.6	17.5	16.8	18.8	17.8	18.1	15.8	15.5	16.2	15.3
Fe_2O_3	4.09	5.21	5.36	4.45	3.30	4.39	.92	.97	.65	.57	.70	.62	.53
FeO	3.08	3.81	3.46	3.52	2.78	4.82	.34	.28	.42	.20	.13	.07	.09
MgO	1.98	2.36	2.13	2.33	1.95	4.24	.23	.21	.25	.23	.24	.16	.18
CaO	5.86	6.59	6.10	6.21	5.32	8.66	1.68	.64	.90	.60	.31	.43	.26
Na_2O	3.10	2.47	2.18	2.58	3.49	3.00	3.81	4.10	5.11	5.63	5.02	5.51	5.57
K_2O	6.42	7.10	7.94	7.18	5.77	3.44	9.36	9.21	7.99	5.05	5.51	5.51	4.79
H_2O	.27	.35	.37	.59	.38	.67	.37	.27	.17	.23	.29	.29	.17
TiO_2	.68	.88	.89	.74	.51	.79	.13	.11	.11	.06	.08	.06	.05
P_2O_5	.36	.45	.41	.44	.29	.49	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MnO	.14	.19	.18	.15	.13	.16	.04	.02	.03	.02	<0.02	.02	.03
CO_2	.09	.04	<0.01	<0.01	<0.01	<0.01	.52	<0.01	.18	<0.01	<0.01	<0.01	<0.01
Total	98.27	98.45	98.62	98.39	98.32	98.26	98.40	98.51	98.51	98.79	98.68	98.57	98.47
							Normative calculations						
D.I.	67.5	64.8	67.6	65.6	67.3	46.8	91.0	95.0	94.6	95.6	96.2	96.2	97.0
Q	2.07	.74	1.03		2.31		1.73	4.24	2.59	16.95	19.91	15.67	20.29
C							.56				.73	.40	.49
Or	38.71	42.77	47.76	43.38	34.81	20.83	56.42	55.40	48.01	30.28	33.09	33.13	28.80
Ab	26.77	21.30	18.78	22.00	30.15	26.01	32.89	35.32	43.97	48.34	43.17	47.44	47.95
An	11.00	7.65	6.72	10.00	15.36	22.76	5.15	3.02	2.90	2.97	1.56	2.17	1.31
Ne				.18									
Ac													
Wo	6.55	9.36	8.92	7.75	4.03	7.51		.09	.20	.02			
En	5.03	5.99	5.40	5.39	4.96	7.04	.58	.53	.63	.58	.61	.40	.46
Fs	1.44	1.62	.80	1.71	1.82	2.81			.11				
Fo				.38		2.65							
Fa				.13		1.17							
Cs													
Mt	6.05	7.70	7.91	6.60	4.88	6.52	.87	.66	.96	.54	.19	.12	.25
Hm							.34	.53		.20	.58	.55	.37
Il	1.32	1.70	1.72	1.44	.99	1.54	.25	.21	.21	.12	.15	.12	.10
Tn													
Ru													
Ap	.87	1.09	.99	1.07	.70	1.19							
Cc	.21	.09					1.21		.42				
Mg													
DI Wo	6.55	8.36	6.96	7.75	4.03	7.51		.09	.20	.02			
DI En	4.65	5.99	5.40	5.39	2.72	4.98	.08	.15	.02				
DI Fs	1.33	1.62	.80	1.71	1.00	1.99		.03					
HY En	.39				2.23	2.06	.58	.46	.48	.56	.61	.40	.46
HY Fs	.11				.82	.82			.08				
OL Fo				.38		2.65							
OL Fa				.13		1.17							
WOL		1.00	1.96										

Table 11.--Whole-rock chemical analyses (in percent) and normative calculations for samples of leucocratic dikes intruding the alkaline complexes at Rainy Creek, Skalkaho, and Warland Creek

[---, means not detected]

	Rainy Creek				Skalkaho	Warland Creek	
	RC-3	RC-5	RC-7A	RC-10A	SK-4	WC-2	WC-4
				Whole-rock chemical analyses			
SiO_2	59.8	59.3	63.5	62.2	69.5	76.3	71.1
Al_2O_3	12.7	21.7	17.1	16.2	17.1	10.1	15.7
Fe_2O_3	5.74	1.70	1.98	2.42	.95	1.69	.26
FeO	.81	.19	.31	.51	.50	.40	.18
MgO	2.7	.20	.52	.68	.30	.21	.17
CaO	4.48	<0.02	1.09	1.79	.89	.62	.24
Na_2O	4.7	.30	3.9	3.0	8.8	1.50	5.34
K_2O	6.58	14.9	10.1	10.9	.45	6.47	5.27
H_2O	.24	1.26	.21	.11	.44	.19	.23
TiO_2	.37	.22	.40	.65	.26	.21	.06
P_2O_5	<0.1	<0.01	<0.01	.10	.10	<0.05	<0.05
MnO	.05	<0.02	<0.02	.02	<0.02	.02	<0.02
CO_2	.60	.01	.01	.01	.03	.02	<0.01
Total	98.77	99.78	99.12	98.59	99.32	98.72	98.55
				Normative calculations			
D.I.	70.4	92.2	93.0	89.3	92.8	94.5	97.1
Q	1.84	.25	.53	.90	14.77	39.17	19.42
C		5.16			.84		.79
Or	39.46	89.37	60.34	65.40	2.69	44.74	31.67
Ab	29.12	2.58	32.08	22.99	75.31	10.58	45.96
An					3.61		1.21
Ac	9.90		1.13	2.45		2.03	
Wo	7.81		2.18	3.37		1.25	
En	6.82	.48	1.31	1.72	.76	.53	.43
Fs							.02
Mt	1.73				.87	.76	.38
Hm	1.21	1.73	1.61	1.61	.36	.49	
Il	.71	.41	.66	1.14	.50	.40	.12
Tn			.14	.15			
Ru		.01					
Ap				.24	.24		
Cc	1.38		.02	.02	.07	.05	
Mg		.02					
DI Wo	7.81		1.52	1.99		.61	
DI En	6.75		1.31	1.72		.53	
DI Fs							.43
HY En	.07	.48			.76		.02
HY Fs							
WOL			.66	1.38		.64	

Table 12.—Minor element analyses (in ppm) for samples of ultramafic rocks and mafic pegmatites from alkaline complexes of northwestern Montana

[N, value below detection limit; —, not determined]

	Rainy Creek pyroxenites			Skalkaho pyroxenites									Skalkaho mafic pegmatites				Bobtail Creek shonkinite
	RC-9	RC-12A	RC-12B	SK-1A	SK-1B	SK-2A	SK-2B	SK-3	SK-5A	SK-5B	SK-5C	SK-8B	SK-9A	SK-9B	SK-9C	SK-9D	BTC-7
Ba	1000	1000	1000	700	200	300	2000	1000	200	300	1500	700	700	15000	15000	500	810
Be	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	2
Co	70	70	70	50	50	50	50	70	30	15	30	50	50	10	10	10	61
Cr	70	70	50	N	2	70	20	5	15	3	30	15	15	7	7	20	9
Cu	15	20	70	150	10	500	100	700	500	70	15	300	200	150	150	20	110
Ga	10	—	—	20	20	30	—	—	20	20	20	20	20	20	20	20	24
Li	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	9
Nb	N	N	N	N	N	N	N	N	30	10	20	50	50	15	15	10	9
Ni	50	70	50	N	10	7	10	5	<10	<10	10	5	5	N	N	N	5
Pb	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	10
Sr	1500	700	700	700	100	500	500	150	500	500	2000	700	700	7000	7000	1000	790
V	200	300	500	700	700	1000	700	1000	700	1000	700	1000	1000	700	700	700	290
Zn	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	150
Th	3.61	3.95	4.74	73.7	25.2	9.54	3.57	4.43	29.3	29.3	29.1	20.0	29.1	17.0	17.3	7.44	—
U	.41	.49	1.04	.52	1.56	.25	.26	.22	4.86	4.44	4.82	3.54	4.82	1.95	2.06	6.05	—
Y	13	12.8	12.8	27.7	28.0	26.5	22.0	14.1	1138	131	137	125	458	151	712	105	23.8
La	27.8	24.4	34.2	20.5	39.3	17.2	19.4	10.5	163	150	149	118	29.8	90.1	31.1	90.2	31.7
Ce	65.0	57.2	77.1	53.2	93.0	49.8	50.0	28.6	495	456	465	398	132	243	163	257	82.2
Pr	10.3	9.1	10.8	8.8	13.9	9.2	8.5	5.3	71.2	66.2	69.0	64.1	26.0	34.0	34.7	37.6	12.1
Nd	47.1	40.5	47.5	44.9	63.5	48.8	41.3	29.2	316	292	304	296	167	151	248	164	53.6
Sm	9.5	7.7	8.2	12.6	13.4	13.1	10.2	7.8	64.2	58.8	62.3	54.2	65.8	31.6	99.4	31.6	9.9
Eu	2.31	1.90	2.03	3.81	3.94	3.83	2.91	2.08	16.7	15.0	16.1	14.1	24.0	10.3	36.8	9.43	2.45
Gd	6.9	5.6	5.9	12.1	10.6	12.0	9.0	6.6	44.0	40.6	42.5	39.1	69.8	27.8	107	23.5	7.8
Tb	<1	<1	<1	1	1	1	1	<1	6	6.	6	6	12	4.	18	4	1
Dy	—	—	—	—	—	—	—	—	31.2	29.2	31.2	30.5	75.8	27.5	117	19.7	1.9
Ho	.59	.55	.50	1.20	1.10	1.18	.92	.65	5.70	5.38	5.61	5.40	16.9	5.96	26.0	3.91	1.0
Er	.8	.9	1.0	2.5	2.6	2.5	2.0	1.1	14.2	13.4	14.1	12.9	53.1	17.2	82.2	11.1	2.1
Tm	.21	.21	.15	.39	.39	.34	.36	.25	1.81	1.78	1.84	1.63	8.30	2.63	12.9	1.66	.3
Yb	.61	.69	.78	1.78	2.18	1.78	1.42	.71	11.4	11.3	11.6	9.04	61.3	18.4	14.0	1.69	2.0
Lu	.08	.09	.10	.24	.31	.26	.19	.09	1.34	1.35	1.46	.99	8.95	2.53	13.9	1.69	.31
REE(La-Lu)	171.21	148.84	188.26	163.02	245.22	160.99	147.20	92.88	1241.75	1147.01	1179.71	1049.96	750.75	666.02	1004.00	657.08	208.36
$(La/Yb)_{CN}$	30.9	23.8	29.8	7.8	12.2	6.5	9.2	10.0	9.7	8.9	8.7	8.8	0.32	3.3	1.5	35.9	10.6
Eu/Sm	.24	.25	.25	.30	.29	.29	.29	.27	.26	.26	.26	.26	.36	.33	.37	.30	.25

Table 13.—Minor element analyses (in ppm) of leucocratic rocks from alkaline complexes in northwestern Montana

[N, value below detection limit; —, not determined]

	Rainy Creek syenites								Skalkaho syenites									
	RC-13A	RC-13B	RC-13C	RC-13D	RC-16	RC-17B	RC-18B	RC-20	SK-6A	SK-6B	SK-20	SK-21	SK-22	SK-23	SK-24	SK-25	SK-26	SK-27
Ba	10000	7000	10000	15000	1200	990	870	38	300	1500	7000	1500	2000	20000	15000	7000	7000	3000
Be	N	1.5	N	N	2	11	5	2	N	N	2	N	N	N	N	N	N	N
Co	7	N	7	5	4	4	5	<1	10	30	10	N	N	N	10	7	7	20
Cr	2	3	7	10	9	7	7	9	10	15	20	N	N	5	100	70	30	20
Cu	150	70	100	20	84	530	100	<1	20	5	20	7	1	7	70	70	50	50
Ga	30	30	30	20	19	38	27	45	20	20	20	15	20	20	20	20	20	20
Li	N	N	N	N	7	42	4	31	N	N		N	N	N	N	N	N	N
Nb	N	N	N	N	15	31	16	8	10	50	10	N	N	N	N	10	10	10
Ni	N	N	N	7	2	3	4	<2	N	5	5	N	N	N	N	N	N	5
Pb	N	15	30	N	16	58	12	7	N	N	10	N	10	N	N	N	N	10
Sr	7000	2000	7000	3000	1200	420	440	55	500	1500	5000	2000	10000	10000	10000	7000	7000	3000
V	500	700	500	300	83	110	260	46	1500	700	500	10	70	200	300	500	300	500
Zn	N	N	N	N	70	150	130	70	N	N	N	N	N	N	N	N	N	N
Th	6.39	9.33	5.22	1.7	—	—	—	—	12.4	14.1	8.02	7.33	26.0	22.4	3.3	4.70	10.9	14.7
U	1.87	2.10	1.52	.59	—	—	—	—	9.55	4.85	2.12	.93	1.61	2.34	.77	.77	1.52	2.29
Y	16.8	12.0	17.2	3.8	21.7	17.9	15.3	.9	51.2	53.8	29.7	1.8	6.2	126	26.6	27.8	25.2	28.9
La	24.7	30.8	26.2	9.4	24.7	51.3	19.8	23.6	95.3	121.	46.3	8.8	75.1	61.6	24.1	32.6	40.2	43.6
Ce	50.2	59.9	51.7	17.3	49.1	76.8	44.9	31.3	206	245	105	19.8	135	129	95.1	92.6	95.3	96.4
Pr	6.6	7.5	6.2	2.7	6.4	7.7	5.6	2.6	26.0	29.4	13.5	1.2	12.0	12.8	13.3	13.6	12.6	11.4
Nd	25.0	26.7	23.9	9.2	26.0	25.2	21.6	5.4	105	117	57.8	5.4	37.2	60.6	60.4	57.8	55.8	52.8
Sm	5.2	5.0	4.8	2.0	5.5	4.6	4.3	.5	19.9	21.0	9.7	—	—	8.4	10.4	9.7	9.2	8.7
Eu	1.39	1.24	1.27	.43	1.37	1.05	.96	.05	5.58	5.87	3.00	.43	.71	4.64	3.29	2.91	3.02	2.73
Gd	4.1	3.8	4.0	1.4	4.9	4.1	3.8	.8	14.5	15.1	9.1	.9	2.1	13.9	9.0	8.2	8.1	8.2
Tb	<1	<1	<1	<1	1	<1	1	<1	2.	3.	1.8	.4	.7	3.5	1.6	1.6	1.3	1.7
Dy	—	—	—	—	3.8	2.3	2.7	.3	10.9	11.6	6.3	.4	1.2	18.2	5.9	5.6	5.3	5.9
Ho	.59	.50	.61	.13	.8	.6	.6	<.1	2.02	2.18	1.22	.11	.19	4.31	1.05	1.04	1.00	1.09
Er	1.8	1.2	1.8	.3	2.2	1.7	1.6	.3	5.25	5.56	3.0	.3	.3	14.4	2.6	2.6	2.3	2.8
Tm	.27	.75	.26	.08	.3	.3	.3	.1	.74	.79	.46	.06	.05	2.37	.34	.35	.29	.41
Yb	1.76	1.09	1.81	.42	2.5	2.1	2.0	.1	4.53	4.95	2.81	.09	.60	18.3	2.1	2.3	2.0	2.8
Lu	.25	.17	.27	.08	.37	.32	.32	.06	.57	.61	.41	.03	.08	3.05	.28	.29	.26	.38
REE(La-Lu)	121.86	138.65	122.82	43.49	128.94	178.07	109.48	65.21	498.29	583.06	260.4	37.92	265.23	355.07	239.46	231.19	236.67	238.91
$(La/Yb)_{CN}$	9.5	19.1	9.7	15.2	6.6	16.5	6.7	158.5	14.2	16.5	11.1	66.0	83.6	2.3	11.0	9.6	13.5	10.5
Eu/Sm	.27	.25	.26	.22	.25	.23	.22	.10	.28	.28	.31	—	—	.55	.32	.30	.33	.31

Table 13.—Minor element analyses (in ppm) of leucocratic rocks from alkaline complexes in northwestern Montana—Continued

[N, value below detection limit; —, not determined]

	Haines Point syenites (surface samples)							Haines Point syenites (drill-core samples)								
	HP-2	HP-3A	HP-3B	HP-4	HP-5	HP-6	HP-8	HA-23 183.5-184.5	HA-23 260-261	HA-23 316-317	HA-23 323-324	HA-23 359.4-360.4	HA-2 146.7-148	HA-20A 194-195	HA-1A 184-185.2	HA-4A 134-135.5
Ba	1900	6000	6700	1200	300	690	2900	290	5200	16000	15000	10000	4500	4200	2300	4500
Be	2	<1	3	1	8	8	4	4	3	<2	<1	3	<2	2	<2	2
Co	2	3	6	4	<2	2	3	<4	7	9	12	9	9	20	11	12
Cr	<5	<5	<5	<5	<5	<5	<5	<4	<4	<4	5	<4	6	<4	<4	<4
Cu	46	45	110	25	14	33	39	84	<4	31	140	23	260	20	50	100
Ga	10	20	10	<10	30	20	20	40	<20	<20	16	<20	<20	<20	<20	<20
Li	79	25	27	<5	<5	19	14	41	100	44	29	56	42	91	47	54
Nb	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	12	<10	<10	<10	<10	<10
Ni	<5	<5	<5	<5	<5	<5	<5	<8	<8	<8	<2	<8	<8	<8	<8	<8
Pb	40	<20	70	<20	<20	<20	<20	30	20	20	<4	20	10	20	20	<10
Sr	850	1700	2000	1500	380	410	1500	290	1700	1400	1800	1300	2100	1500	2000	2100
V	94	130	100	250	75	77	130	130	280	190	280	140	390	200	68	300
Zn	31	70	85	67	53	49	51	100	91	32	54	34	79	160	88	110
Th	6.8	5.20	<3.8	4.5	10.4	15.1	<2.4	37.5	14.4	4.3	6.53	4.1	11.2	11.7	5.88	20.0
U	<2.3	1.43	4.48	1.25	4.05	5.71	1.46	12.2	4.83	2.26	2.29	2.18	3.78	4.91	1.86	5.12
Y	2.7	4.2	6.3	2.7	7.9	18.1	6.8	2.5	25.5	15.8	22.8	7.3	38.6	12.6	1.6	27.2
La	22.0	9.6	28.8	18.5	29.1	21.2	22.5	48.8	45.1	19.1	21.5	17.0	79.0	27.0	24.6	66.6
Ce	37.3	22.9	44.6	43.0	62.4	50.6	50.4	89.0	1.07	29.1	62.3	35.1	17.2	59.5	41.7	141
Pr	3.4	2.9	5.4	5.3	7.2	5.3	6.3	7.7	15.3	6.4	10.2	3.8	22.7	7.7	3.6	16.5
Nd	8.8	12.2	19.5	18.7	24.3	26.8	28.0	19.5	62.4	38.9	53.5	18.9	92.3	34.9	10.4	69.7
Sm	1.0	1.5	1.8	1.3	2.3	4.0	3.7	—	10.2	7.3	12.1	2.9	15.0	5.0	—	9.5
Eu	.19	.46	.57	.50	.75	1.36	1.20	.27	2.99	2.22	3.17	.96	4.61	1.37	.20	3.17
Gd	.9	1.5	2.0	1.4	2.7	4.7	3.3	1.0	8.3	5.9	8.6	2.9	13.2	4.1	.8	9.0
Tb	.2	.5	.4	.4	.7	1.1	.7	.7	1.7	1.1	1.1	.6	2.3	.8	.4	1.7
Dy	.6	.7	1.1	.6	1.4	3.5	1.7	.4	5.2	3.4	4.6	1.5	6.8	2.2	.3	5.0
Ho	.10	.16	.18	.09	.29	.65	.30	.09	.89	.53	.76	.29	1.46	.44	.07	.97
Er	.3	.3	.5	.2	.7	1.6	.6	.1	2.2	1.2	1.9	.6	3.5	1.1	.1	2.3
Tm	<.05	<.05	.07	<.05	.08	.21	.10	<.05	.34	.20	.28	.08	.53	.14	<.05	.33
Yb	.27	.36	.48	.30	1.00	1.8	.88	.20	2.5	1.4	1.90	.61	3.43	1.18	.13	2.42
Lu	.02	.05	.07	.06	.18	.29	.16	.03	.38	.19	.28	.09	.51	.17	.02	.34
REE(La-Lu)	75.08	53.13	105.47	90.35	133.10	123.11	119.84	167.79	264.50	136.94	182.19	85.33	417.34	145.60	82.32	328.53
$(La/Yb)_{CN}$	54.6	18.2	40.4	42.6	19.6	8.0	17.3	157.4	12.1	9.2	7.6	18.9	15.5	15.6	128.1	18.5
Eu/Sm	.19	.31	.32	.38	.33	.34	.32	—	.29	.30	.26	.33	.31	.27	—	.33

Table 13.—Minor element analyses (in ppm) of leucocratic rocks from alkaline complexes in northwestern Montana—Continued

[N, value below detection limit; —, not determined]

	Bobtail Creek syenites						Warland Creek leucocratic rocks						
	BTC-1	BTC-2	BTC-3	BTC-4	BTC-5	BTC-6	WC-1	WC-3	WC-5	WC-6	WC-7	WC-8	WC-9
Ba	1900	2900	2700	2200	1300	1100	1100	750	610	240	520	240	210
Be	2	2	2	2	3	2	3	4	3	6	4	4	5
Co	18	9	24	23	16	31	1	1	<1	<1	<1	<1	<1
Cr	21	14	9	15	14	19	2	3	3	4	2	2	3
Cu	19	89	39	16	16	60	8	11	13	<1	9	5	<1
Ga	20	20	19	18	20	19	18	26	21	25	23	27	25
Li	13	9	8	8	17	37	3	3	3	4	10	<2	6
Nb	13	9	13	10	14	10	17	8	10	6	14	6	<4
Ni	6	5	5	7	7	15	<2	<2	<2	<2	<2	<2	<2
Pb	13	15	14	19	16	16	31	23	19	33	15	7	6
Sr	1500	2100	2200	1900	1300	1700	2200	1300	1100	240	450	250	170
V	190	250	240	210	140	230	69	48	61	24	41	25	30
Zn	90	120	90	80	60	90	60	60	50	70	70	70	60
Th	—	—	—	—	—	—	—	—	—	—	—	—	—
U	—	—	—	—	—	—	—	—	—	—	—	—	—
Y	26.9	28.1	28.5	23.6	26.9	22.3	5.5	9.4	6.5	8.8	7.6	6.5	5.9
La	38.1	34.7	33.4	30.0	41.0	26.8	48.3	17.7	9.3	9.9	16.6	11.0	13.4
Ce	82.5	81.6	83.1	68.8	80.5	61.3	67.4	28.2	18.9	15.3	27.0	19.0	21.8
Pr	10.2	11.7	12.1	9.6	10.1	8.5	6.3	2.9	2.6	1.7	2.5	1.6	2.0
Nd	41.4	48.3	50.4	40.0	38.6	35.9	17.5	8.9	7.5	5.2	8.0	5.8	6.4
Sm	7.6	9.8	11.1	8.6	7.9	7.1	1.8	1.6	1.2	.9	1.3	1.1	1.1
Eu	1.84	2.49	2.83	2.27	1.89	1.82	.42	.33	.28	2.5	.31	.22	.23
Gd	6.4	7.8	8.5	6.7	6.7	5.7	1.3	1.5	1.3	1.1	1.4	1.2	1.3
Tb	1.	1.	1.	1.	1.	1.	<1	<1	<1	<1	<1	<1	<1
Dy	2.8	5.4	5.4	4.6	5.2	4.2	.5	.9	.5	.8	1.0	.7	.8
Ho	1.0	1.1	1.1	.9	1.0	.8	.2	.3	.2	.3	.3	.2	.2
Er	2.6	2.6	2.7	2.2	2.9	2.1	.4	1.0	.8	.9	.9	.7	.6
Tm	.4	.4	.4	.3	.5	.3	.1	.1	.1	.1	.1	.1	.1
Yb	2.8	2.8	3.1	2.4	3.0	2.4	.7	1.4	.9	1.3	.12	.9	.8
Lu	.41	.40	.40	.36	.44	.37	.13	.25	.18	.23	.18	.16	.15
REE(La-Lu)	199.05	210.09	215.53	177.73	200.73	158.29	145.05	65.08	43.76	37.98	60.79	42.68	48.88
$(La/Yb)_{CN}$	9.2	8.4	7.3	8.4	9.2	7.5	47.2	8.5	7.0	5.1	9.4	8.3	11.4
Eu/Sm	.24	.25	.25	.26	.24	.26	.23	.21	.23	.28	.24	.20	.21

Table 14.--Minor element analyses (in ppm) for samples of leucocratic dike rocks intruding the alkaline complexes at Rainy Creek, Skalkaho, and Warland Creek

[N, value below detection limit; ---, not determined]

	Rainy Creek				Skalkaho	Warland Creek	
	RC-3	RC-5	RC-7A	RC-10A	SK-4	WC-2	WC-4
Ba	2000	1500	7000	10000	1500	130	290
Be	1.5	N	N	N	N	5	3
Co	7	N	N	5	N	2	<1
Cr	70	10	15	15	7	7	3
Cu	200	50	7	20	20	9	3
Ga	30	50	20	30	20	26	23
Li	N	N	N	N	N	6	2
Nb	N	N	N	N	N	<4	6
Ni	7	N	N	N	N	3	<2
Pb	N	20	10	N	N	64	6
Sr	1500	1500	1500	3000	700	84	220
V	500	700	200	500	30	300	32
Zn	N	N	N	N	N	60	50
Th	9.12	13.6	3.86	4.12	15.3	---	---
U	3.36	2.78	.60	.54	2.87	---	---
Y	4.4	23.8	4.1	9.2	11.1	8.8	5.7
La	7.3	5.7	10.7	17.4	28.4	30.7	10.7
Ce	14	8.8	22.6	41.1	50.5	53.0	17.1
Pr	1.7	1.5	3.3	5.8	5.9	6.1	1.8
Nd	6.2	5.	11.6	22.2	20.8	18.7	5.3
Sm	1.4	1.1	2.2	4.7	3.6	3.2	.7
Eu	.36	.24	.55	1.11	.87	.56	.19
Gd	1.2	1.5	1.7	3.4	2.6	2.5	1.
Tb	<1.	<1.	<1.	<1.	<1.	<1.	<1.
Dy	---	---	---	---	---	1.7	.3
Ho	.13	.35	.15	.39	.36	.4	.2
Er	.5	1.4	.4	1.	1.1	1.	.7
Tm	.09	.23	.07	.17	.18	.2	<.1
Yb	.64	1.32	.36	.74	1.18	1.2	.8
REE(La-Lu)	33.65	27.38	53.69	98.12	115.68	119.48	38.86
$(La/Yb)_{CN}$	6	2.4	18	16	16	141	35
Eu/Sm	.26	.22	.25	.24	.24	.18	.27