This is to certify that the

thesis entitled

Neogene Flysch Provenance
Variations, Sea of Japan

presented by

Kevin J. Pentony

has been accepted towards fulfillment
of the requirements for

Master degree in Geology

Major professor

Date November 3, 1977

NEOGENE FLYSCH PROVENANCE VARIATIONS,
SEA OF JAPAN

By

Kevin John Pentony

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Geology

1977

ABSTRACT

NEOGENE FLYSCH PROVENANCE VARIATIONS, SEA OF JAPAN

By

Kevin John Pentony

Mineralogical analyses were done on Neogene flysch sediments from the Yamato and Japan Basins in the Sea of Japan in order to : 1) delineate provenance variations both within each basin and between the two basins; and 2) determine if the silt in flysch sands and clays differed in composition. Point-counts of the light mineral fraction and microprobe chemical analyses of feldspars were performed.

Complex provenance variations were deciphered in this manner and supporting evidence was obtained for the rifting hypothesis for the origin of the Sea of Japan. No compositional differences were detected between the silt in flysch sands and clays.

ACKNOWLEDGEMENTS

Many thanks to my thesis adviser, Duncan Sibley, for suggesting an interesting problem, providing assistance when it was needed and allowing me license in seeing the problem through to a favorable conclusion. Critical reading of the thesis together with many helpful comments and suggestions by the other members of my committee, John Wilband and Thomas Vogel, was much appreciated. Technical assistance in sample preparation and microprobe analysis was provided by Craig Tingey and Mr. Viv Shull respectively. Samples were supplied by the Deep Sea Drilling Project, Scripps Institution of Oceanography, through the assistance of the National Science Foundation.

Finally, I am eternally grateful to my wife, Carol, for her love and devotion during the course of my graduate studies, something worth more to me than any thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

INTRODUCTION

Two of the holes drilled in the Sea of Japan on leg 31 of the Deep Sea Drilling Project (Site 299 in the Yamato Basin and Site 301 in the Japan Basin) penetrated unconsolidated Neogene flysch sequences. The purpose of this investigation is to determine whether changes occurred in the sediment source through time (vertically within each hole) and space (laterally between basins) for the flysch sediments at Sites 299 and 301 and to determine if compositional differences between silt fractions in muds and sands exist. Hopefully, this provenance study will lend its support to one or another of the proposed models for the origin of the Sea of Japan outlined below.

A detailed mineralogical analysis using the petrographic microscope and electron microprobe was the method used for determining these provenance variations. Due to its chemical variability, feldspar is a valuable provenance indicator, and therefore the determination of its composition was stressed in this study. Another reason for concentrating on feldspars is that they are an important constituent in shales (the dominant flysch lithology) averaging about 4.5% of the total mineralogy (Shaw and Weaver, 1965). Feldspars also comprise a large portion of the minerals in the sediments from DSDP Sites 299 and 301 (plagioclase is especially abundant). X-ray data indicate that 28% of the bulk sample mineralogy is feldspar (Cook et al., 1975); point-counts show feldspar to compose 23% of the sands (Harrold and Moore, 1975).

FLYSCH PROVENANCE

Turbidity currents play a major role in the deposition of flysch, although arguments have been presented in favor of oscillatory currents (Grossgeym, 1972) and contour following currents (Heezen et al., 1966) for flysch formation. Most inferences as to sediment dispersal patterns and provenance of turbidites have been based on paleocurrent analyses from sedimentary structures. This method is useful in the determination of the provenance of the graywacke interbeds of ancient flysch sequences. However, provenance determination by use of lineated sedimentary structures has its drawbacks: 1) it has limited application for recent deep-sea sediments which can be sampled only by drilling and coring; 2) these structures are usually confined to the undersides of the turbidite sandstones (unit a of Bouma (1962) sequence) and are exposed only if the underlying shales have been eroded away; 3) since these sole marks are restricted to the sandstones, they therefore say nothing of the provenance of the hemipelagic shales; 4) distal turbidites (low sand/shale ratio) may contain only the upper portion of the Bouma sequence (units c-e) suggesting that the depositing medium of the basal unit did not possess the energy or clasticity necessary to produce sole markings; and 5) paleocurrent analysis by use of these structures may be difficult in areas where severe tectonic events inhibit plausible palinspastic restoration.

A more universal technique for determining sediment dispersal patterns and possible source terrains in both ancient flysch and recent deep-sea sediments is analysis of mineralogical composition. Much work has been done on the mineral composition of ancient flysch sequences to infer provenance, mostly in the form of point-counts of the light mineral fraction (Bokman, 1953; McBride, 1962; Ojakangas, 1968, 1972; Gilbert and Dickinson, 1970; Swe and Dickinson, 1970; Dickinson and Rich, 1972; Keighin et al., 1972; Gilbert, 1973; Hein, 1973; Moore, 1973; Murray and Condie, 1973; Lajoie et al., 1974; Ataman and Gökçen, 1975; Eisbacher, 1976; and Graham et al., 1976). There are some comparable studies also on modern equivalents (Hubert and Neal, 1967; Duncan and Kulm, 1970; Vallier et al., 1973; Nelson and Nilson, 1974; Harrold and Moore, 1975; Stewart, 1976; and Campbell and Clark, 1977). Almost all of this petrographic work has been confined to the arenite (graywacke) interbeds. A detailed mineralogical analysis of the clays and shales in flysch deposits is important because: 1) they are more ubiquitous than the sand and sandstone interbeds in both recent and ancient deposits; 2) sandstones may contain a larger percentage of altered mineral grains than do adjacent shale beds (apparently due to the greater permeability of the sandstones); this suggests that shales rather than sandstones should be used for petrographic analyses (Blatt and Sutherland, 1969); and 3) conclusions as to flysch provenance, sediment transport mechanisms and paleogeographic-tectonic setting based only on flysch sandstone mineralogy must be confirmed.

SEA OF JAPAN

The Sea of Japan is a marginal sea or back arc basin, and there are varied explanations for its origin. Unpopular "sinking landmass" ideas are propounded by Minato (1973) and Beloussov (1968). Sychev and Snegovsky (1976) believe that the sea represents a relict oceanic crust which was separated from the Pacific when the Japanese islands were formed by subduction of the Pacific plate. The predominant view holds that the sea originated by tensional subsidence and rifting during the Oligocene-Early Miocene interval (Karig et al., 1975). Uyeda and Miyashiro (1974) postulate that the Japan Sea opened up as a result of collision and subduction by a hypothetical Kula-Pacific ridge. Hasebe et al. (1970) and Matsuda and Uyeda (1971) consider that magmas generated along the upper surface of the descending oceanic plate rise through the upper mantle and create the new oceanic lithosphere of a marginal sea with a resultant oceanward drift of the crust to form an island arc. Karig (1971) has a similar view but emphasizes the periodic diapiric rise of mantle materials from the upper surface of the descending slab instead of the steady rise of a magma.

The Sea of Japan is divisible into a southeastern area of complex bathymetry characterized by major basins and rises and a northern and western area of simple bathymetry termed the Japan Basin or Abyssal Plain (Figure 1). Recent Soviet and Japanese refraction measurements in the Japan and Yamato Basins indicate that the crust is typically oceanic (Ludwig et al., 1975). The Yamato Basin has a shallower sea floor, thinner sediments, a shallower basement surface and a thicker basement layer when compared with the Japan Basin (Ludwig et al., 1975) which may indicate that the eastern part of the sea is younger than the western part. The fact that sediments are thickest on the west side of the Japan Basin may be a result of differential sedimentation rates rather than a decrease in crustal age toward the east. However, there are no large rivers along the Asian coast of the Sea of Japan and the sediments of the Japan Basin have a large biogenous component; hence a greater part of the terrigenous input to that basin is probably derived

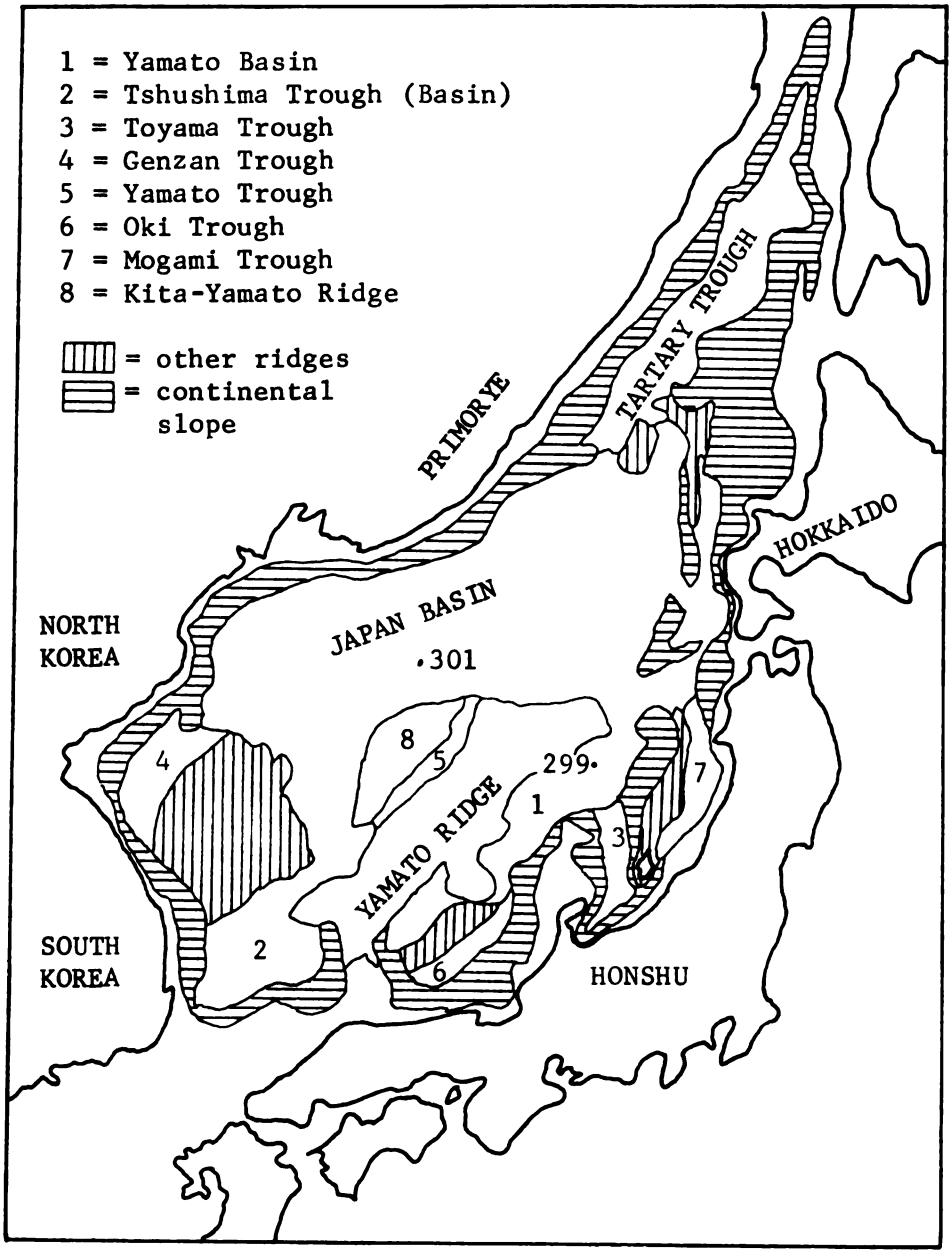


Figure 1. Major physiographic features of the Japan Sea showing locations of Sites 299 and 301 (from Hilde and Wageman, 1973, figure 2).

from Japan (Karig and Moore, 1975). Terrigenous sedimentation is in the form of turbidites which are distributed by channelized turbidity currents passing through Tartary trough, Genzan trough, Toyama trough, Mogami trough and to a lesser extent Tshushima trough (basin), Yamato trough and numerous submarine canyons on the steep continental slope adjacent to Primorye.

Site 299 in the Sea of Japan was drilled in an extension of the Toyama trough within the northeastern Yamato Basin; 532 meters of Recent through Late Miocene sand, silt and clay deposits were penetrated and 172.3 meters of cored sediment were recovered. These sediments have been interpreted as predominantly distal turbidites or alternatively as levee deposits on a deep-sea fan complex (Karig et al., 1975). Site 301 was drilled in the east central portion of the Japan Basin: a location selected so that it would be the furthest possible distance from any of the major channels feeding the abyssal plain (Bouma and Moore, 1975). The hole penetrated 496.5 meters below the sea floor and 183.5 meters of cored sediment were recovered. The section consists of 240.5 meters of Holocene to Late Pliocene distal turbidites, sands, silts and clays underlain by 256 meters of Late Pliocene to Late Miocene pelagic and hemipelagic diatomaceous oozes with a few terrigenous interbeds.

Data regarding source areas for the sediments drilled at Sites 299 and 301 are rather limited and interpretations vary. X-ray data are qualitative because of the large biogenous, amorphous and lithic components in some samples. Only a few analyses were performed: 7 for Site 299 and 9 for Site 301 (Cook et al., 1975). Harrold and Moore (1975) point-counted 28 deep-sea sand samples from leg 31 of the Deep Sea

Drilling Project (including 6 from Site 299 and 4 from Site 301) in order to delineate source areas for the sands. Their compositional analyses were similar in approach to others which have been performed on deep-sea sands and ancient graywackes and have the same drawbacks (see Flysch Provenance section). In addition, the large percentage of rock fragments (72% for Site 299 and 24% for Site 301) in this tectonic setting may preclude comparison of Harrold and Moore's data to ancient rocks because diagenesis and low-grade metamorphism may quickly reduce the percentage of lithic fragments (Cummins, 1962).

SAMPLE COLLECTION AND PREPARATION

Samples from Sites 299 and 301 in the Sea of Japan were obtained from the Deep Sea Drilling Project and are listed in Tables 1 and 2. For Site 299, these include 33 one cc samples from 8 cores and for Site 301, 8 one cc samples from 4 cores. The lithology of the sediments is dominantly silty clay and silty sand.

The very fine sand-coarse silt size fraction was separated out from each sample and used for the compositional analysis. Fan (1976) has shown that the silt fraction is more representative of total sediment composition than either the sand or clay fraction in Recent silts in the Santa Clara drainage basin. Sufficient material was present within this size class for all but 5 of the samples (3,4,40,46 and 47) and these five were therefore not included in the analysis. Samples 34 and 39 were excluded from the study because they contained only volcanic rock fragments and volcanic glass respectively.

Use of the same size fraction in different lithologies effectively eliminated the effects of textural sorting which have been shown to

Table 1. List of samples from Site 299, DSDP, leg 31.

Sample no.	Core-section	Interval (cm.)	Depth* (m.)	Age	Lithology
1	1-1	53-54	.53	L.Plst.-Hol.	silty clay
2	"	64-65	.64	"	"
5	2-3	75-76	13.25	"	sandy clay
6	"	100-101	13.5	"	"
7	5-5	53-54	44.53	L.Plst.	sandy silty clay
8	"	80-81	44.8	"	"
9	"	98-99	44.98	"	"
10	16-3	1-2	145.51	E.Plst.	silty clay
11	"	30-31	145.8	"	"
12	"	49-50	145.99	"	"
13	18-3	2-3	164.52	"	"
14	"	5-6	164.55	"	"
15	"	9-10	164.59	"	"
16	"	30-31	164.8	"	clayey silty sand
17	"	35-36	164.85	"	"
18	"	39-40	164.89	"	"
19	"	60-61	165.1	"	silty clay
20	"	65-66	165.15	"	clay
21	"	69-70	165.19	"	"
22	"	75-76	165.25	"	silty clay
23	"	80-81	165.3	"	"
24	"	84-85	165.34	"	"
25	"	120-121	165.7	"	clayey silty sand
26	"	125-126	165.75	"	"
27	"	129-130	165.79	"	"
28	24-2	100-101	221	"	silty clay
29	"	113-114	221.13	"	"
30	"	124-125	221.24	"	"
31	30-5	54-55	329.54	"	"
32	"	78-79	329.78	"	"
33	"	96-97	329.96	"	"
35	36-1	110-111	495.1	L.Mioc.	sandy clay
36	"	125-126	495.25	"	"

*indicates depth below sea floor to top of sample

Table 2. List of samples from Site 301, DSDP, leg 31.

Sample no.	Core-section	Interval (cm.)	Depth* (m.)	Age	Lithology
37	4-4	54-55	160.04	E.Plst.	silty clay
38	"	76-77	160.26	"	"
41	5-3	85-86	177.85	"	"
42	"	144-145	178.44	"	"
43	11-1	56-57	317.06	L.Plioc.	sandy silty clay
44	"	96-97	317.46	"	"
45	"	140-141	317.9	"	"
48	19-5	139-140	485.39	L.Mioc.	clay

*indicates depth below sea floor to top of sample

occur in turbidites (Shideler et al., 1975).

The samples were heated for 20 minutes in full strength HNO_3 to remove carbonates and grain coatings and to oxidize any organic matter present. They were then heated for another 20 minutes in .1M KOH to dissolve oxidized organic matter. The residue was then completely dispersed by treating the samples for 20 minutes with a .05M sodium hexametaphosphate ($Na_6P_6O_{18}$) solution in an ultrasonic bath. After each was washed and centrifuged 3 to 5 times after each intermediate step, the samples were subjected to a final set of washings and were wet-sieved using 200 and 325 mesh sieves. This procedure was generally effective in achieving its objectives and in order to assure that no apparent chemical or physical alteration occurred, the same treatments were first carried out on orthoclase, microcline, albite, labradorite and bytownite grains of equivalent size.

The sediment within each size fraction was dried and stored and the material retained on the 325 mesh sieve was weighed. The average weight in the very fine sand-coarse silt size class (the size fraction used in the study) was .19 grams with a large variation: ranging from 1.5 grams (in a sand unit) to .002 grams (in a clay unit).

Part of the material was mounted on a glass slide with Lakeside 70 (n=1.54) and used for the petrographic microscope work. Another split was retained for a polished grain mount necessary for the electron microprobe. For this purpose, ¼ inch lengths of 3/4 inch diameter glass tubing were glued to frosted slides on which a grid had been drawn. A-271 epoxy (Armstrong Products Co.) was then mixed with the sample in this receptacle and centrifuged for 12 minutes at 1800 RPM on a model K International Centrifuge with an attachment device developed specifically for this purpose. This technique insured that each grain of sediment lay on the glass slide with its long axis parallel to the slide and came to rest on a cleavage plane (if present). The preferred orientation of the cleavage plane and axis is useful in optical studies where a specific mineral orientation is desired. Finally, the epoxy-filled glass tubing was cut off slightly above the slide and polished grain mounts were prepared using the procedure outlined by Woodbury and Vogel (1970).

DATA COLLECTION AND ANALYSIS

Because certain minerals and mineral suites may be more predominant in a particular size range, use of different size fractions in different lithologies may introduce mineralogical sorting. Also, Shideler et al. (1975) demonstrated the occurrence of mineralogical sorting in cases where no textural differences exist between the top and bottom of a sandstone bed. Such sorting would be controlled by the specific gravity and shape of the various mineral constituents. The mineralogical sorting possibly introduced by these factors was probably not significant in this study because quartz and the various feldspars do not differ markedly in shape or specific gravity (the lowest - microcline has an SG of 2.54; the highest - anorthite has an SG of 2.76; quartz is intermediate at an SG of 2.65).

Petrographic analysis

Point-counts were made of the 41 Lakeside-mounted slides until approximately 250 monocrystalline quartz, feldspar: $n<1.54$ and feldspar: $n>1.54$ mineral grains were identified on each slide; the actual average is somewhat lower ($\bar{x}=241$, $s=24$) because some samples did not contain enough grains. Feldspar: $n<1.54$ includes the alkali feldspars as well as plagioclase between An0 and An30; feldspar: $n>1.54$ includes plagioclase between An30 and An100. A large percentage of the feldspar: $n<1.54$ (greater than 50% in each sample) is altered, probably a result of albitization of originally calcic plagioclase. The point-counts for each of the above categories were converted to percentages and various ratios were computed: feldspar: $n>1.54$/feldspar: $n<1.54$, monocrystalline quartz/feldspar and monocrystalline quartz/feldspar: $n<1.54$ (Tables 3 and 4). The means and standard deviations were computed for each of the above categories for all the samples at Sites 299 and 301 (Table 7); in addition, $\bar{x}$ and s were computed for the samples in each category within the Early Pleistocene and Late Miocene time intervals (Table 8). The Chi-square test (corrected for continuity) was used to determine if statistically significant differences could be detected in %monocrystalline quartz, %feldspar: $n<1.54$ and %feldspar: $n>1.54$ for a particular sample and the sample immediately under it. If a significant difference exists ($\alpha=.05$) an asterisk (*) is shown next to the percentage; a highly significant difference ($\alpha=.01$) is indicated by 2 asterisks (**). Finally, $\bar{x}$ and s were computed for each category for

Table 3. Point-count data for Site 299 samples.

Spl. no.	Age	A	B	C	D	E	F	G	H
1	L.Plst.-Hol.	183	44.3	40.9	14.8	55.7	.36	.80	1.08
2	"	247	43.7	40.1	16.2	56.3	.40	.78	1.09
5	"	250	36.8**	43.2**	20.0	63.2	.46	.58	.85
6	"	249	20.5**	59.8**	19.7	79.5	.33	.26	.34
7	L.Plst.	176	34.1	41.5	24.4	65.9	.59	.52	.82
8	"	136	38.2*	36.8	25**	61.8	.68	.62	1.04
9	"	249	26.1*	29.3	44.6**	73.9	1.52	.35	.89
10	E.Plst.	251	36.7	36.7	26.7	63.3	.73	.58	1
11	"	247	29.6*	37.2	33.2	70.4	.89	.42	.80
12	"	247	40.5	30	29.6	59.5	.99	.68	1.35
13	"	249	40.6	32.5	26.9	59.4	.83	.68	1.25
14	"	249	35.3	30.1	34.5	64.7	1.15	.55	1.17
15	"	249	41	31.7	27.3	59	.86	.69	1.29
16	"	250	40.8	32.8	26.8	59.6	.82	.68	1.24
17	"	249	41.4	24.9*	33.7	58.6	1.35	.71	1.66
18	"	248	39.5	33.5	27	60.5	.81	.65	1.18
19	"	248	41.9	33.9	24.2	58.1	.71	.72	1.24
20	"	217	46.1	35.9	18	53.9	.50	.86	1.28
21	"	212	45.3	35.8	18.9	54.7	.53	.83	1.27
22	"	248	46.4	30.6	23	53.6	.75	.87	1.52
23	"	248	44.8	37.5	17.7	55.2	.47	.81	1.19
24	"	248	41.5	35.9	22.6	58.5	.63	.71	1.16
25	"	248	43.1	36.3	20.6	56.9	.57	.76	1.19
26	"	248	42.3	34.3	23.4**	57.7	.68	.73	1.23
27	"	248	33.5*	26.6*	39.9**	66.5	1.50	.50	1.26
28	"	248	44	35.5	20.6	56	.58	.79	1.24
29	"	250	38.8	36	25.2	61.2	.70	.63	1.08
30	"	250	38*	36.8**	25.2	62	.68	.61	1.03
31	"	250	48	24.4*	27.6*	52	1.13	.92	1.97
32	"	250	47.2	33.2	19.6	52.8	.59	.89	1.42
33	"	250	49.6	36	14.4*	50.4	.40	.98	1.38
35	L.Mioc.	251	49	28.3	22.7	51	.80	.96	1.73
36	"	251	53.4	25.1	21.5	46.6	.86	1.15	2.13

A - total monocrystalline quartz + feldspar
B - %monocrystalline quartz[1]
C - %feldspar: n<1.54
D - %feldspar: n>1.54
E - %total feldspar[2]
F - feldspar; n>1.54/feldspar: n<1.54
G - monocrystalline quartz/feldspar
H - monocrystalline quartz/feldspar: n<1.54

[1]sum of %monocrystalline quartz, %feldspar: n<1.54 and %feldspar: n>1.54 is approximately 100% for each sample.

[2]altered feldspar grains are included in the point-count data.

Table 3 (contd.).

*indicates a significant difference (α=.05) in this component for this sample and the one immediately under it

**indicates a highly significant difference (α=.01) in this component for this sample and the one immediately under it

the clays and sands of core-section 18-3 from Site 299 (Table 9).

Electron microprobe analysis

Analyses of K, Ca and Na were performed on 993 feldspar grains in 41 polished grain mounts ($\bar{x}$=24, s=5) using a 3-spectrometer ARL model EMX-SM electron microprobe. Each grain was analyzed in 5 places at a beam current of 40,000 microamps (constant) and voltage of 15 kV for approximately 10 seconds per analysis. The composition of each grain was determined in terms of Wt% Anorthite (An), Wt% Albite (Ab) and Wt% Orthoclase (Or) using the formulae:

$$\text{Wt\% An} = \frac{\dfrac{CPS_u^{Ca}}{CPS_{An\ Std}^{Ca}} \cdot B_{An\ Std}^{Ca}}{\dfrac{CPS_u^{Ca}}{CPS_{An\ Std}^{Ca}} \cdot B_{An\ Std}^{Ca} + \dfrac{CPS_u^{Na}}{CPS_{Ab\ Std}^{Na}} \cdot B_{Ab\ Std}^{Na} + \dfrac{CPS_u^{K}}{CPS_{Or\ Std}^{K}} \cdot B_{Or\ Std}^{K}} \times 100$$

$$\text{Wt\% Or} = \frac{\dfrac{CPS_u^{K}}{CPS_{Or\ Std}^{K}} \cdot B_{Or\ Std}^{K}}{\dfrac{CPS_u^{K}}{CPS_{Or\ Std}^{K}} \cdot B_{Or\ Std}^{K} + \dfrac{CPS_u^{Ca}}{CPS_{An\ Std}^{Ca}} \cdot B_{An\ Std}^{Ca} + \dfrac{CPS_u^{Na}}{CPS_{Ab\ Std}^{Na}} \cdot B_{Ab\ Std}^{Na}} \times 100$$

where CPS is counts per second, u is the unknown and the B's are correction factors computed according to Sweatmen and Long (1969) for the

Table 4. Point-count data for Site 301 samples.

Spl. no.	Age	A	B	C	D	E	F	G	H
37	E.Plst.	250	64**	23.6	12.4	36	.53	1.78	2.71
38	"	250	50*	29.6	20.4	50	.69	1.0	1.69
41	"	250	40.4	36	23.6	59.6	.66	.68	1.12
42	"	250	43.6	38.4	18	56.4	.47	.77	1.14
43	L.Plioc.	232	48.7*	34.9	16.4*	51.3	.47	.95	1.40
44	"	251	38.6	35.9	25.5	61.4	.71	.63	1.08
45	"	250	45.2	33.6	21.2	54.8	.63	.82	1.35
48	L.Mioc.	250	47.2	34.4	18.4	52.8	.53	.89	1.37

A - total monocrystalline quartz + feldspar
B - %monocrystalline quartz[1]
C - %feldspar: n<1.54
D - %feldspar: n>1.54
E - %total feldspar[2]
F - feldspar: n>1.54/feldspar: n<1.54
G - monocrystalline quartz/feldspar
H - monocrystalline quartz/feldspar: n<1.54

[1]sum of %monocrystalline quartz, %feldspar: n<1.54 and %feldspar: n>1.54 is approximately 100% for each sample.

[2]altered feldspar grains are included in the point-count data.

*indicates a significant difference (α=.05) in this component for this sample and the one immediately under it

**indicates a highly significant difference (α=.01) in this component for this sample and the one immediately under it mineral standards used. Wt% Ab was found by subtracting Wt% An + Wt% Or from 100% to insure that no rounding error occurred. It should be noted that only unaltered feldspar grains were analyzed with the microprobe, whereas many of these altered grains were included in the petrographic analysis. Therefore a literal comparison of microprobe and point-count data cannot be made.

The composition of each grain was plotted in the ternary system of An, Ab and Or; the feldspar grains in each sample are illustrated in this manner in 41 separate triangular diagrams (see Appendix). In order to evaluate the microprobe data quantitatively, the points in each diagram were arranged in certain compositional groups which consistently contained significant numbers of grains (Tables 5 and 6). The means and standard deviations were computed for each compositional group for all the samples at Sites 299 and 301 (Table 7); in addition, $\bar{x}$ and s were computed for the samples in each category within the Early Pleistocene and Late Miocene time intervals (Table 8). The Fisher exact probability test (Siegel, 1956) and the Chi-square test (where applicable) were used to determine if statistically significant differences could be detected in any of the compositional groups for a particular sample and the sample immediately under it. If a significant difference exists (α=.05), an asterisk is shown next to the percentage; a highly significant difference (α=.01) is indicated by two asterisks.

The average %An values of the plagioclase in each sample and the average %An values of the total feldspar in each sample are listed in Tables 5 and 6; their means and standard deviations for total and age (as described above) are listed in Tables 7 and 8. Differences in these two groups were not evaluated using the Fisher test or Chi-square

Table 5. Microprobe data[1] for Site 299 samples.

Spl. no.	Age	# of grns.	An 0-10 (%)	An 10-20 (%)	An 20-30 (%)	An 30-40 (%)	An 50-60 (%)	An 60-70 (%)	Or 85-100 (%)	Or 40-60 (%)	An 0-30 (%)	An 20-50 (%)	An 30-50 (%)	An 50-70 (%)	An 50-90 (%)	Avg. %An plag.	Avg. %An total feld.
1	L.Plst.-Hol.	27	7	4	19	11	7	15	11	0	30	37	19*	22	37	43.7	37.3
2	"	24	8	8	17	0	4	21	25	8	33	17	0*	25	33	42.3	28.4
5	"	27	15*	15	7	11	19	11	7	0**	37*	30	22	30	33	36.1	33.5
6	"	29	0	7	3	0	14	7	10	31	10	17	14	21	31	51.7	30.2
7	L.Plst.	30	10	0	7	10	17	10	3**	20	17	30	23	27	37	45.6	35.6
8	"	25	8	4	4	4	16	20	20	4*	16	20	16	36	44	48.6	37.1
9	"	26	8	4	8	4*	19	8	8	31**	19	12**	4**	27	35	44.2	26.8
10	E.Plst.	25	4	4	12	24	20	8	4	0	20	56	44	28	32	42.2	40.5
11	"	34	3	6	0	21	18	9	6	0	9	41	41	26	35	45.9	39.2
12	"	27	11	4	4	7	22	19	7	4	19	26	22	41	48	45.8	40.8
13	"	25	4	4	0*	12	12	36*	20	0	8**	20	20	48	52	51.2	41
14	"	15	20	7	27	13	13	7	0*	0	53	47	20	20	27	33.1	33.1
15	"	25	16	0*	28	8	0*	16	24*	0	44	44**	16	16	16	31	23.7
16	"	16	19	25	6	0	19	19	0	0	50	6	0	38	50	38.6	38.6
17	"	18	28*	6	6	11	6	11	17	0	39	22	17	17	28	34.5	29.6
18	"	16	0	6	13	25	13	6	19	0	19	50	38	19	25	40.6	33
19	"	30	33	7	10	13	3	3*	20	0	50	30	20	7	10	23.2	18.7
20	"	17	24	0	6	18	6	24	18	0	29	29	24	29	29	36.4	30
21	"	19	16	11	21	11	16	16	11	0	47	32	11	32	32	34	30.5
22	"	27	11	4	15	15	7	15	19	0	30	37	22	22	26	38.7	30.3
23	"	27	4	4	19	15*	22	19	4**	0	26	48	30*	41	41	43.2	41.6
24	"	28	7*	7	18	0	11	14	32	0	32	25	7	25	29	38.3	26.1
25	"	20	35	5	10	10	10	5	15	0	50	20	10	15	25	29.6	25.3
26	"	20	20	15	0	0*	0	20	30	10	35	5*	5	20	20	34.2	21.8
27	"	23	22	9	4	22	9	13	13	0	35	30	25	22*	26	32.5	28.3
28	"	18	6	17	6	17	0*	0	28	0	28	33	28	0**	6*	36.8	24.7
29	"	26	4*	4	4	31**	27	4	8	0	12*	46**	42**	31	35	42.6	37.8
30	"	18	33*	11	0	6	22	11	11	0	44	6	6	33	39	32	28.5
31	E.Plst.	29	7	7	0	0	28	24	14	3	14	10	10	52	59	50.6	41.9

Table 5 (contd.).

Spl. no.	Age	# of grns.	An 0-10 (%)	An 10-20 (%)	An 20-30 (%)	An 30-40 (%)	An 50-60 (%)	An 60-70 (%)	Or 85-100 (%)	Or 40-60 (%)	An 0-30 (%)	An 20-50 (%)	An 30-50 (%)	An 50-70 (%)	An 50-90 (%)	Avg. %An plag.	Avg. %An total feld.
32	E.Plst.	24	13	0	13	4	25	25	13	0	25	17	4	50	58	46.6	40.8
33	"	26	19	4	8	12	19	15	23	0	31	19	12	35	35	36.1	27.8
35	L.Mioc.	21	14	5	5	14	14	19	19	0	24	19	14	33	43	44.6	36.2
36	"	26	0	4	8	4	12	27	19	0	12	27	19	38	46	51.7	39.9

Table 6. Microprobe data[1] for Site 301 samples.

Spl. no.	Age	# of grns.	An 0-10 (%)	An 10-20 (%)	An 20-30 (%)	An 30-40 (%)	An 50-60 (%)	An 60-70 (%)	Or 85-100 (%)	Or 40-60 (%)	An 0-30 (%)	An 20-50 (%)	An 30-50 (%)	An 50-70 (%)	An 50-90 (%)	Avg. %An plag.	Avg. %An total feld.
37	E.Plst.	24	38*	4	8	4	8	4	29	0	50	17	8	13	13	21.7	15.5
38	"	27	7	7	15	4	7	15	26	4	30	22	7	22	22	35.9	22.4
41	"	29	3	0	10	14	3	3	45	7	14	38	28*	7	7	35.9	17.7
42	"	16	13	6	19	0	0	0	56	6	38	19	0*	0	0	17.9	7
43	L.Plioc.	27	19*	7	11	11	4	7	30	0*	37	33	22	11	11	28.5	20.2
44	"	27	0	7	19	19	4	0	33	19	26	37	19	4	4	28.5	14
45	"	27	11	4	11	19	7	4	15	11	26	44	33	11	11	33.1	23.9
48	L.Mioc.	28	18	18	7	7	4	18	11	0	43	21	14	21	21	30.6	24.3

*indicates a significant difference (α=.05) in this component for this sample and the one immediately under it

**indicates a highly significant difference (α=.01) in this component for this sample and the one immediately under it

[1]Only those microprobe compositional groups which contain significant numbers of grains and in which statistically significant vertical compositional changes can be detected are included in Tables 5 and 6; therefore some compositional intervals are missing from these tables. Complete microprobe data can be found in the Appendix. Some feldspar compositional groups overlap because certain arrangements better represent the differences between 2 samples than others. Note that altered feldspar grains were excluded from the microprobe analysis.

since these tests require specific counts rather than percentages. The average %An values of the total feldspar in each sample are plotted in a triangular diagram (Figure 2).

The means and standard deviations were computed for each compositional group for the clays and sands of core-section 18-3 from Site 299 (Table 9).

<u>Summary of point-count and microprobe data</u>

In order to facilitate the comparison of appropriate sets of data, the means and standard deviations of the foregoing analyses are listed in Tables 7, 8 and 9. Means were compared using the t-test and where applicable, the Fisher test or Chi-square. Significant differences (α=.05) and highly significant differences (α=.01) are indicated by one and two asterisks respectively. The histograms in Figure 3 illustrate the petrographic and microprobe data at Sites 299 and 301.

Certain correlations between compositional groups and between compositional groups and depth below the sea floor were evaluated. The simple correlation coefficient (r) was computed for each correlation and tested for significance. Those correlations judged to be significant (α=.05) and highly significant (α=.01) are listed in Table 10 for each site. Figure 4 illustrates the correlations of depth with %monocrystalline quartz and %feldspar: $n<1.54$; %feldspar: $n>1.54$ with %feldspar: $n<1.54$ and %monocrystalline quartz; and %feldspar: $n<1.54$ with %monocrystalline quartz for Site 299. Figure 5 illustrates the correlations of %monocrystalline quartz with %feldspar: $n>1.54$ and %feldspar: $n<1.54$ at Site 301.

Since each point-count and microprobe compositional group is presented as a percentage out of 100, a lack of independence between the

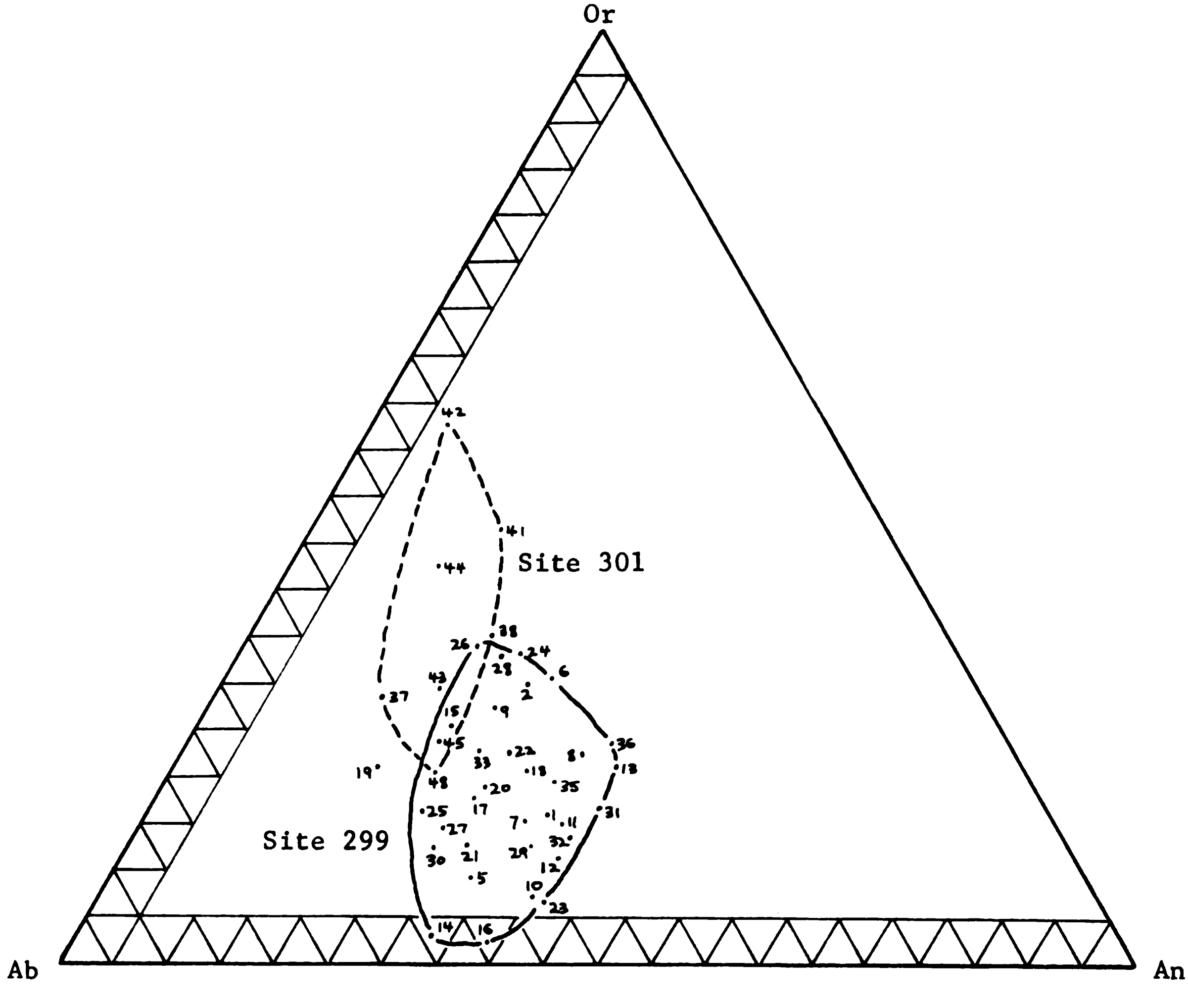


Figure 2. Plot of the average %An (and %Or) values of the total probe-analyzed feldspar in each sample. Note that Site 299 is more basic or conversely that Site 301 is more acidic.

Table 7. Summary of point-count and microprobe data for samples at Sites 299 and 301.

	SITE 299		SITE 301	
Point-count	$\bar{x}$	s	$\bar{x}$	s
%monocrystalline quartz	40.7*	(6.8)	47.2	(7.8)
%feldspar: n<1.54	34.6	(6.5)	33.3	(4.7)
%feldspar: n>1.54	24.7*	(6.8)	19.5	(4.1)
%total feldspar	59.3*	(6.8)	52.8	(7.8)
feldspar: n>1.54/ feldspar: n<1.54	.75	(.30)	.59	(.10)
monocrystalline quartz/ feldspar	.71	(.18)	.94	(.36)
monocrystalline quartz/ feldspar: n<1.54	1.22	(.33)	1.48	(.53)
Microprobe	$\bar{x}$	s	$\bar{x}$	s
%An0-10	13	(10)	14	(12)
%An10-20	7	(5)	7	(5)
%An20-30	9	(8)	13	(5)
%An30-40	11	(8)	10	(7)
%An50-60	14	(8)	5	(3)
%An60-70	14	(8)	6	(7)
%Or85-100	14*	(9)	31	(15)
%Or40-60	3	(8)	6	(7)
%An0-30	29	(13)	33	(11)
%An20-50	28	(14)	29	(10)
%An30-50	18	(12)	16	(11)
%An50-70	28**	(12)	11	(8)
%An50-90	34**	(12)	11	(8)
Avg. %An				
-plagioclase	40.2**	(7)	29.2	(6.7)
-total feldspar	32.7**	(6.5)	18.1	(5.9)

*indicates a significant difference (α=.05) in this component between this mean and the equivalent mean at Site 301

**indicates a highly significant difference (α=.01) in this component between this mean and the equivalent mean at Site 301

Table 8. Summary of point-count and microprobe data for Early Pleistocene and Late Miocene samples at Sites 299 and 301.

	EARLY PLEISTOCENE				LATE MIOCENE		
	Site 299		Site 301		Site 299		Site 301
Point-count	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$
%monoxln. quartz	41.5	(4.7)	49.5	(10.5)	51.2	(3.1)	47.2
%feldspar: n<1.54	33.3	(3.8)	31.9	(6.7)	26.7*	(2.3)	34.4
%feldspar: n>1.54	25.3*	(6)	18.6	(4.7)	22.1	(.9)	18.4
%total feldspar	58.5	(4.7)	50.5	(10.5)	48.8	(3.1)	52.8
feldspar: n>1.54/ feldspar: n<1.54	.79	(.27)	.59	(.11)	.83	(.04)	.53
monoxln. quartz/ feldspar	.72	(.14)	1.06	(.50)	1.06	(.13)	.89
monoxln. quartz/ feldspar: n<1.54	1.27	(.23)	1.67	(.75)	1.93	(.28)	1.37
Microprobe	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$
%An0-10	15	(11)	15	(16)	7	(10)	18
%An10-20	7	(6)	4	(3)	5	(1)	18
%An20-30	10	(8)	13	(5)	7	(2)	7
%An30-40	12	(9)	6	(6)	9	(7)	7
%An50-60	14	(9)	5	(4)	13	(1)	4
%An60-70	14	(8)	6	(7)	23	(6)	18
%Or85-100	15**	(9)	39	(14)	19	(0)	11
%Or40-60	1	(2)	4	(3)	0	(0)	0
%An0-30	31	(14)	33	(15)	18*	(9)	43
%An20-50	29	(15)	24	(10)	23	(6)	21
%An30-50	20	(13)	11	(12)	17	(4)	14
%An50-70	28	(13)	11	(9)	36	(4)	21
%An50-90	33**	(14)	11	(9)	45	(2)	21
Avg. %An							
-plagioclase	38.2*	(6.9)	28.3	(9.9)	48.2	(5)	30.6
-total feldspar	32.2**	(7.1)	15.7	(6.4)	38.1	(2.6)	24.3

*indicates a significant difference (α=.05) in this component between this mean and the mean of equivalent age at Site 301

**indicates a highly significant difference (α=.01) in this component between this mean and the mean of equivalent age at Site 301

Table 9. Summary of point-count and microprobe data[1] for clay and sand samples, core-section 18-3, E. Pleistocene, Site 299.

	CLAY[2]		SAND[3]	
Point-count	$\bar{x}$	s	$\bar{x}$	s
%monocrystalline quartz	42.5	(3.5)	40.1	(3.5)
%feldspar: n<1.54	33.8	(2.7)	31.4	(4.6)
%feldspar: n>1.54	23.7	(5.4)	28.6	(7.1)
%total feldspar	57.5	(3.5)	60	(3.5)
feldspar: n>1.54/ feldspar: n<1.54	.71	(.22)	.96	(.38)
monocrystalline quartz/ feldspar	.75	(.11)	.67	(.09)
monocrystalline quartz/ feldspar: n<1.54	1.26	(.11)	1.29	(.18)
Microprobe	$\bar{x}$	s	$\bar{x}$	s
%An0-10	15	(10)	21	(12)
%An10-20	5	(4)	11	(8)
%An20-30	16	(9)	7	(5)
%An30-40	12	(5)	11	(11)
%An50-60	10	(7)	10	(6)
%An60-70	17	(10)	12	(6)
%Or85-100	16	(10)	16	(10)
%Or40-60	0	(0)	2	(4)
%An0-30	35	(14)	38	(12)
%An20-50	35	(10)	22	(17)
%An30-50	19	(7)	16	(14)
%An50-70	27	(13)	22	(8)
%An50-90	29	(12)	29	(11)
Avg. %An - plagioclase	36.6	(7.9)	35	(4)
Avg. %An - total feld.	30.6	(7.5)	29.4	(5.9)

[1] Note that no statistically significant differences were found between the clay and sand samples.

[2] Number of samples = 9 (samples 13-15 and 19-24).

[3] Number of samples = 6 (samples 16-18 and 25-27).

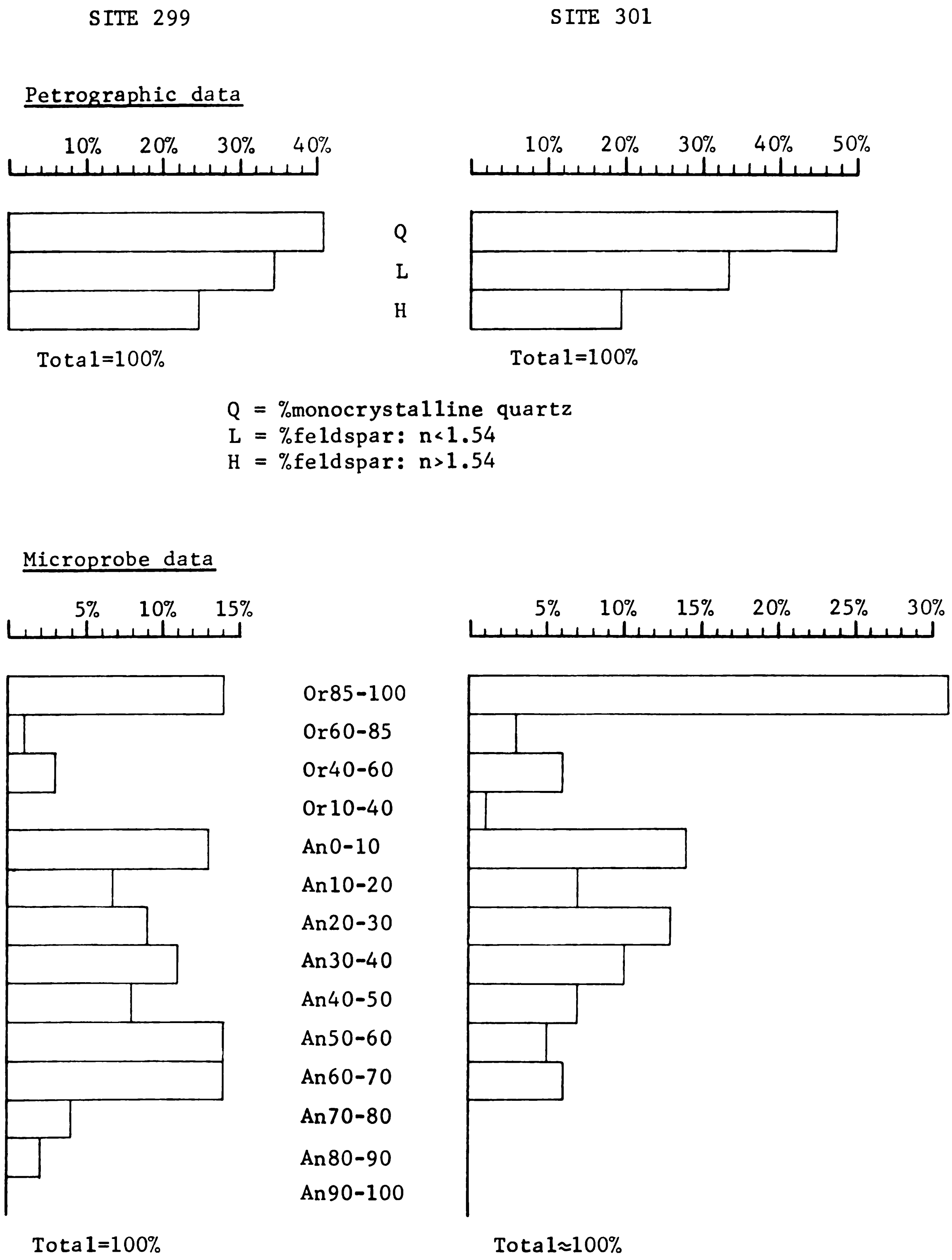


Figure 3. Histograms illustrating petrographic data (including altered feldspar grains) and microprobe data (for all the feldspar grains analyzed) for Sites 299 and 301 samples. Note that altered feldspars were excluded from the microprobe analysis.

Table 10. Significant correlations of point-count and microprobe data.

SITE 299 (Number of samples = 33)

Correlation	"r"
depth and %monocrystalline quartz	.634**
depth and %feldspar: n<1.54	-.571**
depth and monoxln. quartz/feldspar: n<1.54	.777**
%feldspar: n>1.54 and %feldspar: n<1.54	-.483**
%feldspar: n>1.54 and %monoxln. quartz	-.534**
%feldspar: n<1.54 and %monoxln. quartz	-.482**
%Or85-100 and %monocrystalline quartz	.422*

SITE 301 (Number of samples = 8)

Correlation	"r"
%feldspar: n>1.54 and %monoxln. quartz	-.876**
%feldspar: n<1.54 and %monoxln. quartz	-.903**
%An0-10 and %monocrystalline quartz	.913**
%An0-30 and %monocrystalline quartz	.755*

*indicates a significant (α=.05) value of "r".

**indicates a highly significant (α=.01) value of "r".

variables may result; this may be especially true for the point-count data because there are only three components. In this circumstance, there is a strong bias toward negative correlation between the variables of the closed array (Chayes, 1962). To remedy this situation, Chayes suggests the use of the Fisher z transformation (Steele and Torrie, 1960). The z transformation was done on the correlation coefficients of Table 10 and the subsequently performed t-tests confirmed the statistical significance of the "r"'s listed.

VERTICAL CHANGES IN SEDIMENT COMPOSITION

Site 299

Vertical changes in sediment composition at Site 299 are assumed to occur where statistically significant differences in a compositional group exist between a particular sample and the one immediately under

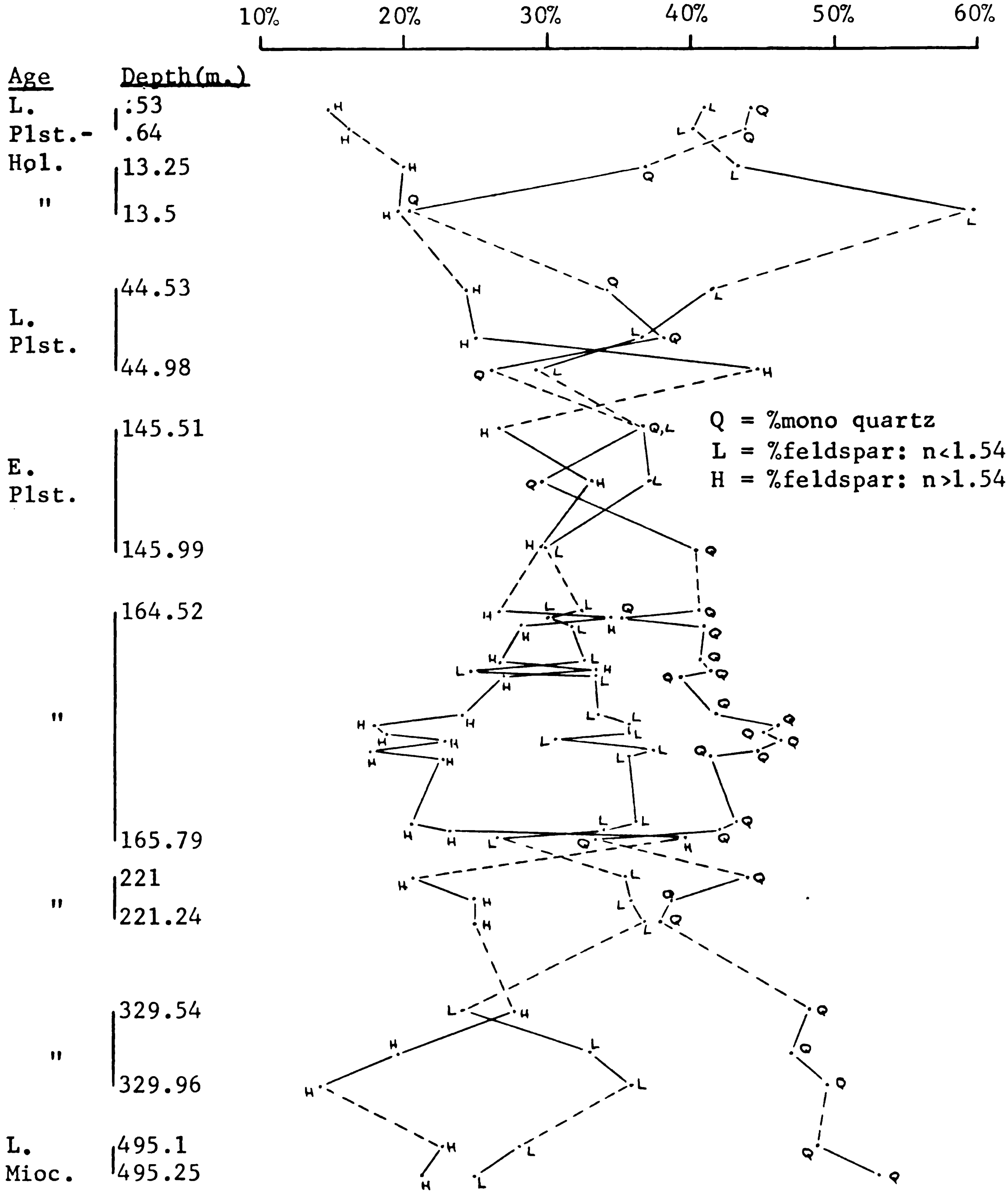


Figure 4. Diagram illustrating the correlations of depth with Q and L, H with L and Q, and L with Q at Site 299.

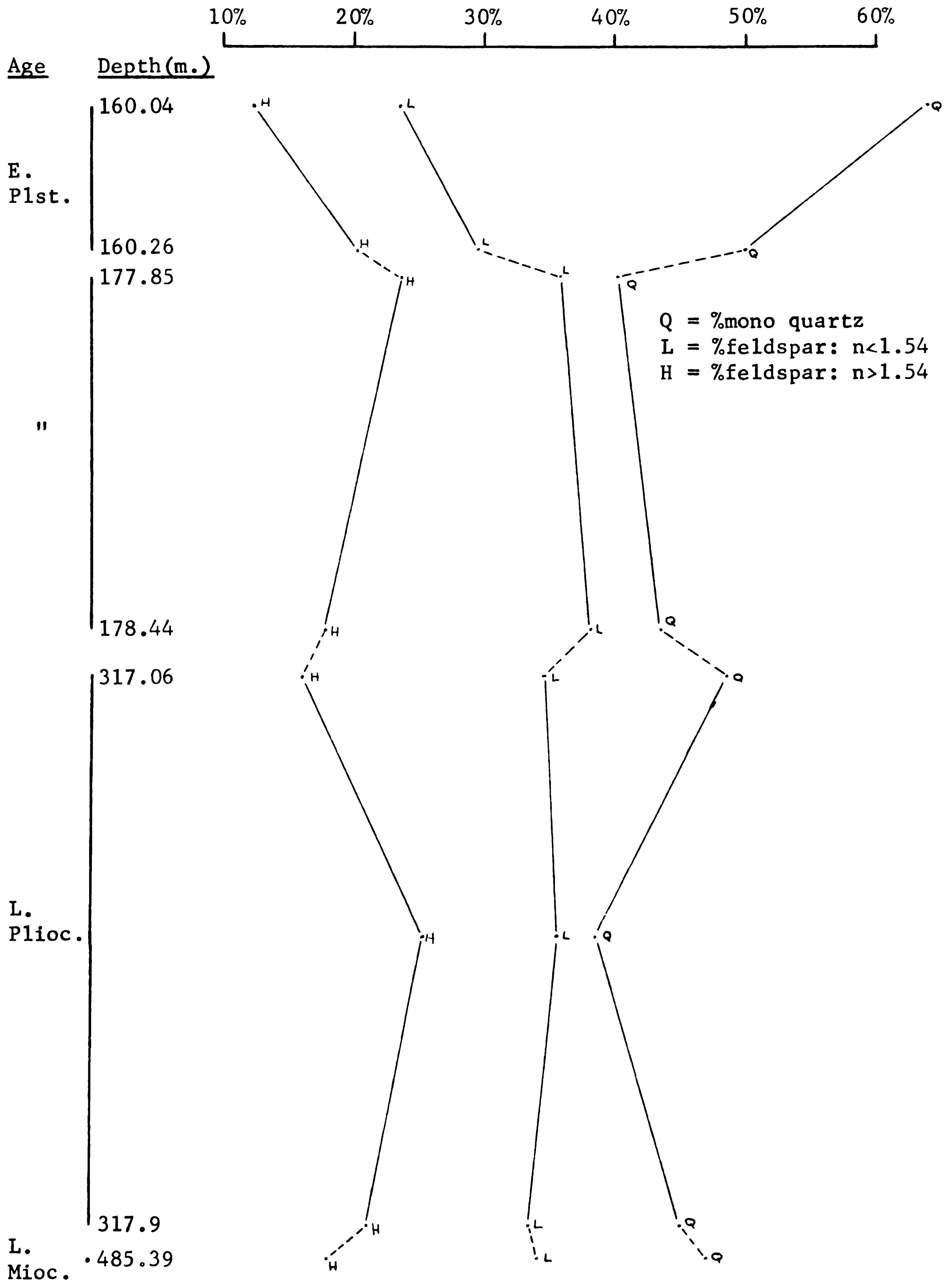


Figure 5. Diagram illustrating the correlations of Q with H and L at Site 301.

it (see Tables 3 and 5). These changes are noted in Table 11 for the sake of clarification; some unenlightening redundant data have been omitted. Sample 1 contains 44.3% monocrystalline quartz, 40.9% feldspar: n<1.54 and 14.8% feldspar: n>1.54; its triangular diagram (Figure A-1) indicates Or85-100 (11%) and An0-10 (7%) components with the rest of the feldspar spread from An17 to An78.

In most cases, the probe and point-count compositional changes of Table 11 agree or at least can be rationalized; for example, in the interval 5-6 an increase in %feldspar: n<1.54 can be explained by a corresponding increase in %Or40-60 even though the increase in %feldspar: n<1.54 conflicts with the decreases in %monocrystalline quartz, %An0-10 and %An0-30. The microprobe is obviously more sensitive to feldspar compositional changes than is the microscope (especially as used in this study) and therefore changes in probe compositional groups are justifiably more frequent than changes in microscope compositional groups.

The correlations listed in Table 10 indicate that the percent of monocrystalline quartz increases and the percent of feldspar: n<1.54 decreases with depth below the sea floor at Site 299; there is also a negative correlation of %monocrystalline quartz with %feldspar: n<1.54. One might expect a positive correlation of quartz and feldspar: n<1.54. The negative correlation may be explained by a large influx through time of non-quartz related detrital feldspar: n<1.54 although the effect of the constant sum data may be influential also. The presence of this feldspar may be a result of low-grade metamorphism or spilitization of basic igneous rocks in the source area causing albitization of Ca plagioclase in the rock; rocks of this type were present in the

Table 11. Vertical changes in sediment composition at Site 299.

Sample interval	COMPOSITIONAL CHANGES Increase	Decrease
1-2		%An30-50
2-5	%An30-50	
5-6	%feldspar: n<1.54; %Or40-60	%monocrystalline quartz; %An0-10; %An0-30
6-7	%monocrystalline quartz	%feldspar: n<1.54
7-8	%Or85-100	
8-9	%feldspar: n>1.54; %Or40-60	%monocrystalline quartz
9-10	%monocrystalline quartz; %An30-50	%feldspar: n>1.54; %Or40-60
11-12	%monocrystalline quartz	
13-14	%An20-30; %An0-30	%An60-70
14-15	%Or85-100	
15-16	%An10-20; %An50-60	%Or85-100; %An20-50
17-18	%feldspar: n<1.54	%An0-10
19-20	%An60-70	
23-24	%Or85-100	%An30-50
24-25	%An0-10	
26-27	%feldspar: n>1.54; %An30-40	
27-28	%monocrystalline quartz; %feldspar: n<1.54	%feldspar: n>1.54; %An50-70
28-29	%An50-60	
29-30	%An0-10	%An30-50
30-31	%monocrystalline quartz	%feldspar: n<1.54; %An0-10
31-32	%feldspar: n<1.54	%feldspar: n>1.54
33-35	%feldspar: n>1.54	

source area of Site 299 during Neogene time. The negative correlation of %monocrystalline quartz and %feldspar: n>1.54 and the positive one of %monocrystalline quartz with %Or85-100 are evidence that the data themselves are legitimate. That is, these last two correlations argue against the possibility that the negative correlation of %monocrystalline quartz with %feldspar: n<1.54 is simply due to the influence of a quartz-rich, feldspar-poor source (e.g., a quartz arenite). A large number of the feldspar: n<1.54 grains are altered and were therefore not included in the probe data because good compositional analyses were impossible to obtain on these grains. Therefore the lack of a correlation of %An0-10 or %An0-30 with %monocrystalline quartz makes the strongly felt presence of a sedimentary-type source conceivable but improbable.

Site 301

No significant correlations of any compositional groups with depth were obtained at Site 301; this was most likely due to the small number of samples (8) procured. However, highly significant negative correlations of %monocrystalline quartz with %feldspar: n<1.54 and %feldspar: n>1.54 are present at this site also; the latter can be interpreted in the same manner as at Site 299 and the former is again evidence that the data are legitimate. The positive correlations of %An0-10 and %An0-30 with %monocrystalline quartz also support the legitimacy of the data.

Vertical changes in sediment composition at Site 301 are assumed to occur where statistically significant differences in a compositional group exist between a particular sample and the one immediately under it (see Tables 4 and 6). These changes are summarized in Table 12.

Table 12. Vertical changes in sediment composition at Site 301.

	COMPOSITIONAL CHANGES	
Sample interval	Increase	Decrease
37-38		%monocrystalline quartz %An0-10
38-41		%monocrystalline quartz
41-42		%An30-50
42-43	%An30-50	
43-44	%feldspar: n>1.54; %Or40-60	%monocrystalline quartz; %An0-10

Sample 37 contains 64% monocrystalline quartz, 23.6% feldspar: n<1.54 and 12.4% feldspar: n>1.54; its ternary diagram (Figure A-34) indicates predominant components of Or85-100 (29%) and An0-10 (38%) with the remaining feldspar spread from An10 to An66.

Fewer compositional changes occur at Site 301 in large part due to the paucity of samples and therefore the correspondence of probe-microscope changes cannot be properly evaluated.

LATERAL CHANGES IN SEDIMENT COMPOSITION

Table 7 presents a summary of microprobe and point-count data for Sites 299 and 301. The large compositional variations within the samples at each site prevent many compositional differences between the sites from being recorded. There are however, statistically significant differences in %monocrystalline quartz, %feldspar: n>1.54, %Or85-100, %An50-90, average %An-plagioclase and average %An-total feldspar between Sites 299 and 301 (this last difference is illustrated in Figure 2); Site 299 sediments on the average contain higher percentages of %feldspar: n>1.54, %An50-90, average %An-plagioclase and average

%An-total feldspar and lower percentages of %monocrystalline quartz and %Or85-100 than do Site 301 sediments.

Late Miocene

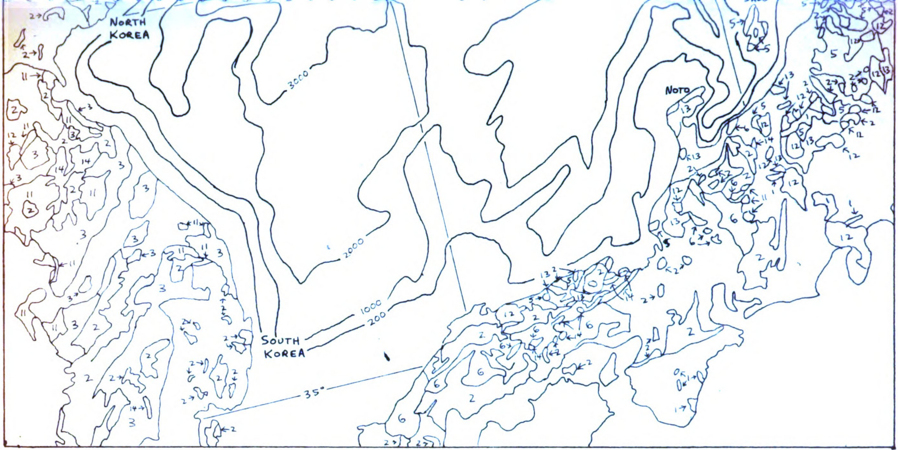
Table 8 contains a summary of point-count and probe data for Late Miocene and Early Pleistocene samples at Sites 299 and 301. The small number of samples of Late Miocene age (2 for Site 299 and 1 for Site 301) preclude many statistical comparisons from being made. However, Site 299 contains less feldspar: n<1.54 and less %An0-30 than Site 301. Some statistically non-significant differences between the two sites are: Site 299 contains higher percentages of %feldspar: n>1.54, average %An-plagioclase, average %An-total feldspar and %An50-90 and a lower percentage of %Or85-100 than Site 301.

Early Pleistocene

Early Pleistocene sediments at Site 299 contain less %Or85-100 and higher percentages of %feldspar: n>1.54, %An50-90, average %An-plagioclase and average %An-total feldspar than do Site 301 sediments of the same age (Table 8).

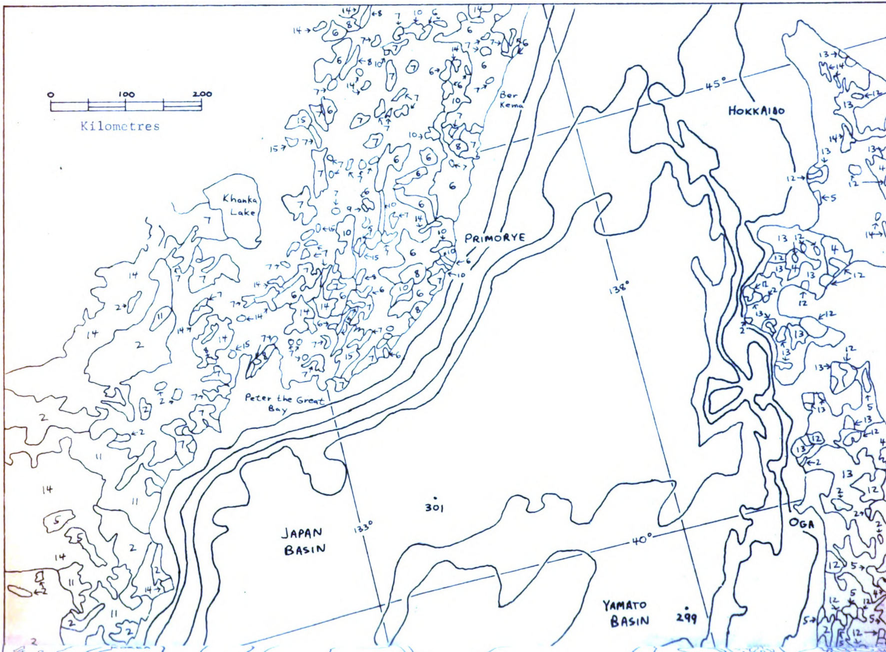
VERTICAL PROVENANCE VARIATIONS

The vertical changes in sediment composition that were outlined in a previous section can be related to changes in source area with the aid of generalized geologic maps of the areas bordering the Sea of Japan. Site 301 does not appear to be influenced by any one particular trough entering the Sea of Japan (see Figure 1) and not many samples were obtained from this site. Therefore Figure 6 (small scale geologic map) was used to infer tentative source areas for sediments at Site



1 - Tertiary acid intrusives
2 - pre-Tertiary acid intrusives
3 - granite gneiss
4 - Quaternary acid volcanics
5 - Neogene acid volcanics
6 - pre-Tertiary acid volcanics
7 - pre-Neogene acid-intermediate intrusives
8 - pre-Tertiary acid-intermediate volcanics
9 - syenites
10 - pre-Tertiary intermediate volcanics
11 - crystalline schist
12 - Quaternary intermediate-basic volcanics
13 - Neogene intermediate-basic volcanics
14 - Neogene basic volcanics
15 - pre-Tertiary basic and ultrabasic intrusives

Figure 6. Generalized geologic map of the regions bordering the Sea of Japan showing igneous and metamorphic rock types. Locations of Sites 299 and 301 are also shown (modified from UNECAFE, 1971; and Gnibidenko, 1977, figure 2).



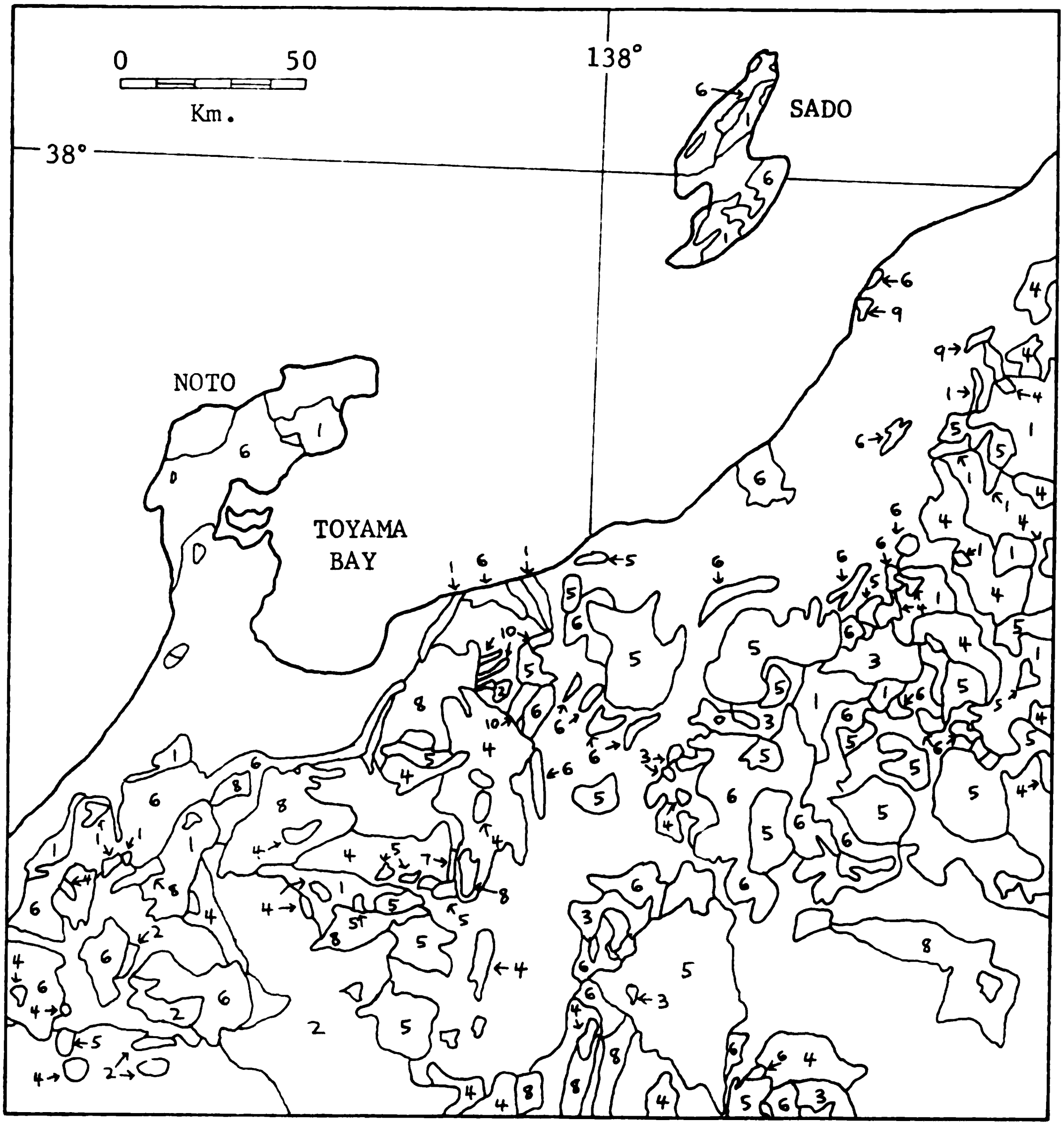
0
100
200
Kilometres
Khanka Lake
Peter the Great Bay
PRIMORYE
Ber Kema
HOKKAIDO
OGA
JAPAN BASIN
YAMATO BASIN
301
299
133°
138°
40°
45°

301. Sediments reach the Yamato Basin primarily through the Toyama trough in the form of turbidity flows (Figures 1 and 6). Although contour-following bottom currents have been shown to influence deep-sea sedimentation (Heezen et al., 1966) they are probably not present in the Yamato Basin. Contour-following currents (where present) are restricted to the western sides of ocean basins and have not been reported in enclosures as small as the Sea of Japan. Furthermore, the sand deposits of contour-following bottom currents (contourites) are well sorted, have sharp upper and lower contacts and contain less than 5% matrix ($<2\mu$) (Bouma and Hollister, 1973). The sand as well as other beds at Site 299 are poorly sorted, have gradational contacts and contain greater than 10% matrix thus precluding their classification as contourites. For these reasons and because such a large number of samples (33) were procured from Site 299, Figure 7 alone (large scale geologic map of the Toyama region) was justifiably used to delineate source areas for these sediments.

Site 299

Late Pleistocene-Holocene

Sample interval	Provenance variations
1	- acid source: rock type 1 (tip of Noto peninsula, E side of Toyama Bay, 35-80 km. SW of Toyama Bay); rock type 2 (large exposure 50-100 km. S of Toyama Bay, a few isolated outcrops just W of this region). intermediate source: rock type 5 (numerous outcrops in central and eastern part of Toyama); rock type 6 (Sado island, Noto peninsula and numerous outcrops 30-100 km. SW of Toyama Bay); rock type 8 (large exposures 15 km. SE and 25-50 km. S of Toyama Bay). basic source: rock type 9 (isolated outcrops 35 and 65 km. ESE of Sado island); rock type 10 (2 exposures 20-25 km. S of E side of Toyama Bay).
1-2	- decrease in intermediate source: rock types 5,6 and 8 (as located in Sample interval 1*).



1 - Neogene acid extrusives
2 - Cretaceous acid extrusives
3 - Miocene acid-interm. intrusives
4 - pre-Miocene acid-interm. intrusives
5 - Quaternary interm. extrusives
6 - Neogene interm. extrusives (including green tuff)
7 - Cretaceous interm. extrusives
8 - Paleozoic schists and gneisses
9 - Neogene basic extrusives
10 - pre-Tertiary basic-ultrabasic intrusives

unnumbered - sedimentary rocks

Figure 7. Generalized geologic map of the Toyama region of Honshu, Japan showing igneous and metamorphic rock types (modified from Geological Survey of Japan, 1956, 1964).

Sample interval	Provenance variations
2-5	- increase in intermediate source: rock types 5,6 and 8.
5-6	- increase in intermediate source: rock types 5 and 6 (especially green tuff of 6).
6-7	- influence of a sedimentary source (any of the unnumbered regions of the map area). decrease in quartz-poor, acid-intermediate source: rock type 6 (especially green tuff area).
7-8	- increase in acid source: rock types 1 and 2.
8-9	- increase in intermediate-basic source: rock types 5,6 and 8; rock types 9 and 10. decrease in acid source: rock types 1 and 2.

Early Pleistocene

Sample interval	Provenance variations
9-10	- decrease in basic source: rock types 9 and 10. increase in intermediate source: rock types 5 and 6.
11-12	- increase in sedimentary source (as located in Sample interval 6-7).
13-14	- increase in acid-intermediate source: rock types 1 and 2; rock type 3 (few isolated exposures in west-central part of map area); rock type 4 (numerous exposures in NE corner of map area, numerous exposures 25-50 km. S and SSE of Toyama Bay); rock types 5 and 8. decrease in basic source: rock type 9.
14-15	- increase in acid source: rock types 1 and 2.
15-16	- increase in intermediate source: rock types 3,4 and 8 (as located in Sample intervals 13-14 and 1). decrease in acid source: rock types 1 and 2. increase in basic source: rock type 9.
17-18	- increase in intermediate source: rock types 5,6 and 8. decrease in acid source: rock types 1 and 2.
19-20	- increase in basic source: rock type 9.
23-24	- increase in acid source: rock types 1 and 2. decrease in intermediate source: rock types 5 and 6.
24-25	- increase in acid source: rock types 1 and 2.
26-27	- increase in intermediate source: rock types 5 and 6.
27-28	- increase in acid source: rock types 1 and 2. decrease in basic source: rock type 9.
28-29	- increase in basic source: rock type 9.

Sample interval	Provenance variations
29-30	- increase in acid source: rock types 1 and 2. decrease in intermediate source: rock types 5 and 6.
30-31	- increase in sedimentary source (as located in Sample interval 6-7). decrease in acid source: rock types 1 and 2.
31-32	- increase in acid source: rock types 1 and 2. decrease in basic source: rock types 9 and 10.

Late Miocene

Sample interval	Provenance variations
33-35	- increase in intermediate-basic source: rock types 5,6,9 and 10.

*locations of all rock types are given in Sample interval 1 unless otherwise indicated.

Site 301

Turbidite sediments reach the Japan Basin via numerous troughs (see Figure 1). Since there are more possible source areas for Site 301 sediments, the delineation of these source areas cannot be as specific here as at Site 299; and therefore a more general small scale geologic map (Figure 6) was used to deduce provenance variations.

Early Pleistocene

Sample interval	Provenance variations
37	- predominant acid source: rock types 1,2,5 and 6 in the Yamato Basin-Toyama trough area; rock types 2 and 5 in the Mogami trough area(between Oga and Sado); rock types 6 and 7 along W margin of Tartary trough (coast of Primorye); rock types 2 and 3 in the Genzan trough area (adjacent to Korea). weak intermediate-basic source: rock types 12 and 13 in the Toyama trough area; rock types 12 and 13 in the Mogami trough area; rock types 12 and 13 along the E margin of the Tartary trough (coast of Hokkaido); rock type 10 along W side of Tartary trough.

Sample interval	Provenance variations
37-38	- decrease in acid source: rock types 1,2,5,6 and 7 (as located in Sample interval 37).
38-41	- decreasing influence of a sedimentary source (any of the unnumbered regions near the major troughs) or a quartz-rich metamorphic source: rock type 11 in Genzan trough area.
41-42	- decrease in intermediate-basic source: rock types 12 and 13 (as located in Sample interval 37).

Late Pliocene

Sample interval	Provenance variations
42-43	- increase in intermediate-basic source: rock types 12 and 13 (as located in Sample interval 37).
43-44	- decrease in acid source: rock types 1,2,5,6 and 7 (as located in Sample interval 37). increase in basic source: rock types 13 and 14 in the Toyama trough area; rock type 13 in Mogami trough area; rock types 13 and 14 along the E margin of the Tartary trough; rock types 14 and 15 along the W margin of the Tartary trough; rock type 14 in the Genzan trough area.

LATERAL PROVENANCE VARIATIONS

The lateral changes in sediment composition that were outlined in a previous section were related to changes in source area with the aid of Figures 6 and 7. Contributions from a basic source are definitely more influential at Site 299 than at Site 301. This seems reasonable considering that Site 299 is close to an island arc while Site 301 is closer to a continent. Source areas for the Toyama, Mogami and Tartary troughs are similar in nature; however, source areas for the Genzan and Tshushima troughs contain much less basic and far more quartz-rich rocks. Presumably, Site 301 sediments receive no preferential sedimentation from any of the troughs feeding the abyssal plain. The fact that sediments are more basic at Site 299 than at Site 301 may indicate that the Genzan and possibly the Tshushima troughs contribute more sediments to the Japan Basin than do the other major troughs. Late Miocene and Early Pleistocene comparisons between Sites 299 and 301 follow the same trends as the overall comparisons listed above.

FLYSCH SANDS AND CLAYS

Table 9 contains a summary of data for Early Pleistocene clay and sand samples from Site 299. No statistically significant differences in composition could be found between the clays and sands.

CONCLUSIONS

1 - The increase of %monocrystalline quartz with depth at Site 299 indicates that sediment contributions from a quartz-rich source decreased through Neogene time. Since there does not appear to be much change in acid igneous activity in the Toyama area during Neogene time, a presumption is made that this area was closer to a quartz-rich source in Late Miocene time and gradually was removed from that source. That is, Late Miocene Japan was closer to Asia or possibly the granitic Yamato rise acted as a source area at this time.

2 - This increase of %monocrystalline quartz with depth would seem to refute Sychev and Snegovsky's (1976) hypothesis that the Japan Sea is a relict ocean basin with no relative displacement of the Japanese islands from the Asian continent. This is consistent with the rifting hypothesis for the origin of the Sea of Japan.

3 - The decrease of %feldspar: n<1.54 with depth at Site 299 and the negative correlation of %monocrystalline quartz with %feldspar: n<1.54 indicate an increasing contribution of a quartz-poor, feldspar : n<1.54 source through Neogene time. This probably reflects the increasing contribution of the Neogene green tuff through time. It could also reflect the increasing albitization of Ca plagioclase in the basic igneous rocks of the source area.

4 - The negative correlation of %monocrystalline quartz and %feldspar: n<1.54 at Site 301 may indicate that the Neogene green tuff of the Toyama region served as a source area for Japan Basin sediments.

5 - The Genzan and possibly the Tshushima troughs are more effective in delivering sediment to the Japan Basin than are the Toyama, Mogami or Tartary troughs.

6 - Turbidity currents rather than contour-following bottom currents are responsible for the deposition of sands in the Yamato Basin.

7 - Complex provenance variations can be deciphered if enough is known of the geology of the source area and if specific compositional determinations can be made.

8 - Feldspar is a valuable provenance indicator because of its chemical variability, although the albitization of Ca plagioclase may confuse interpretations (this may be especially true in lithified flysch).

9 - The examination of very fine sand-coarse silt size mineralogy is worthwhile because this size class is a convenient one to work with and is present in sufficient quantity in both clays and sands.

10 - The laboratory techniques used in this study allow sufficient information to be obtained from miniscule samples.

11 - No compositional differences exist between the silt in flysch sands and clays; therefore clays rather than sands should be used for petrographic studies because of their greater availability and because presumably less diagenetic mineral alteration occurs in clays.

APPENDIX

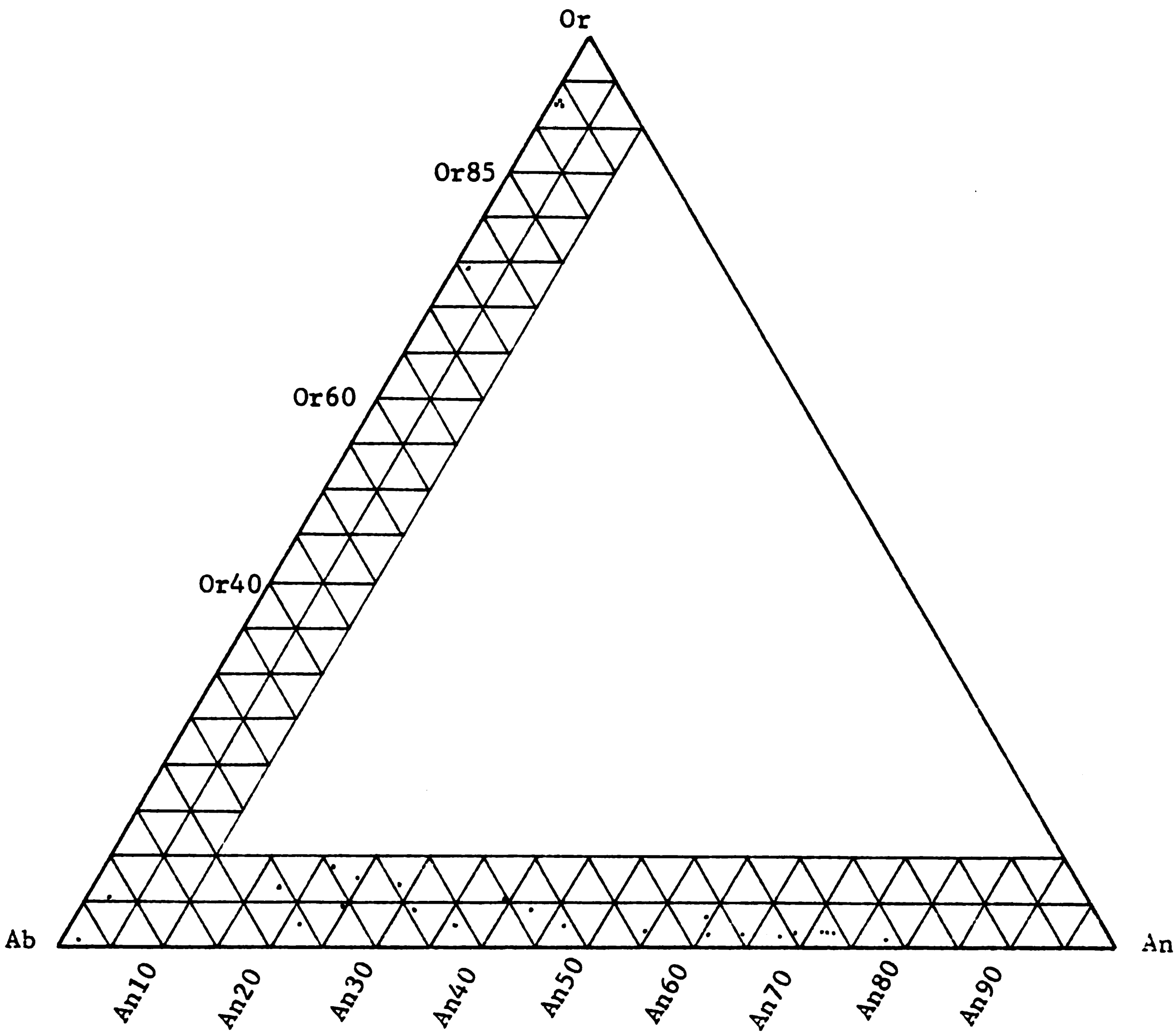


Figure A-1. Compositional plot of 27 feldspar grains in sample 1.

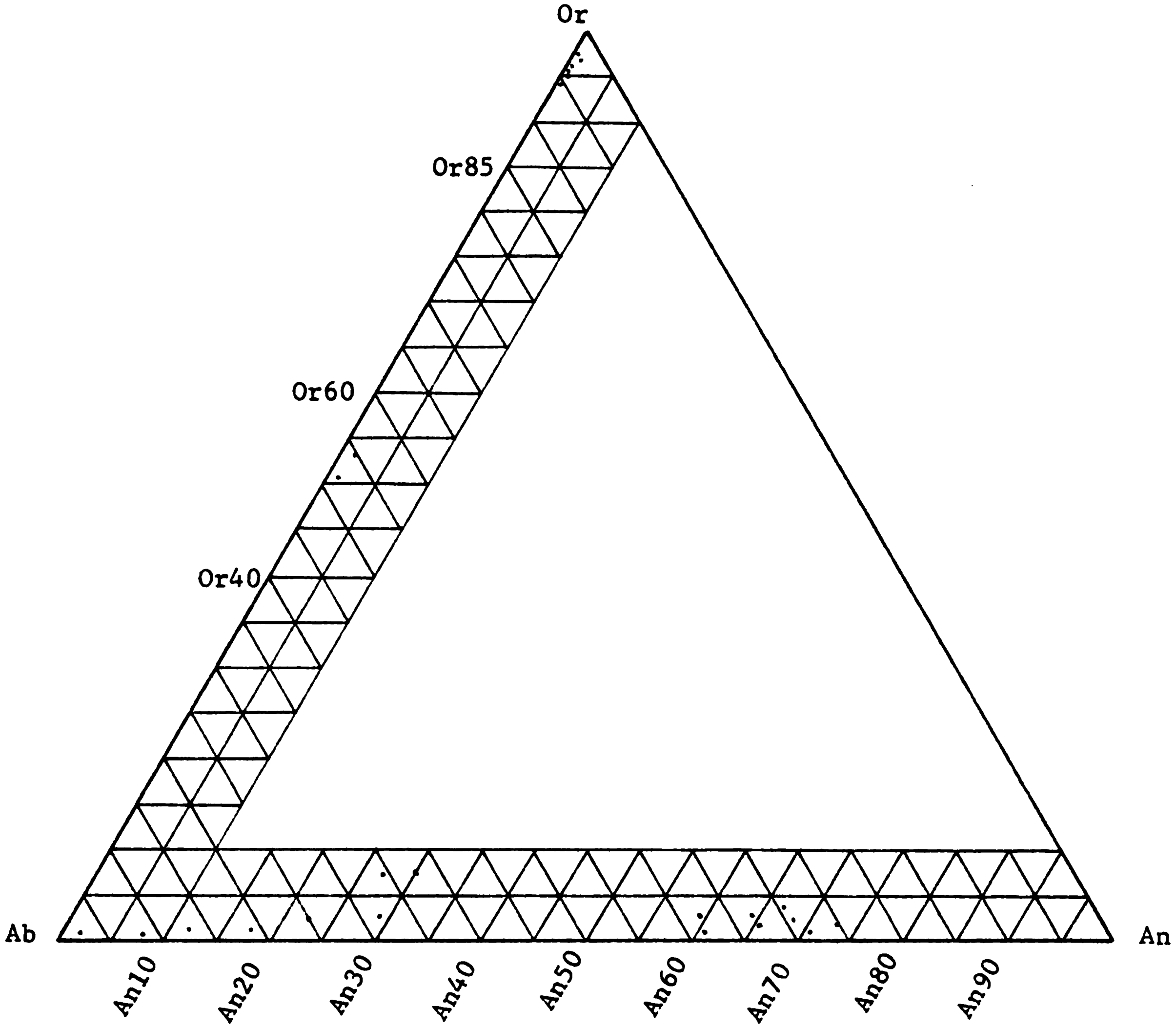


Figure A-2. Compositional plot of 24 feldspar grains in sample 2.

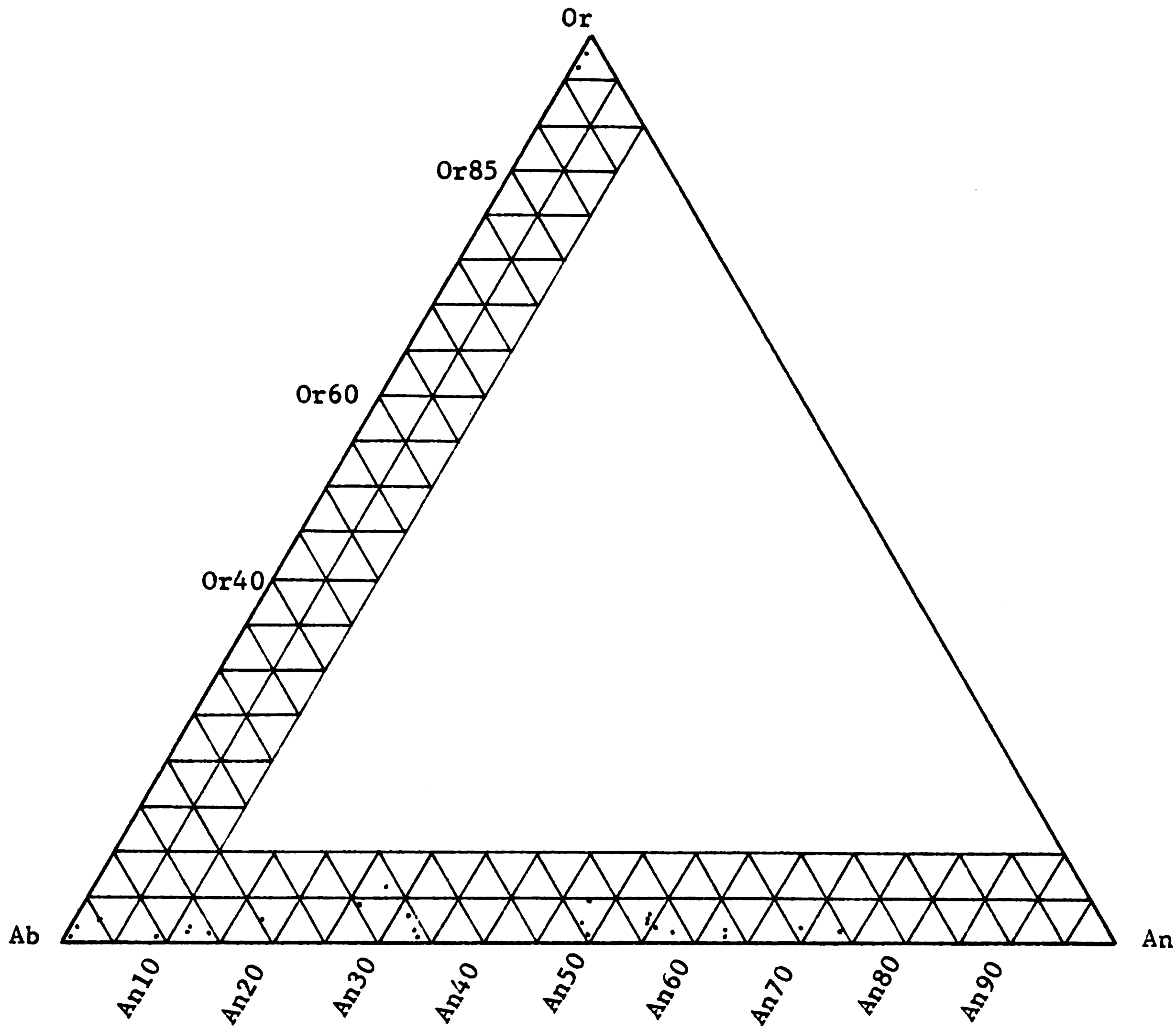


Figure A-3. Compositional plot of 27 feldspar grains in sample 5.

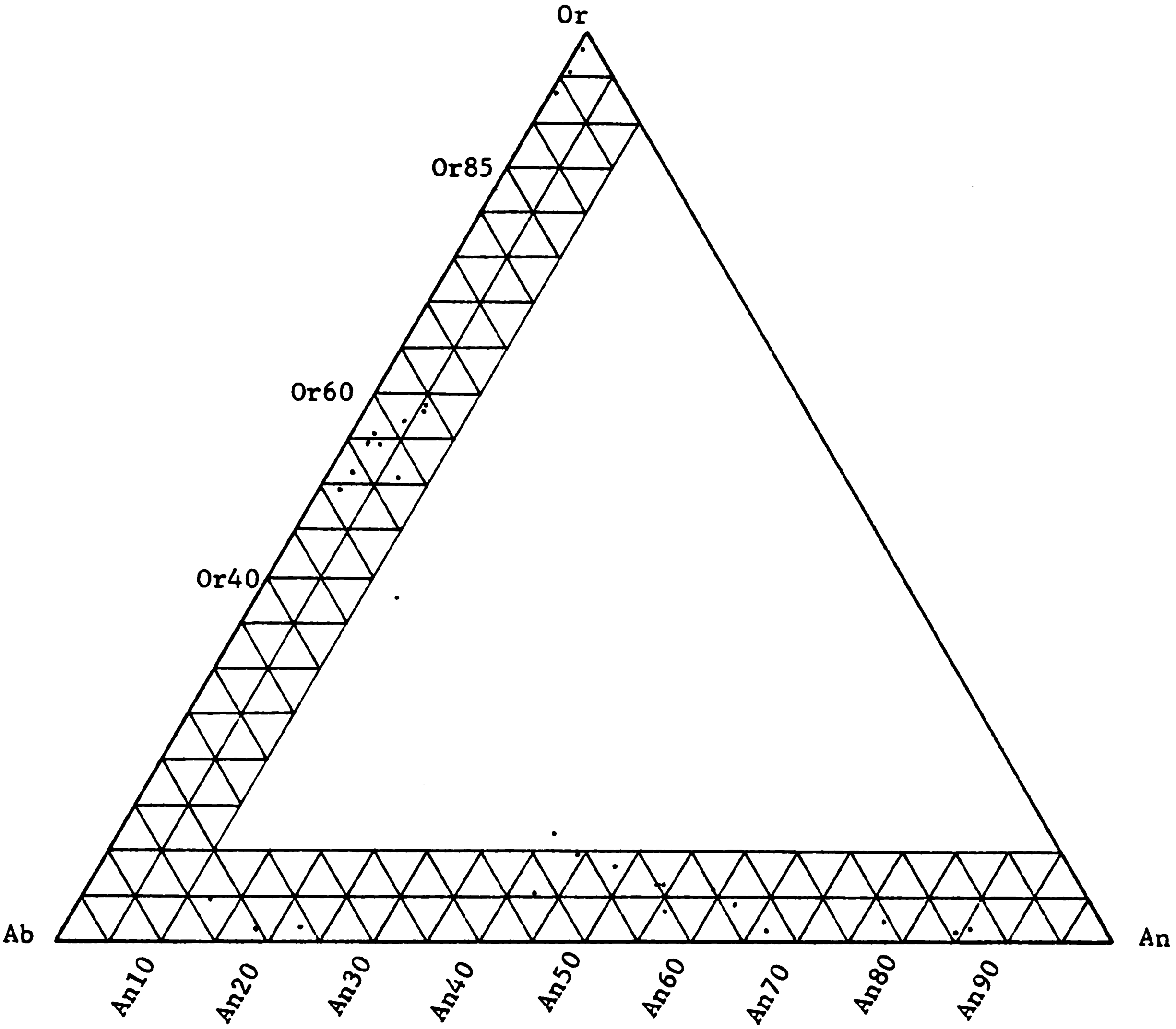


Figure A-4. Compositional plot of 29 feldspar grains in sample 6.

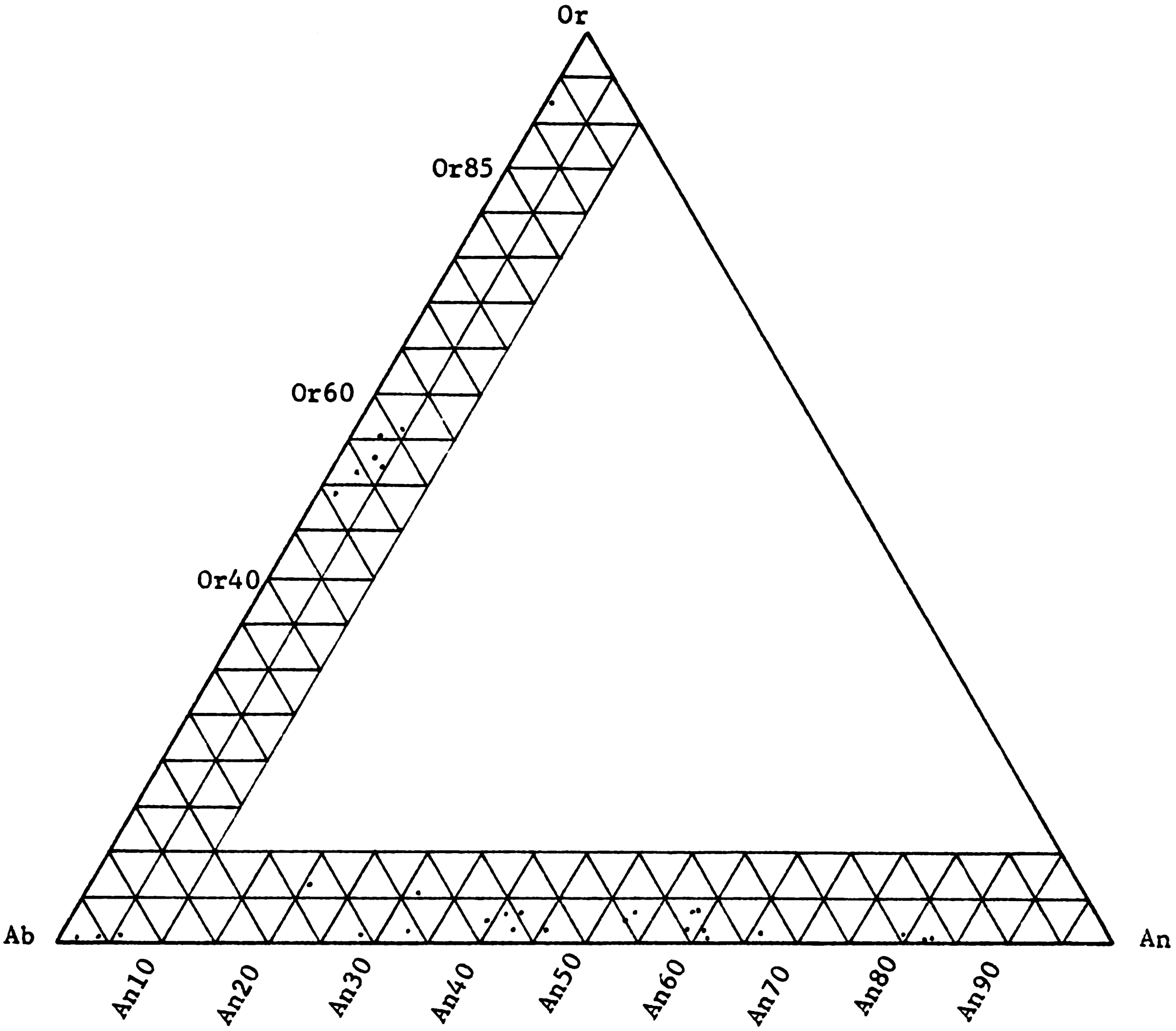


Figure A-5. Compositional plot of 30 feldspar grains in sample 7.

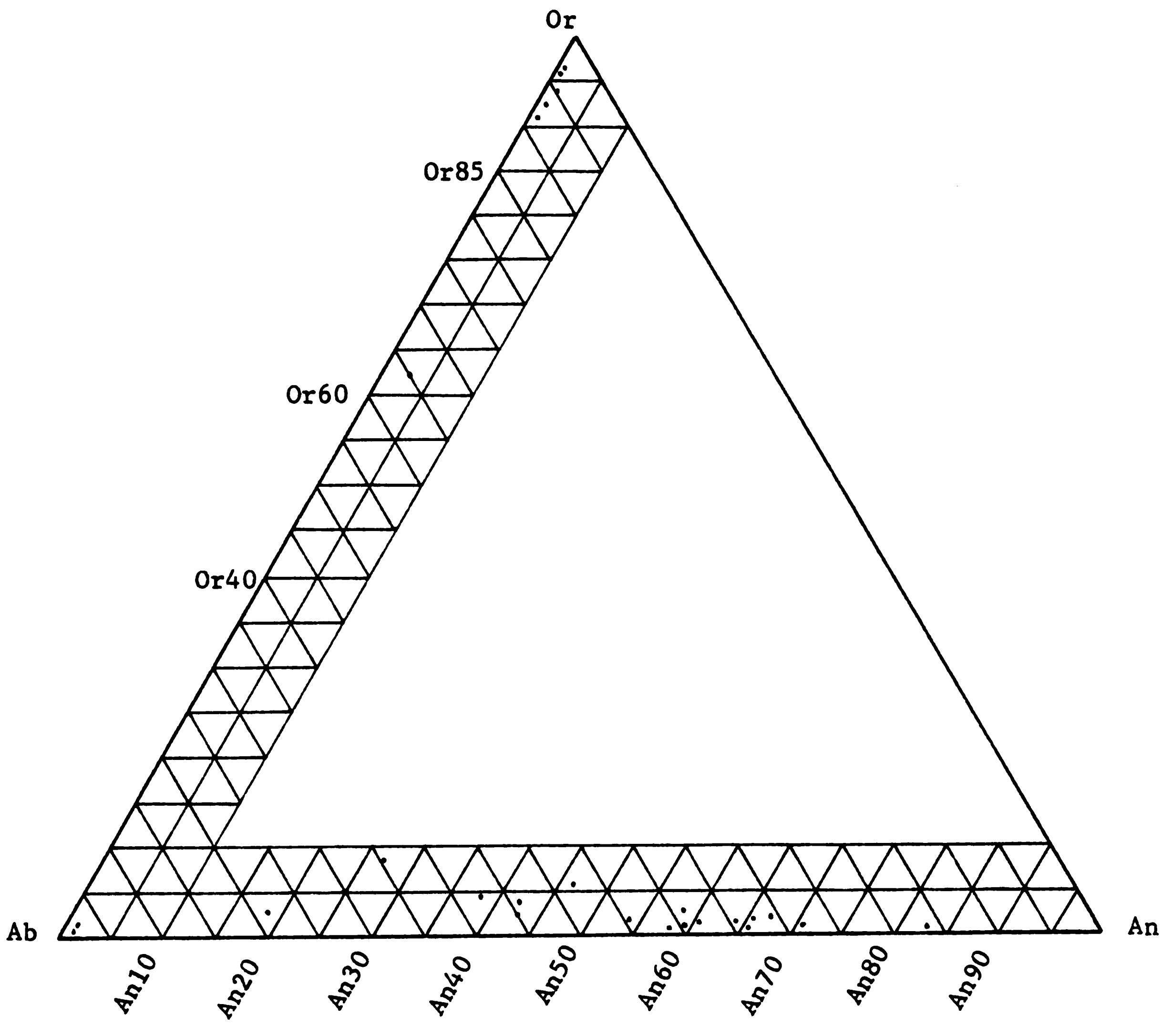


Figure A-6. Compositional plot of 25 feldspar grains in sample 8.

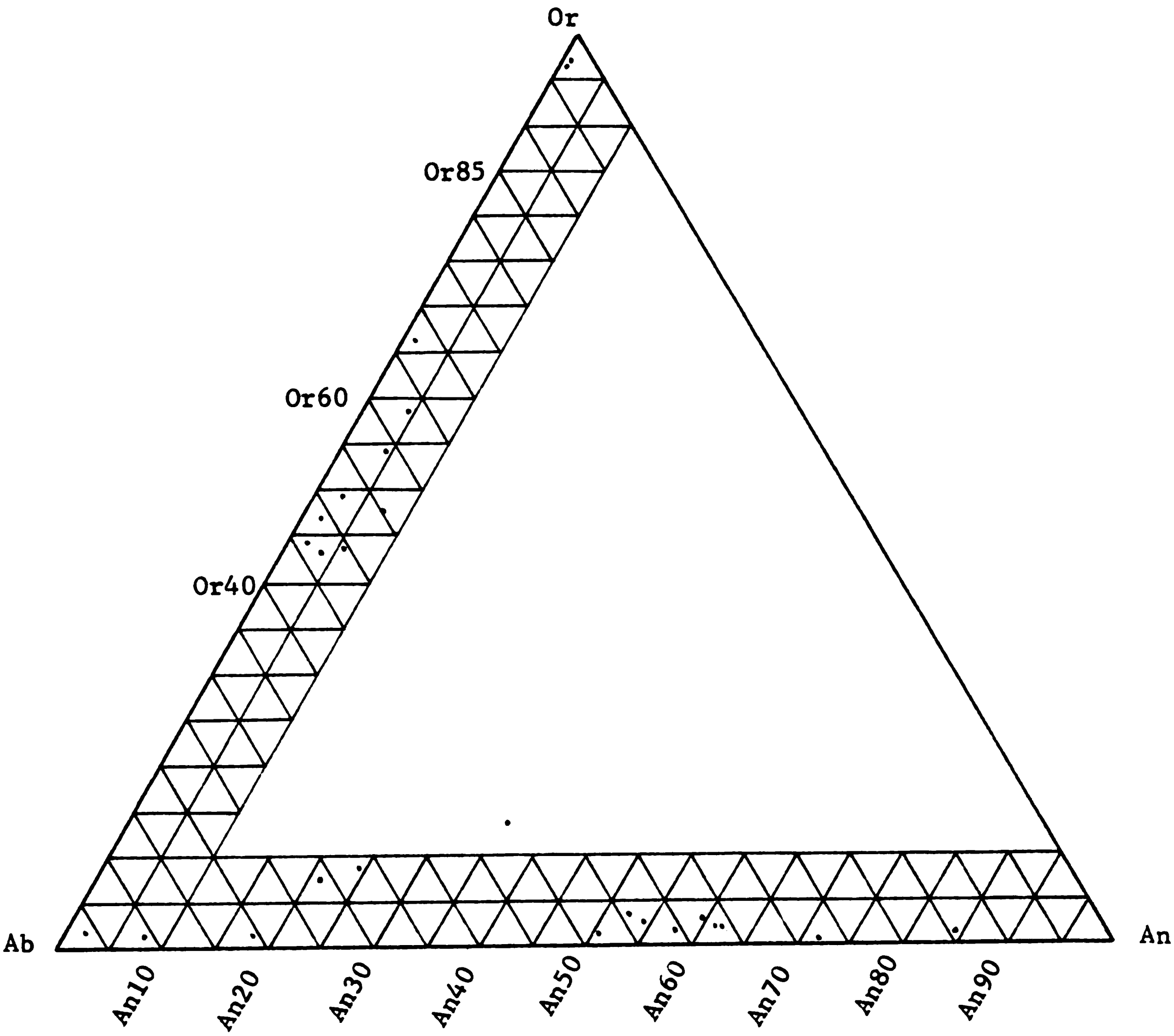


Figure A-7. Compositional plot of 26 feldspar grains in sample 9.

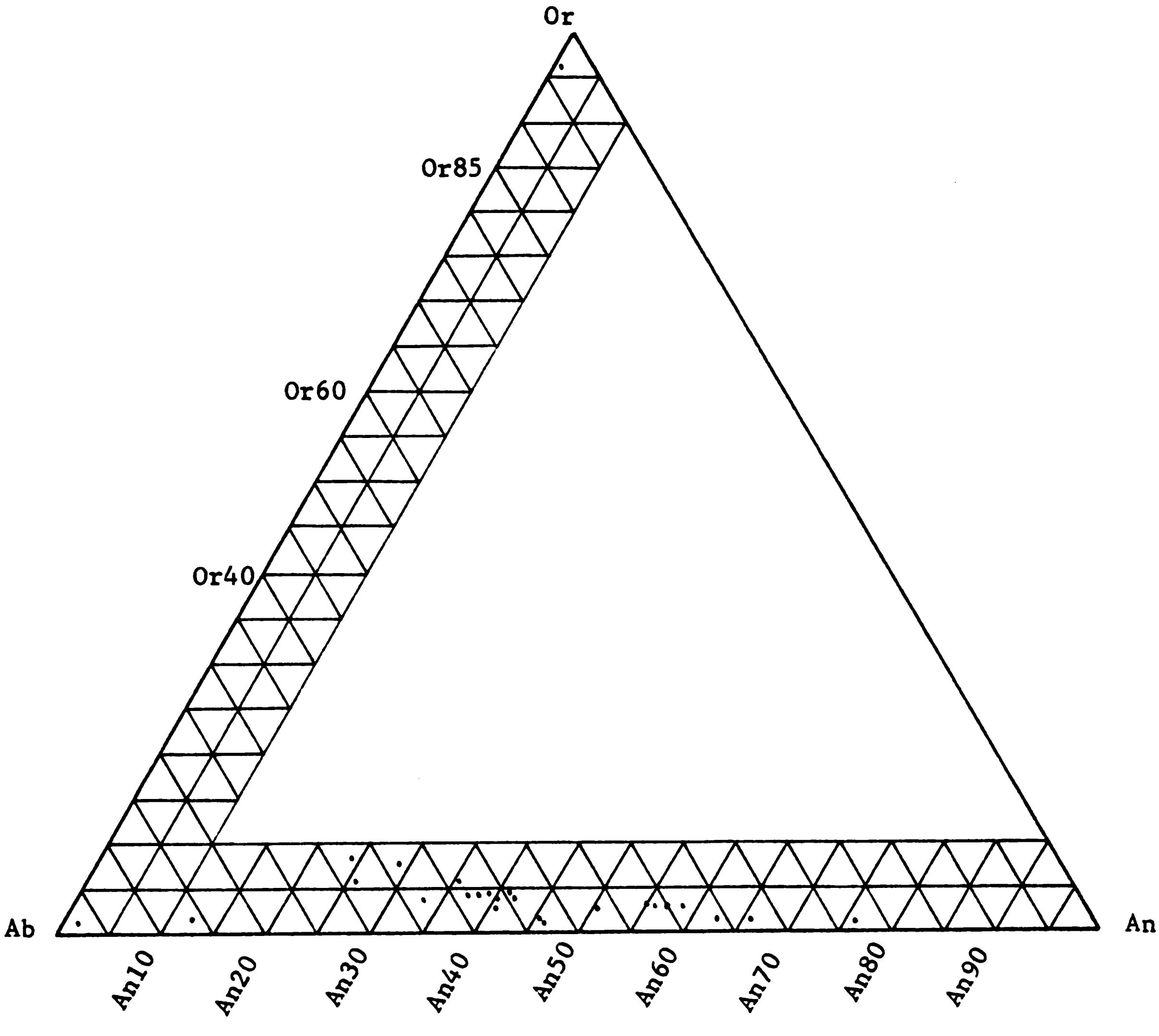


Figure A-8. Compositional plot of 25 feldspar grains in sample 10.

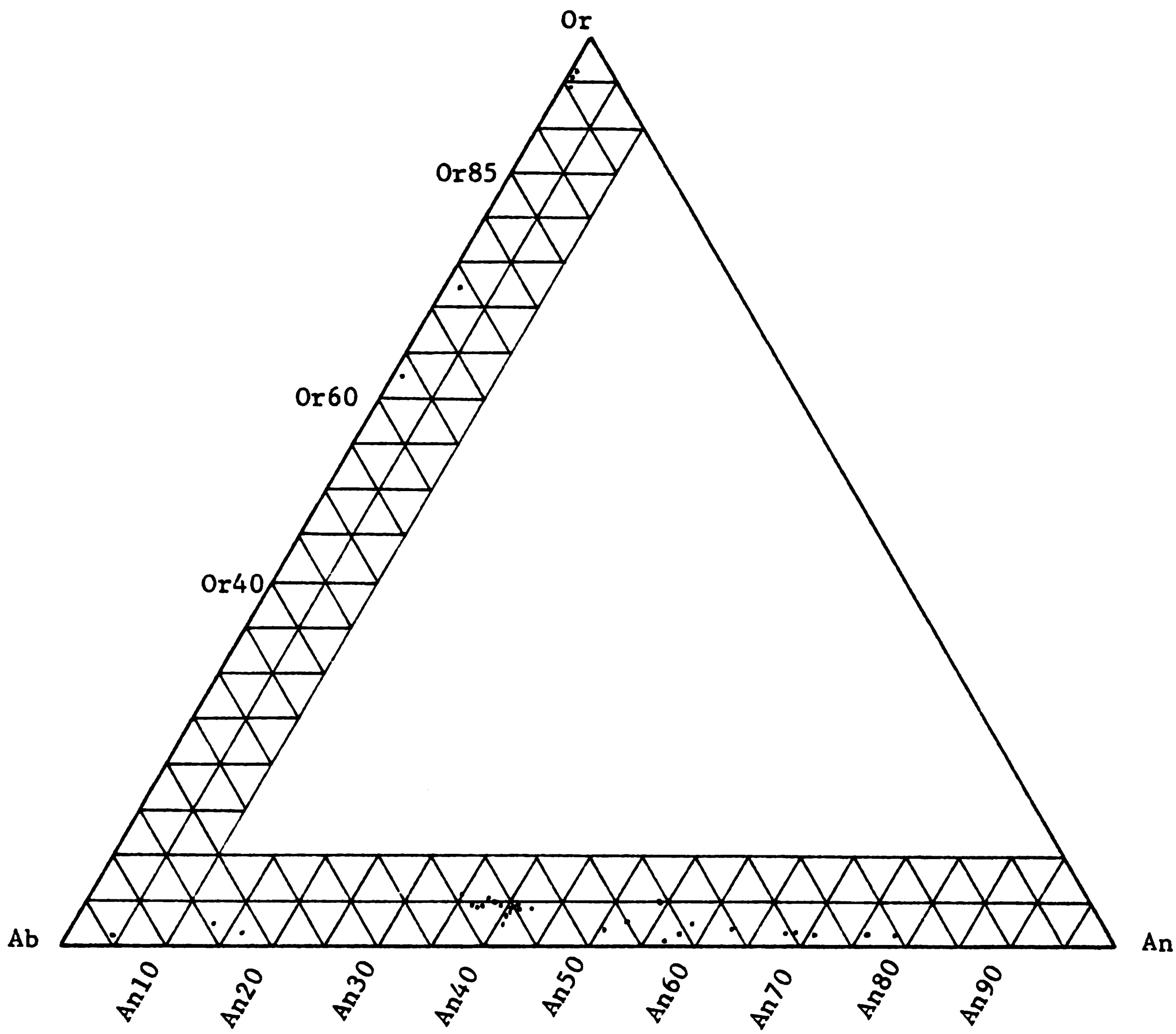


Figure A-9. Compositional plot of 34 feldspar grains in sample 11.

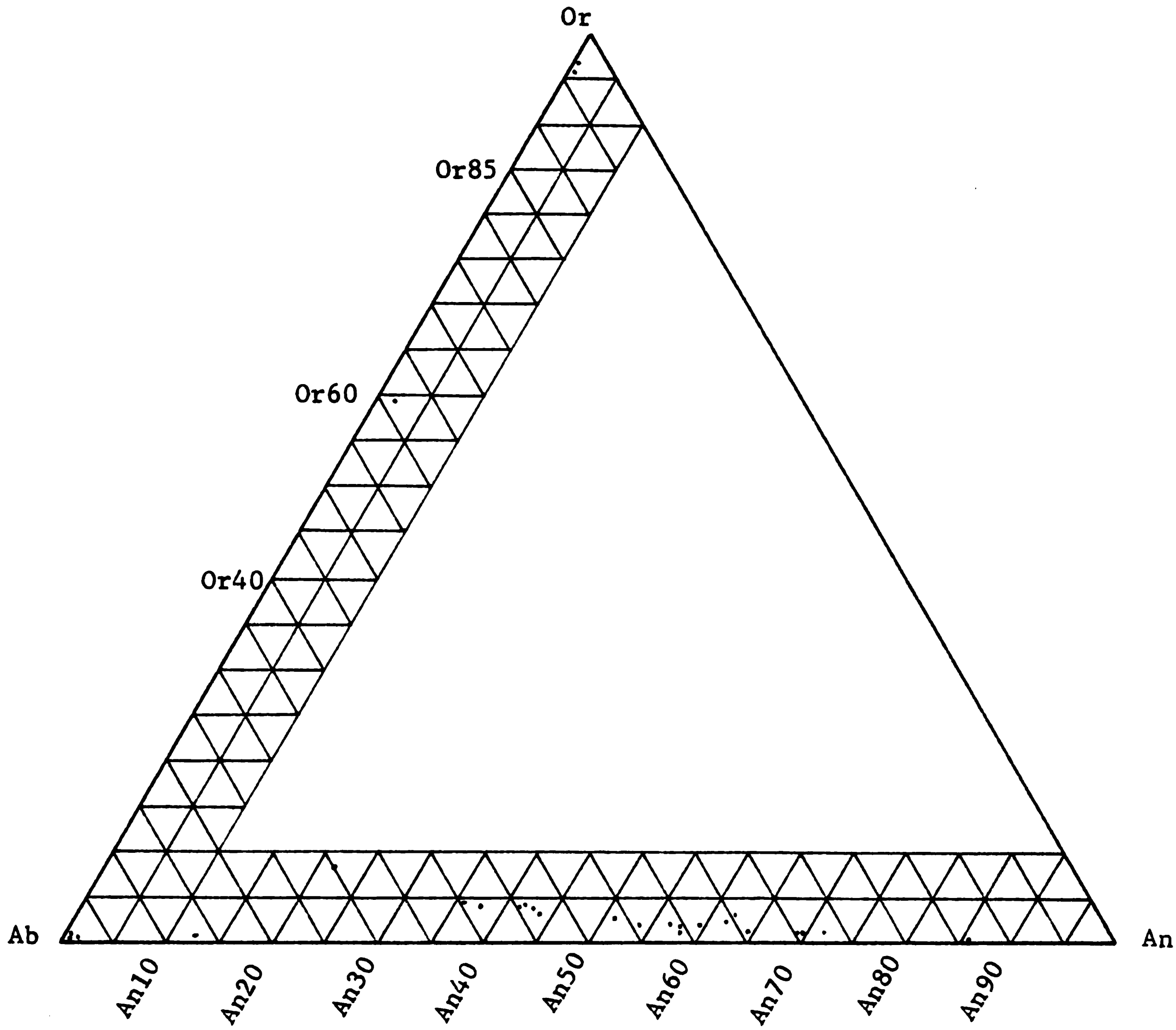


Figure A-10. Compositional plot of 27 feldspar grains in sample 12.

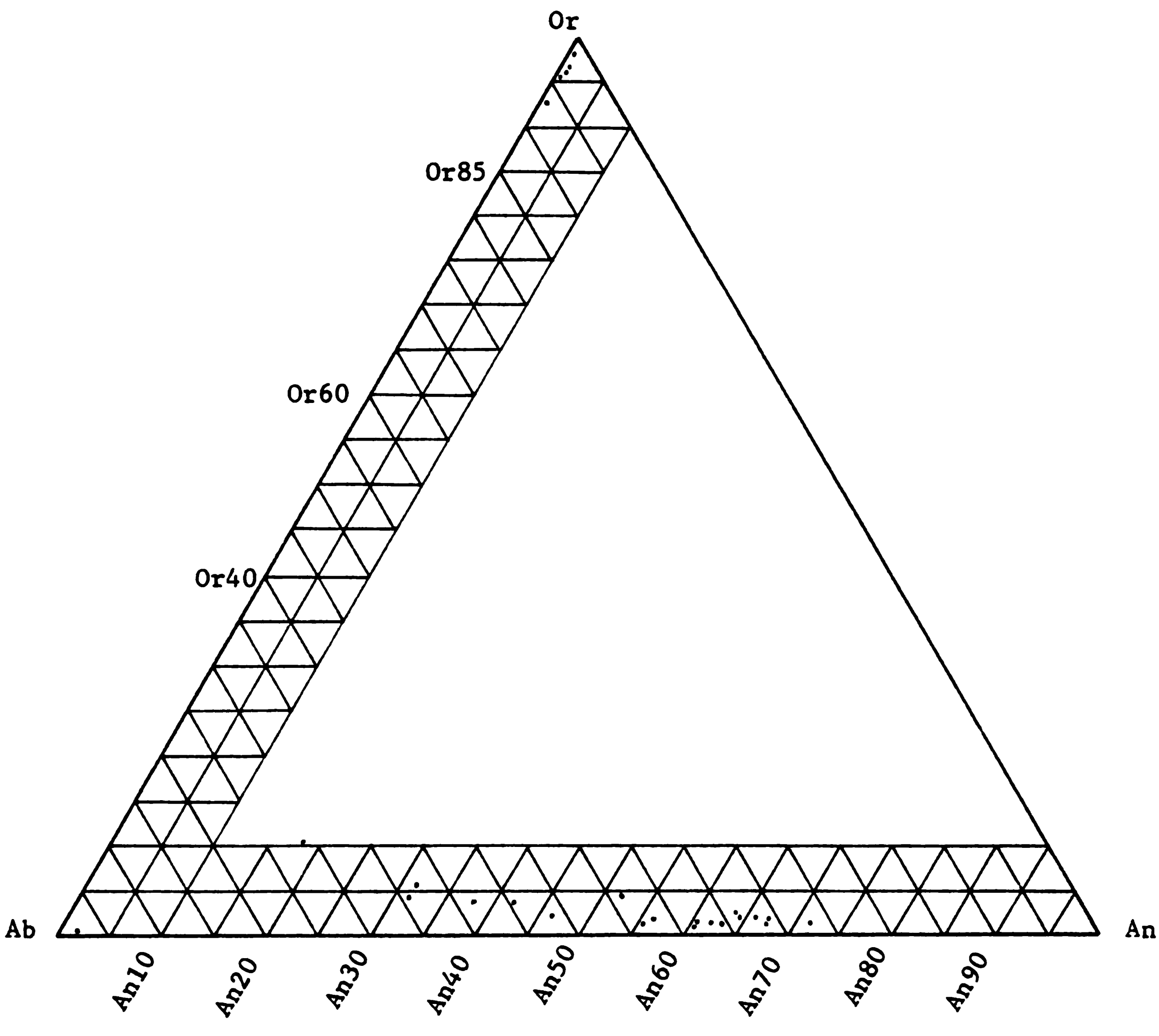


Figure A-11. Compositional plot of 25 feldspar grains in sample 13.

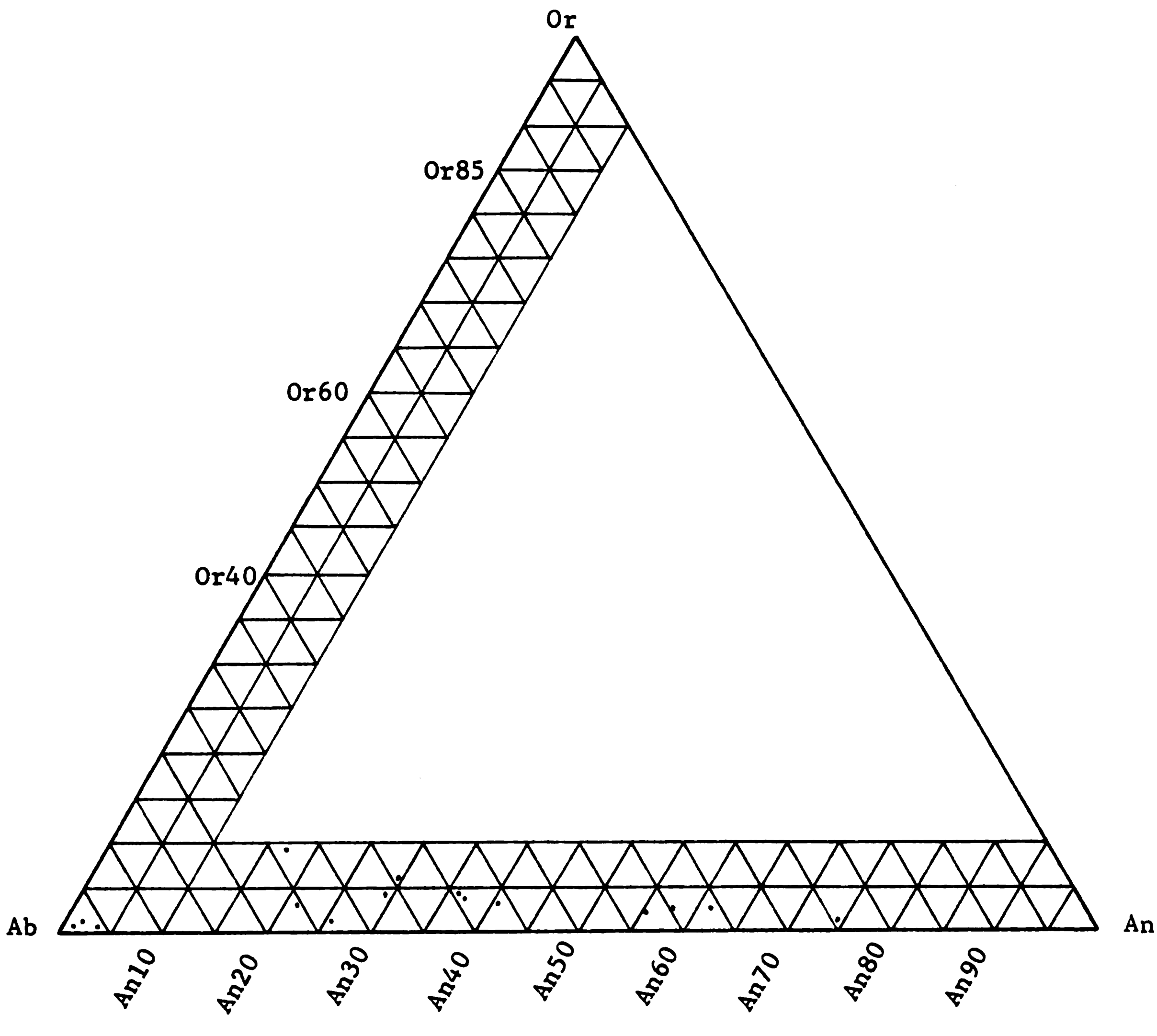


Figure A-12. Compositional plot of 15 feldspar grains in sample 14.

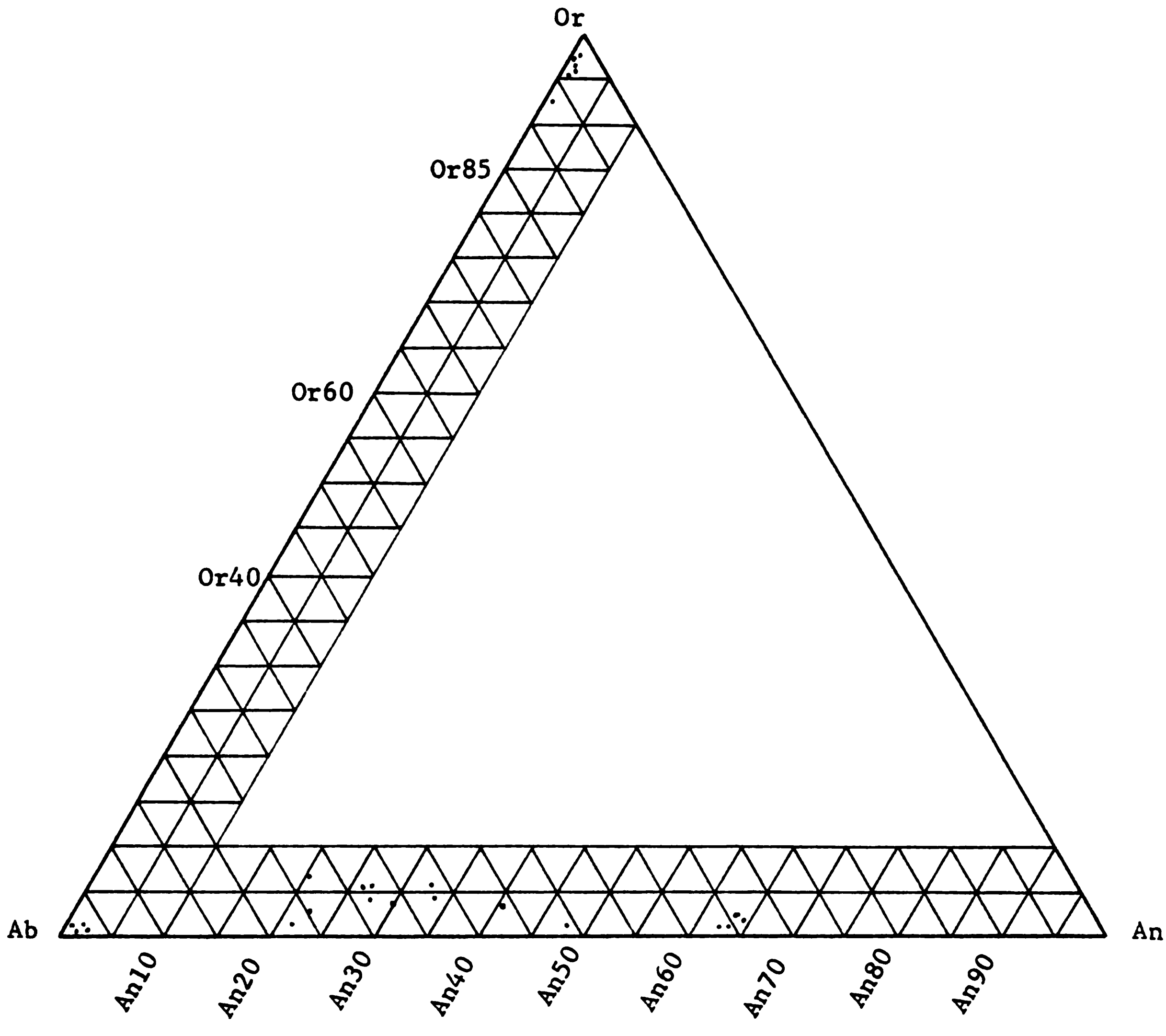


Figure A-13. Compositional plot of 25 feldspar grains in sample 15.

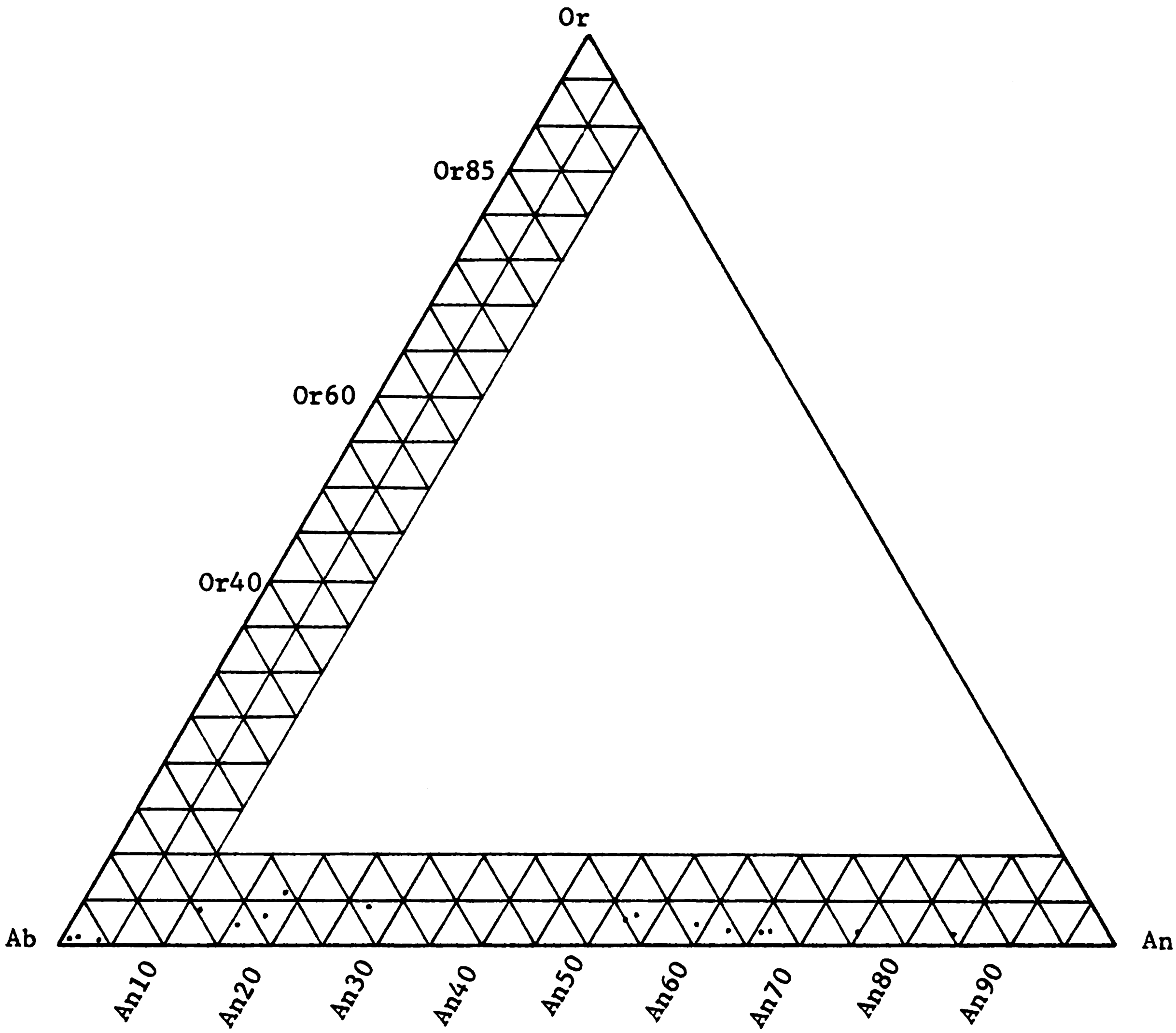


Figure A-14. Compositional plot of 16 feldspar grains in sample 16.

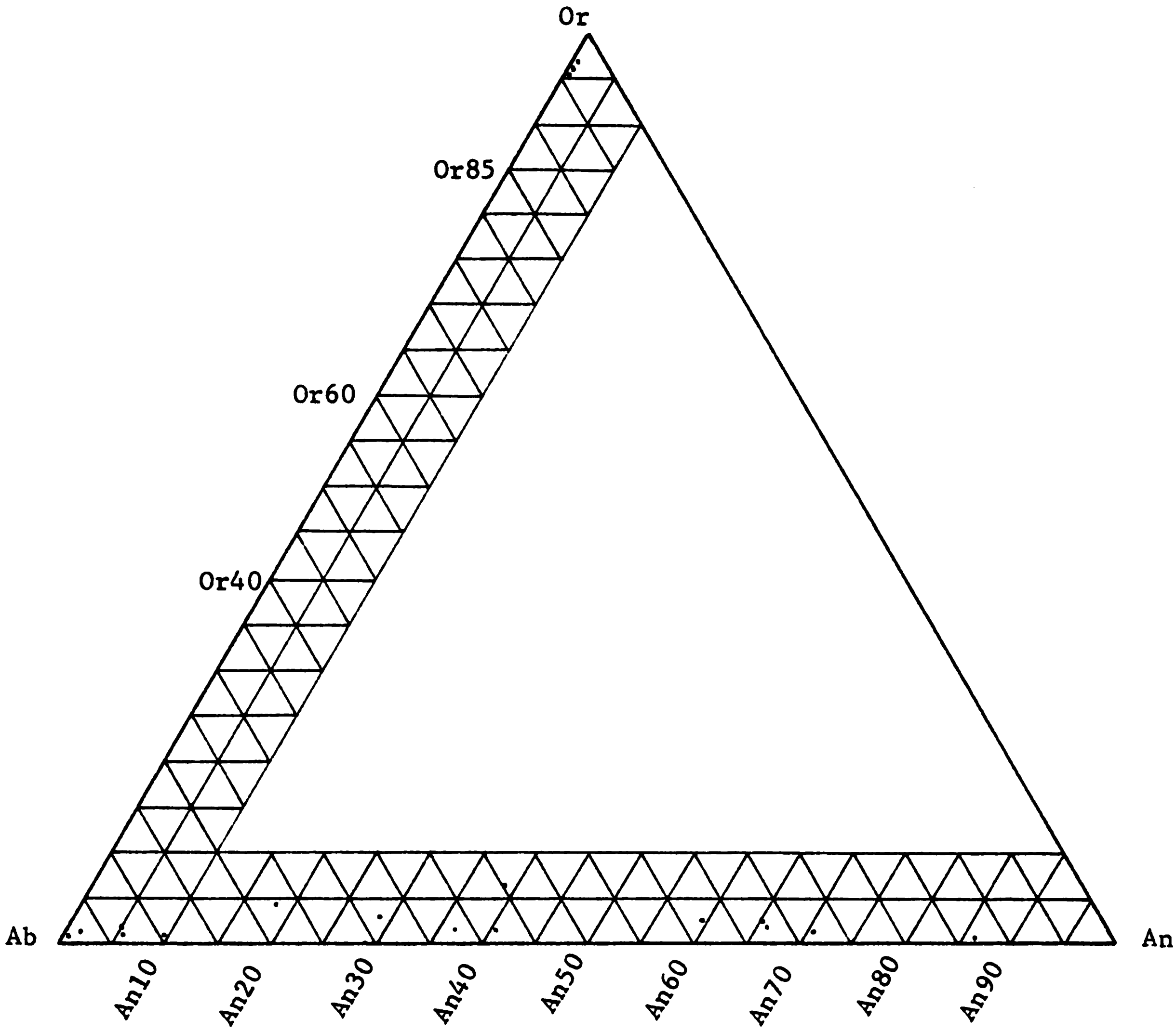


Figure A-15. Compositional plot of 18 feldspar grains in sample 17.

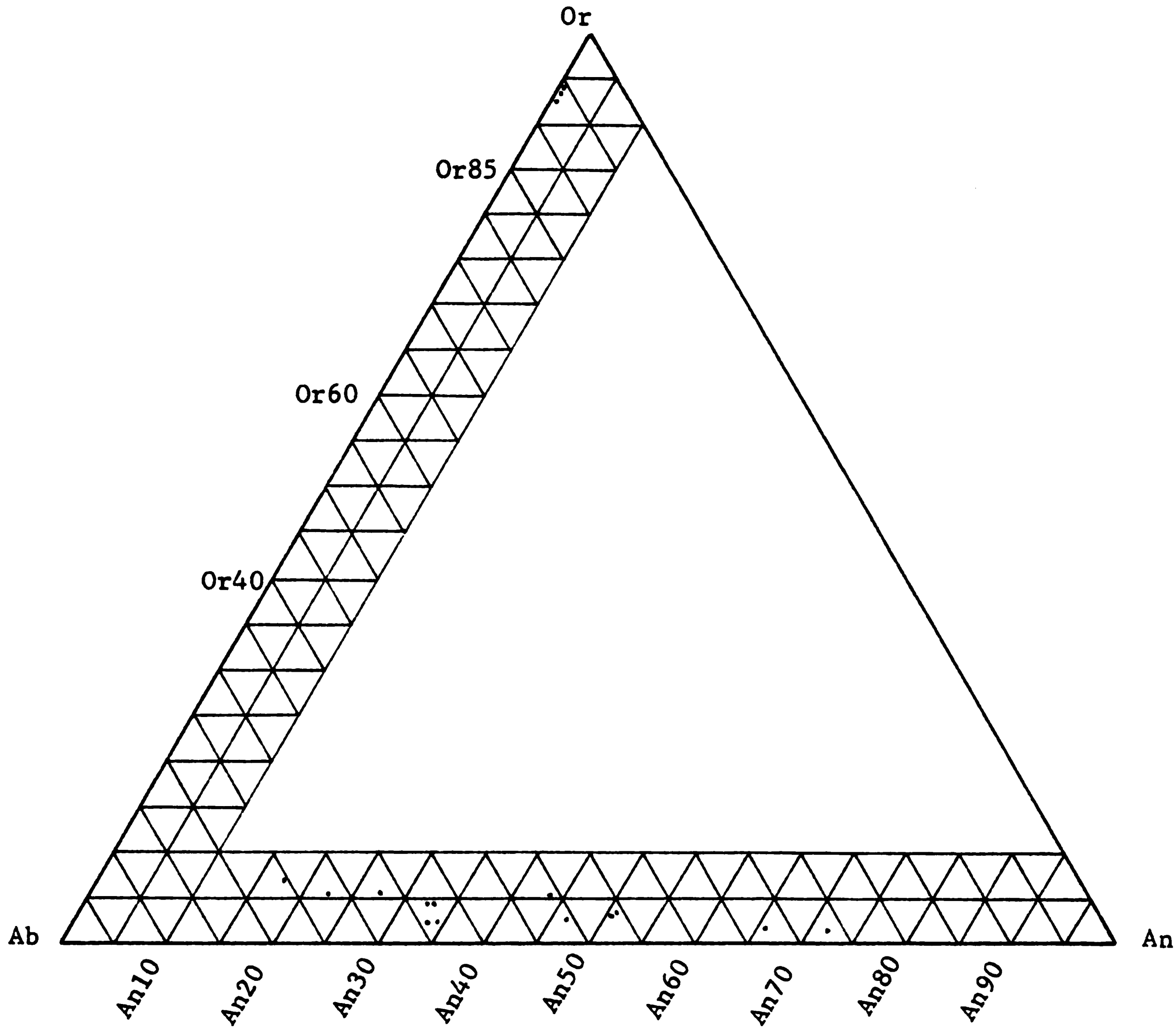


Figure A-16. Compositional plot of 16 feldspar grains in sample 18.

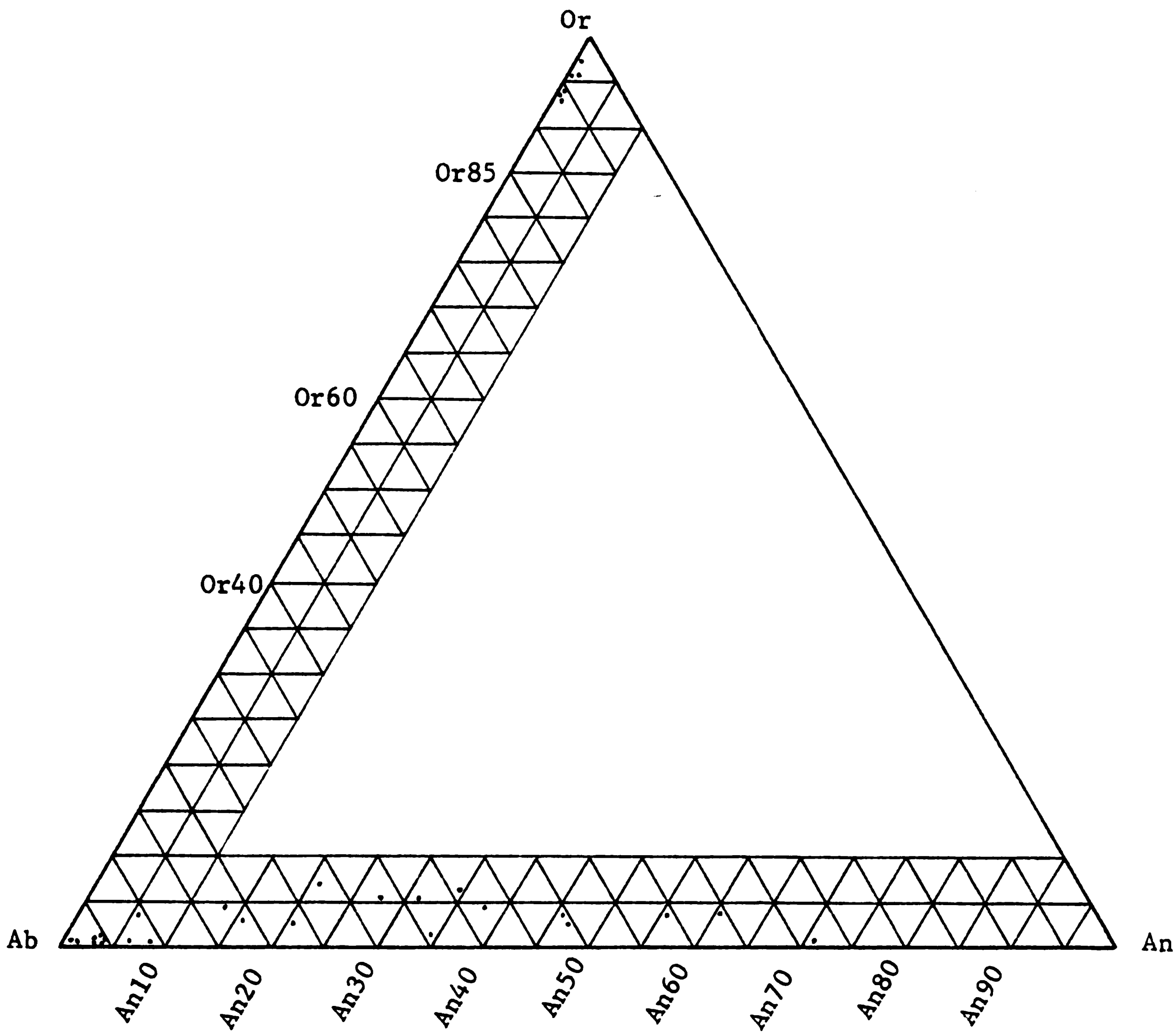


Figure A-17. Compositional plot of 30 feldspar grains in sample 19.

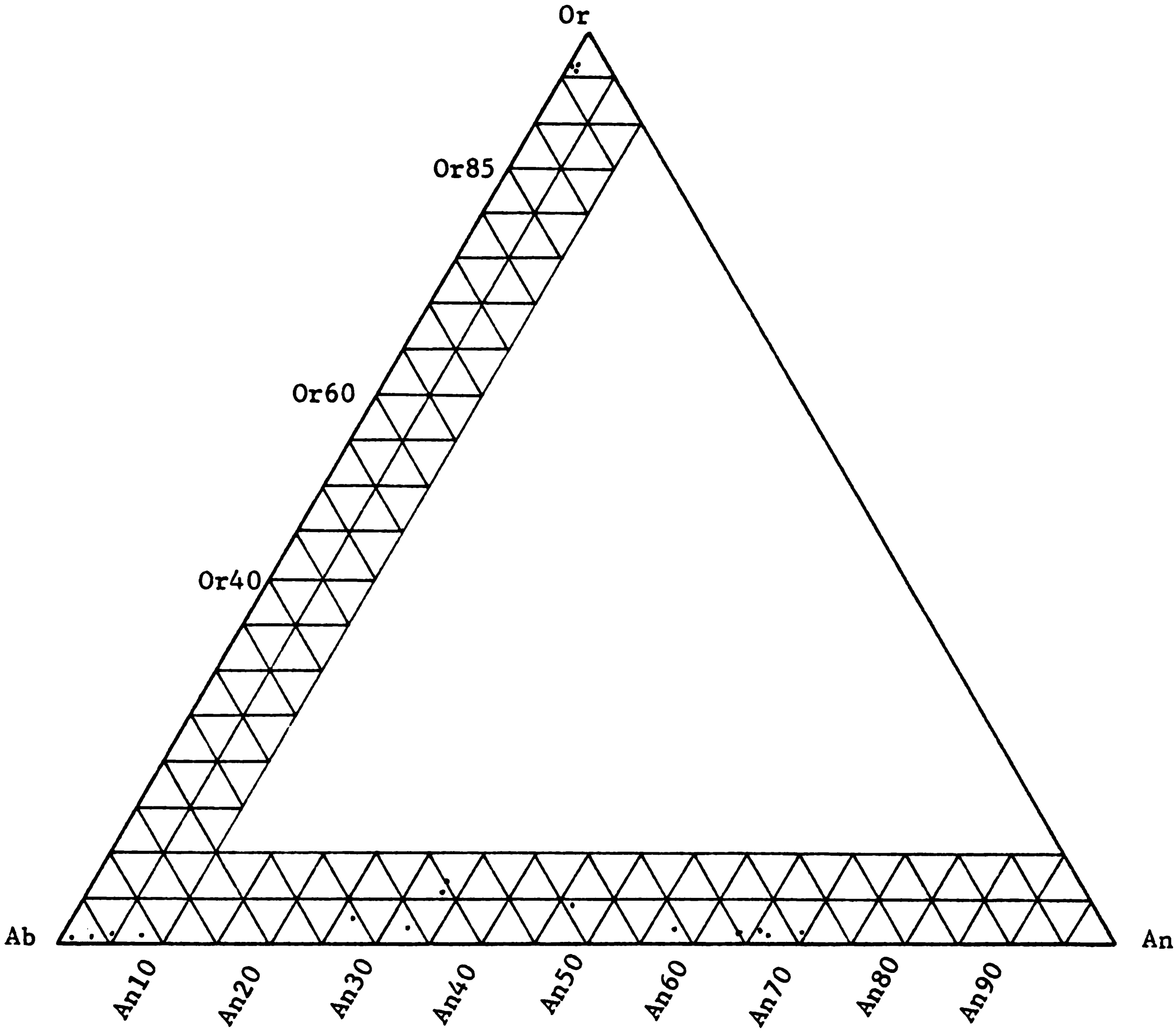


Figure A-18. Compositional plot of 17 feldspar grains in sample 20.

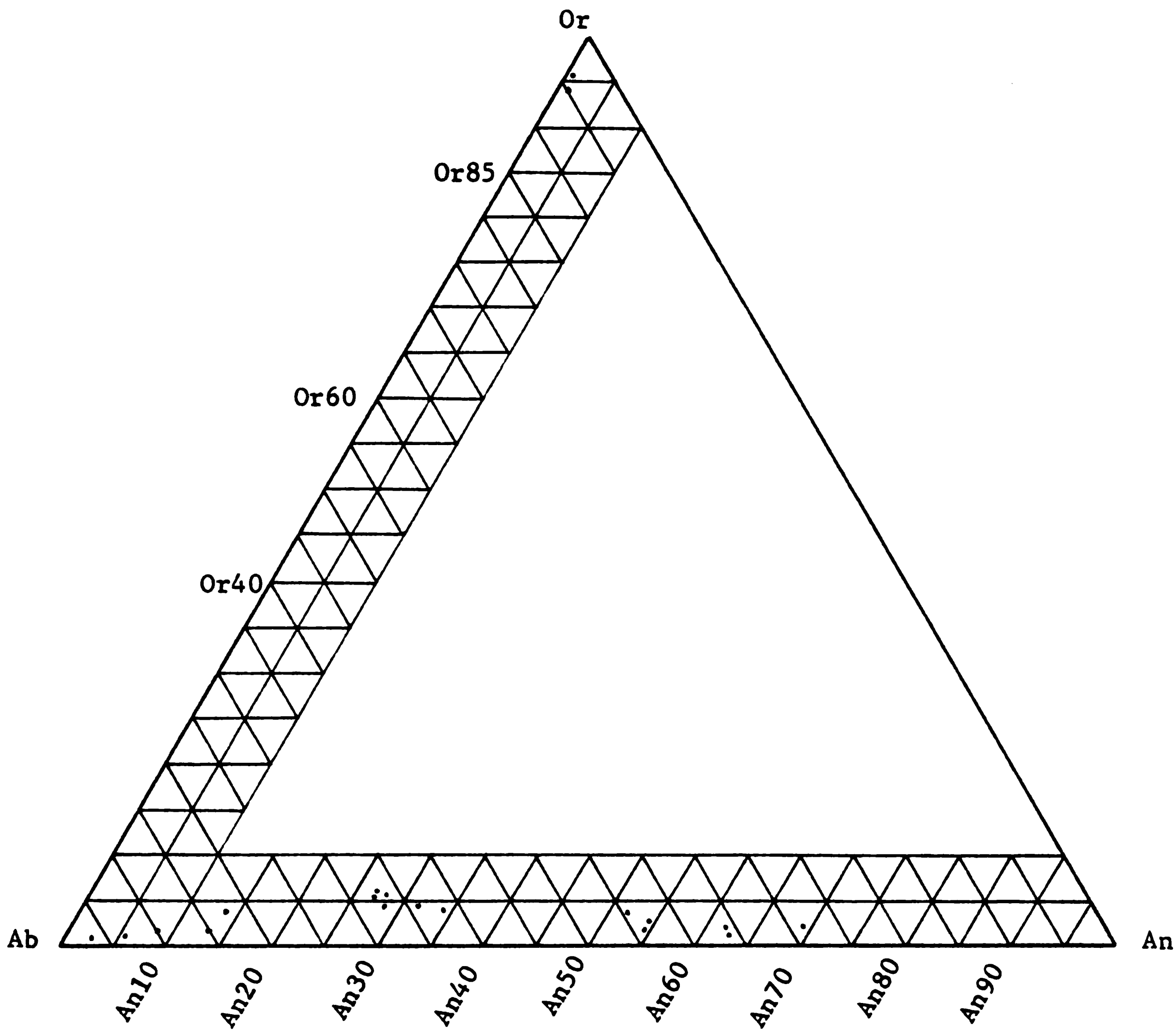


Figure A-19. Compositional plot of 19 feldspar grains in sample 21.

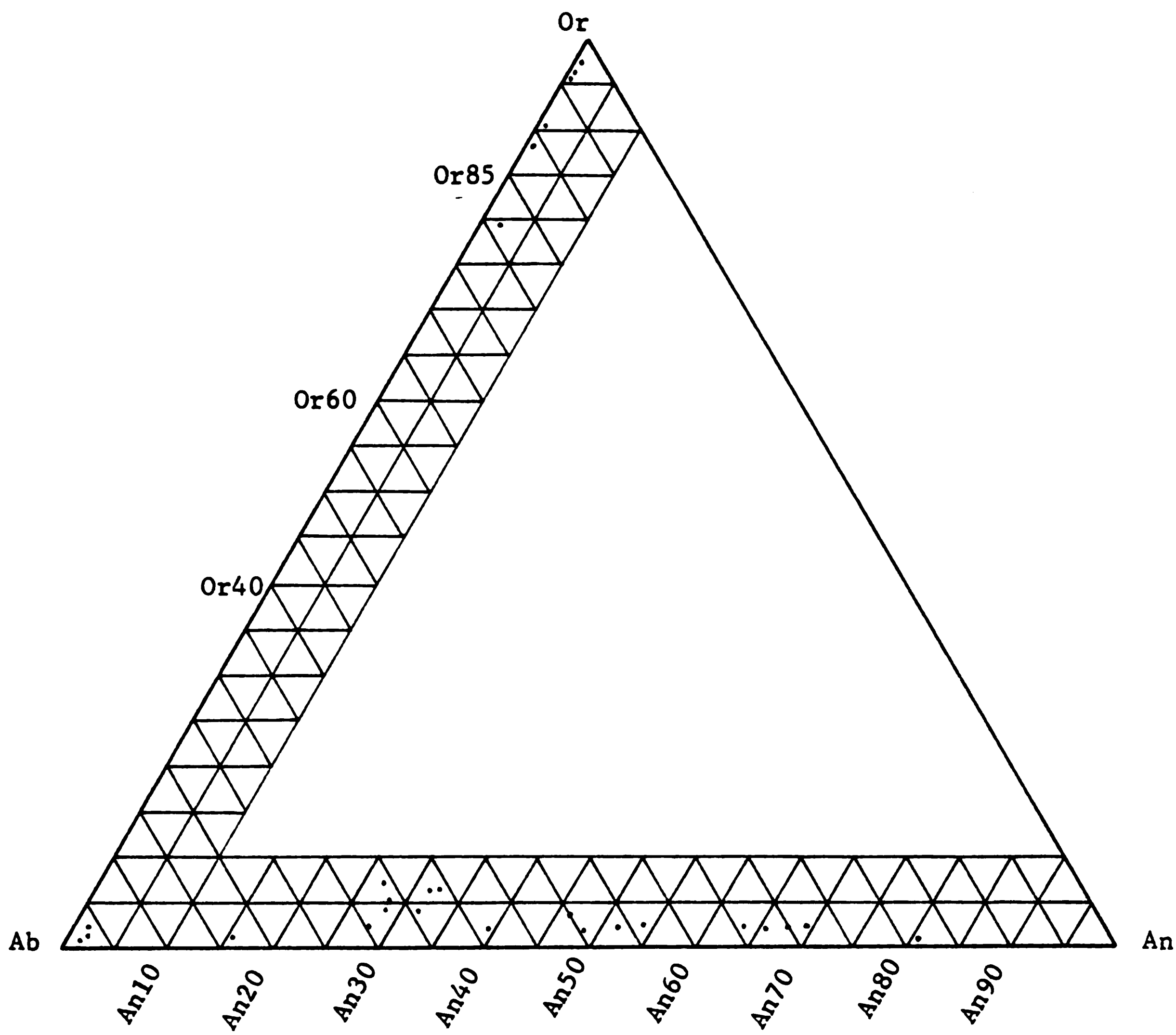


Figure A-20. Compositional plot of 27 feldspar grains in sample 22.

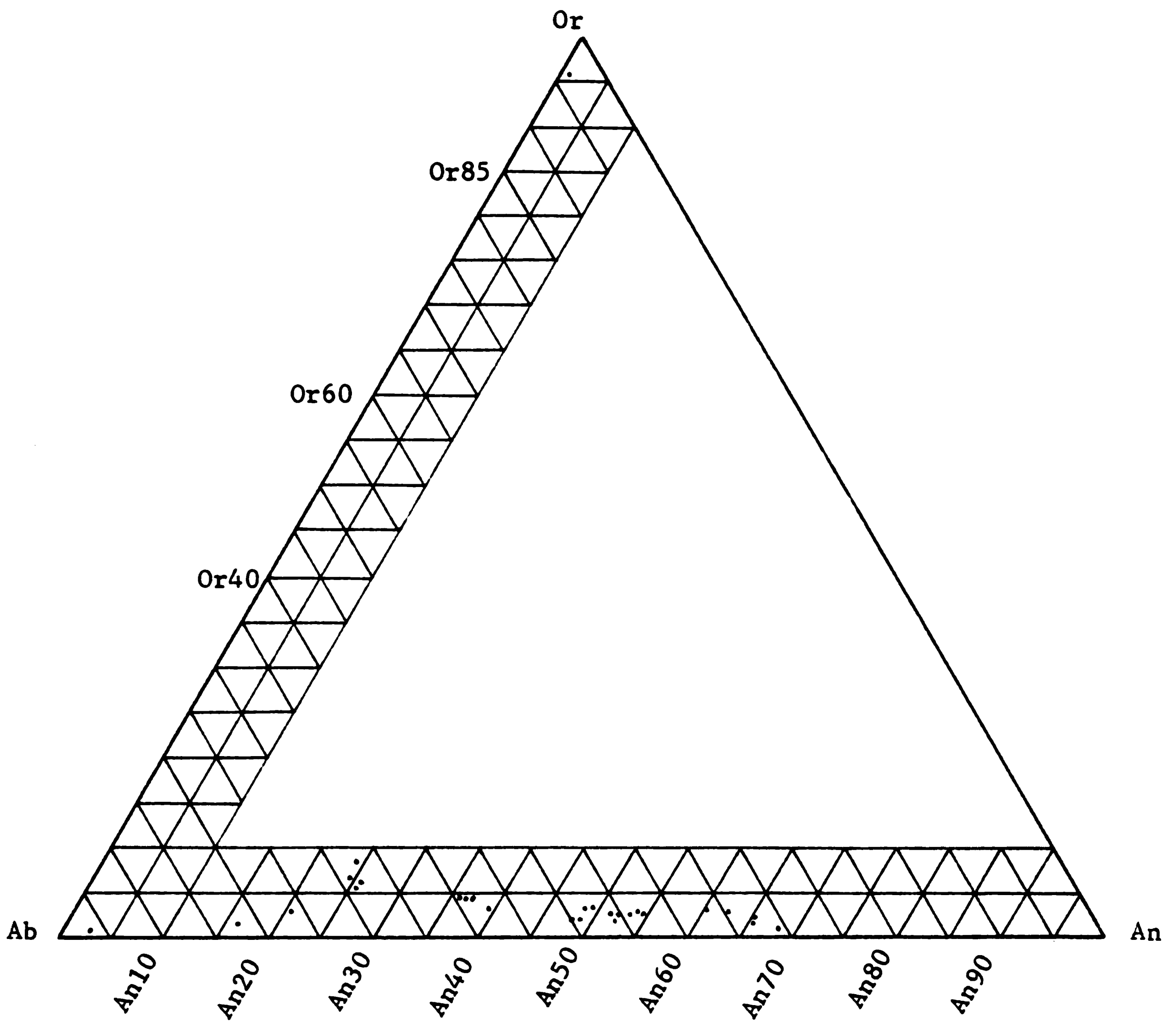


Figure A-21. Compositional plot of 27 feldspar grains in sample 23.

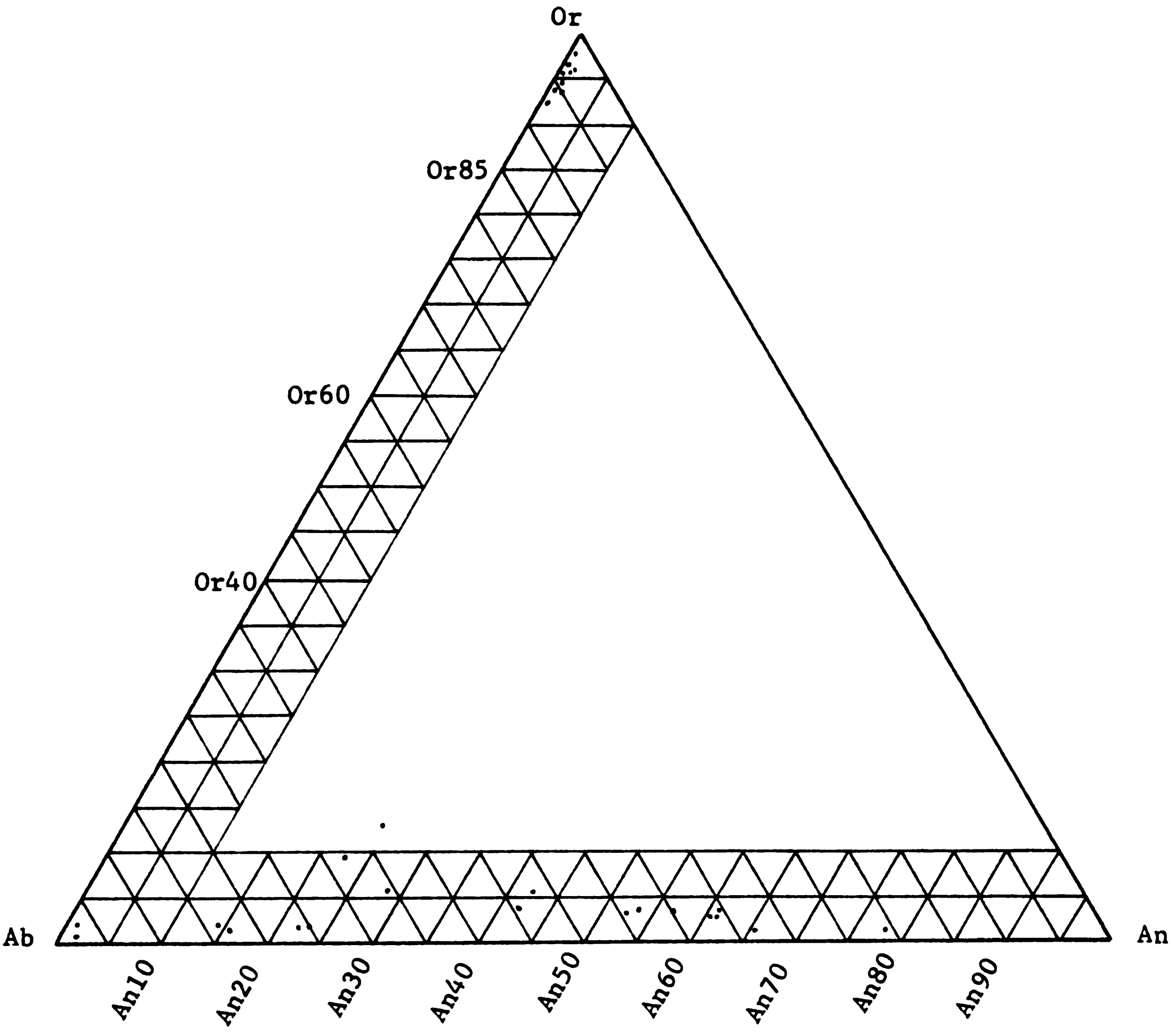


Figure A-22. Compositional plot of 28 feldspar grains in sample 24.

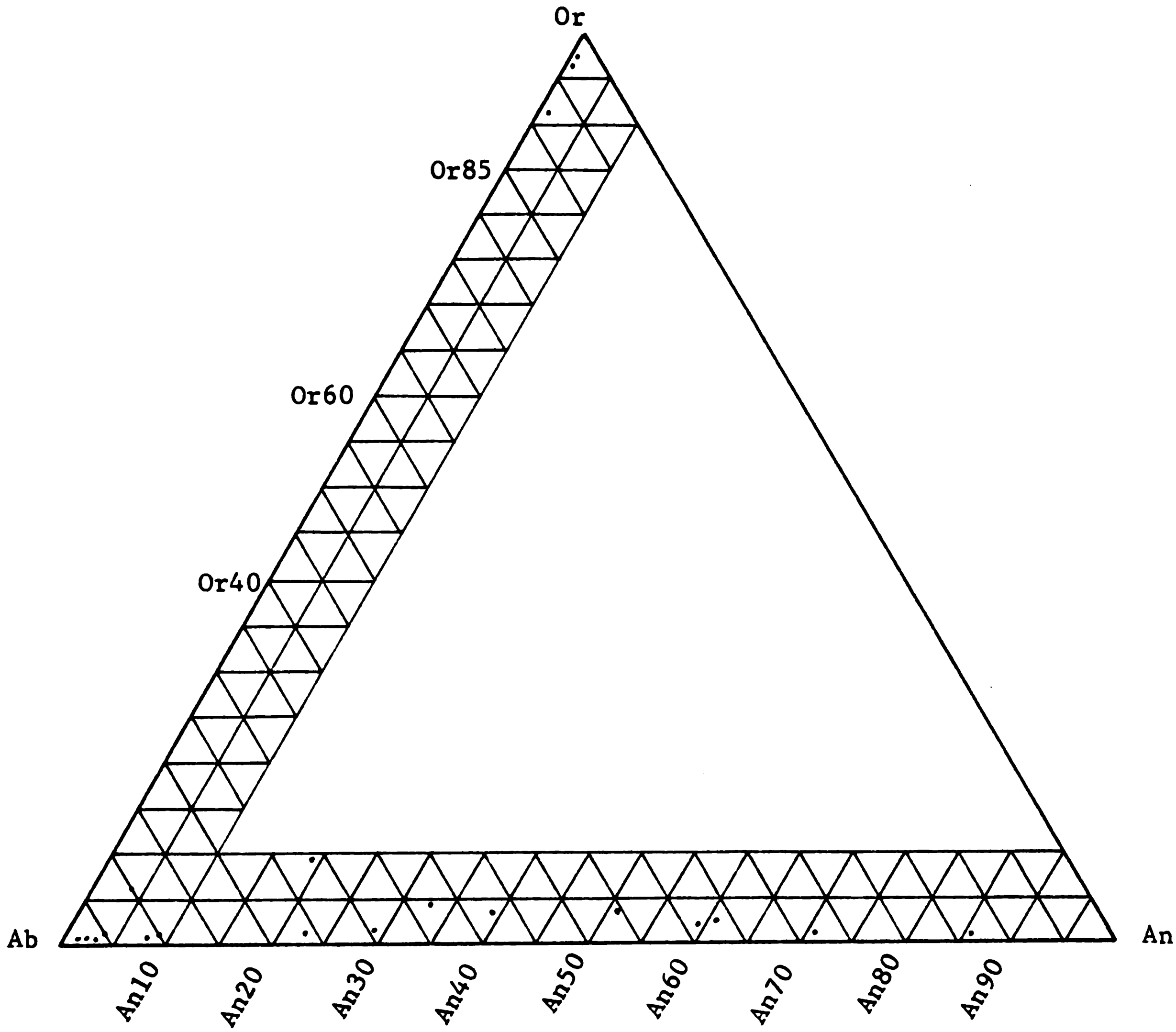


Figure A-23. Compositional plot of 20 feldspar grains in sample 25.

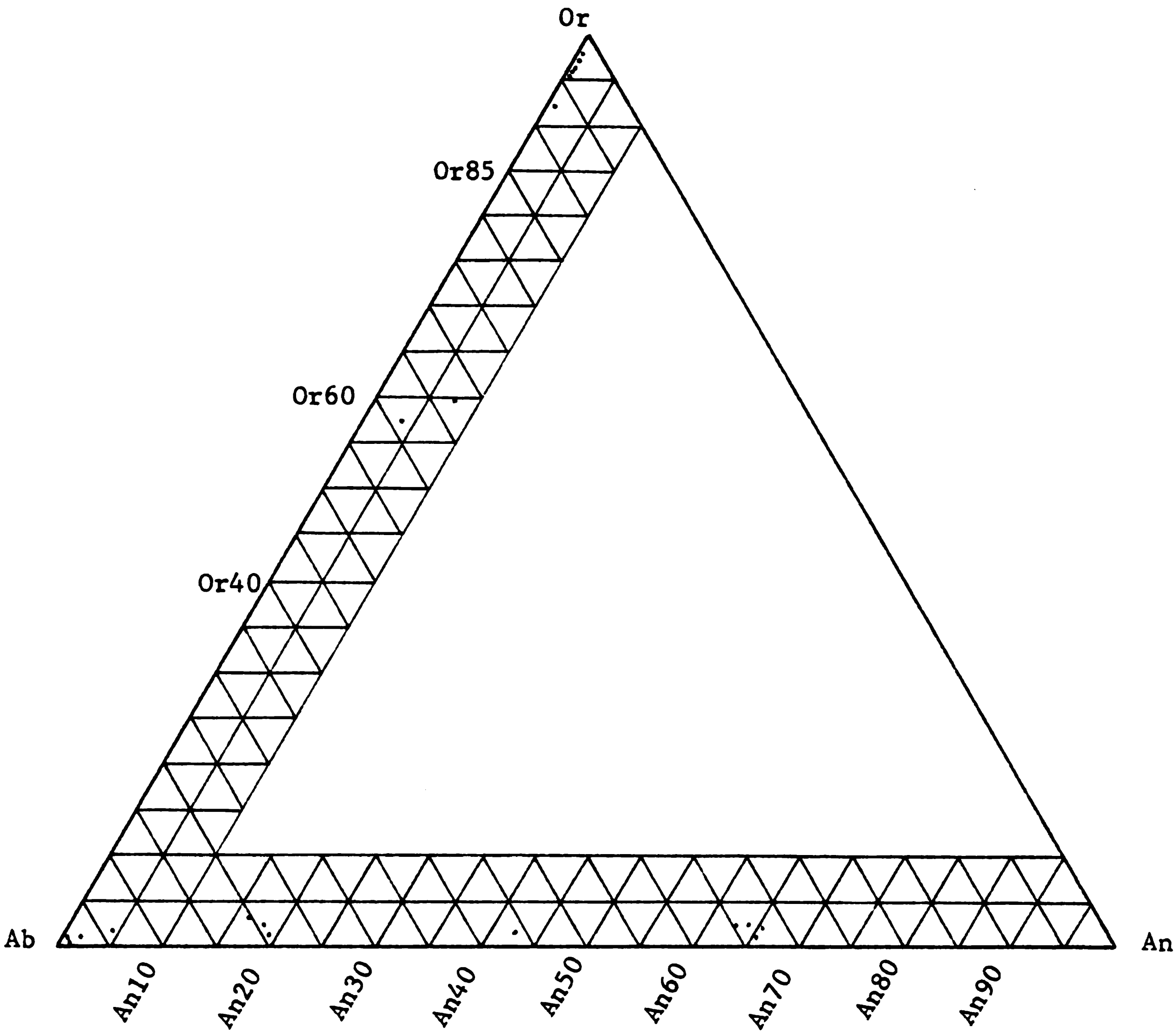


Figure A-24. Compositional plot of 20 feldspar grains in sample 26.

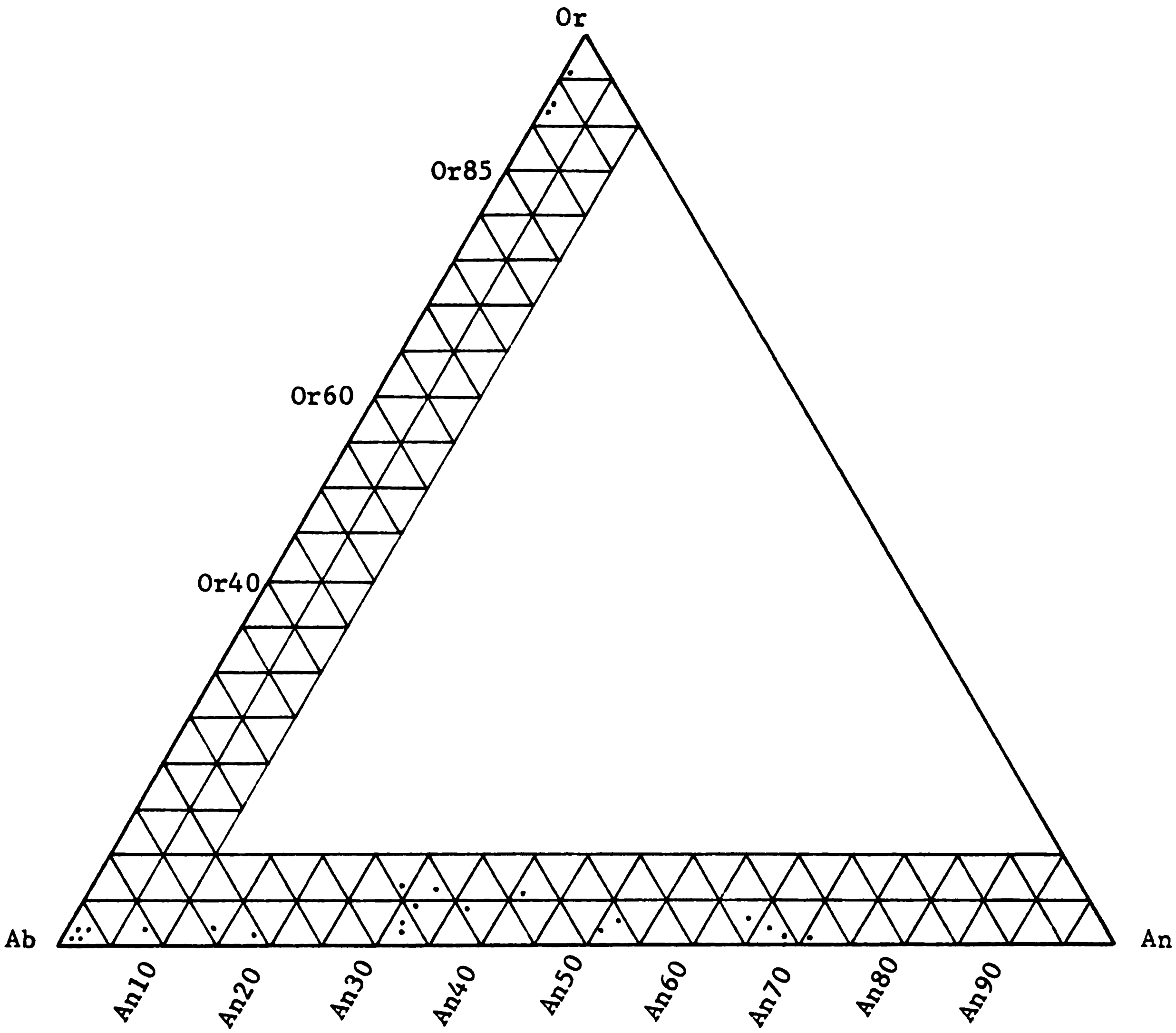


Figure A-25. Compositional plot of 23 feldspar grains in sample 27.

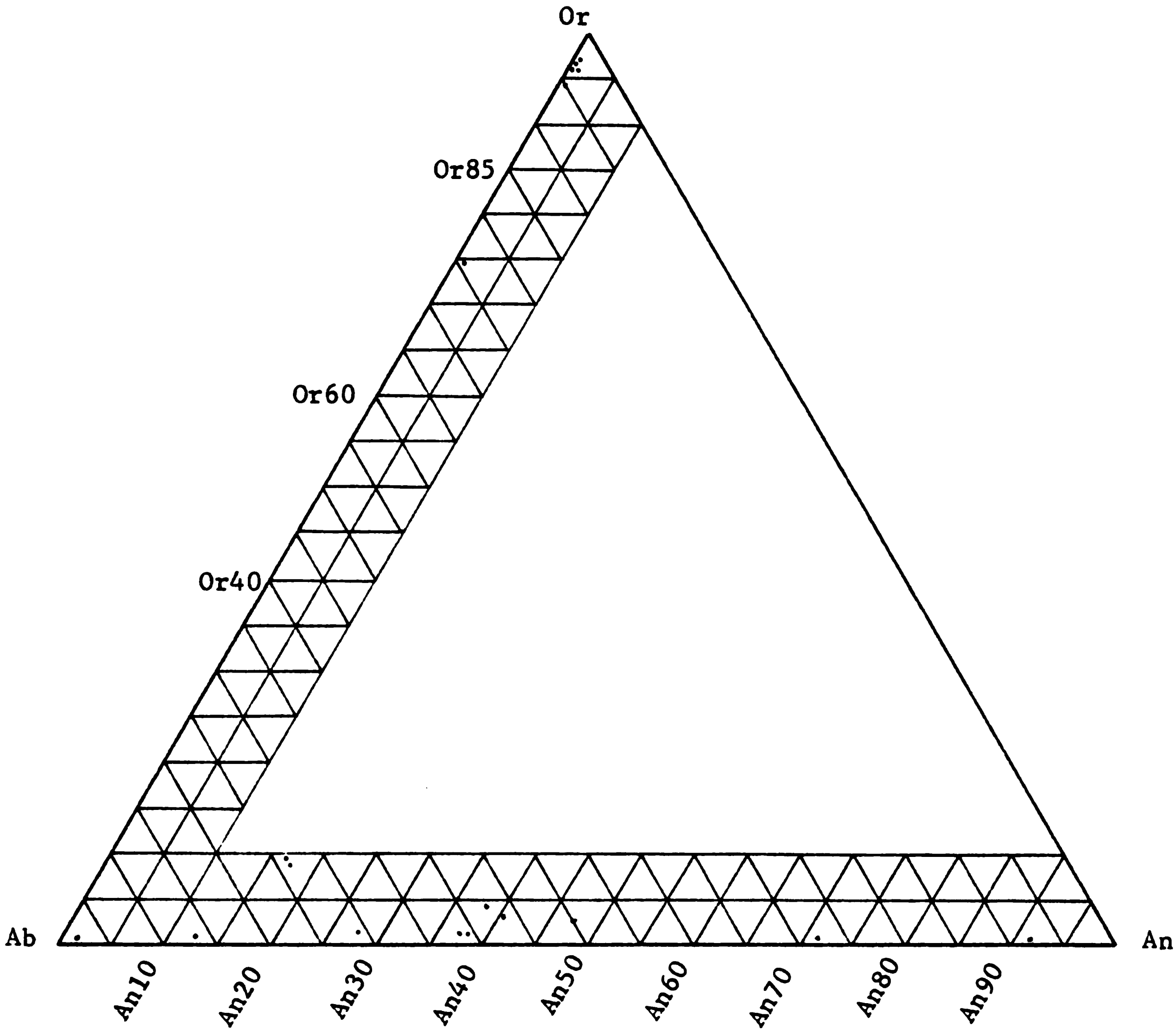


Figure A-26. Compositional plot of 18 feldspar grains in sample 28.

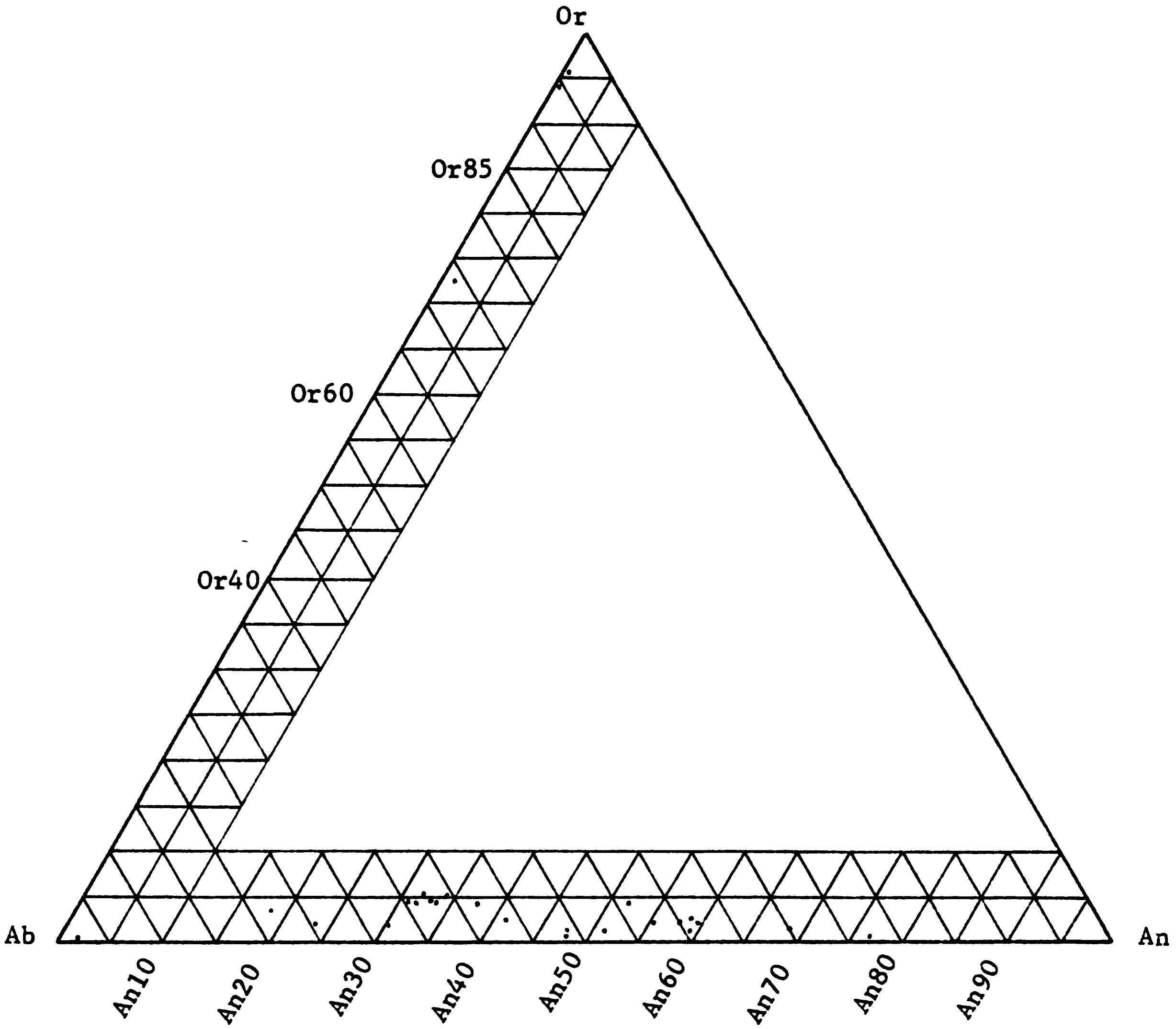


Figure A-27. Compositional plot of 26 feldspar grains in sample 29.

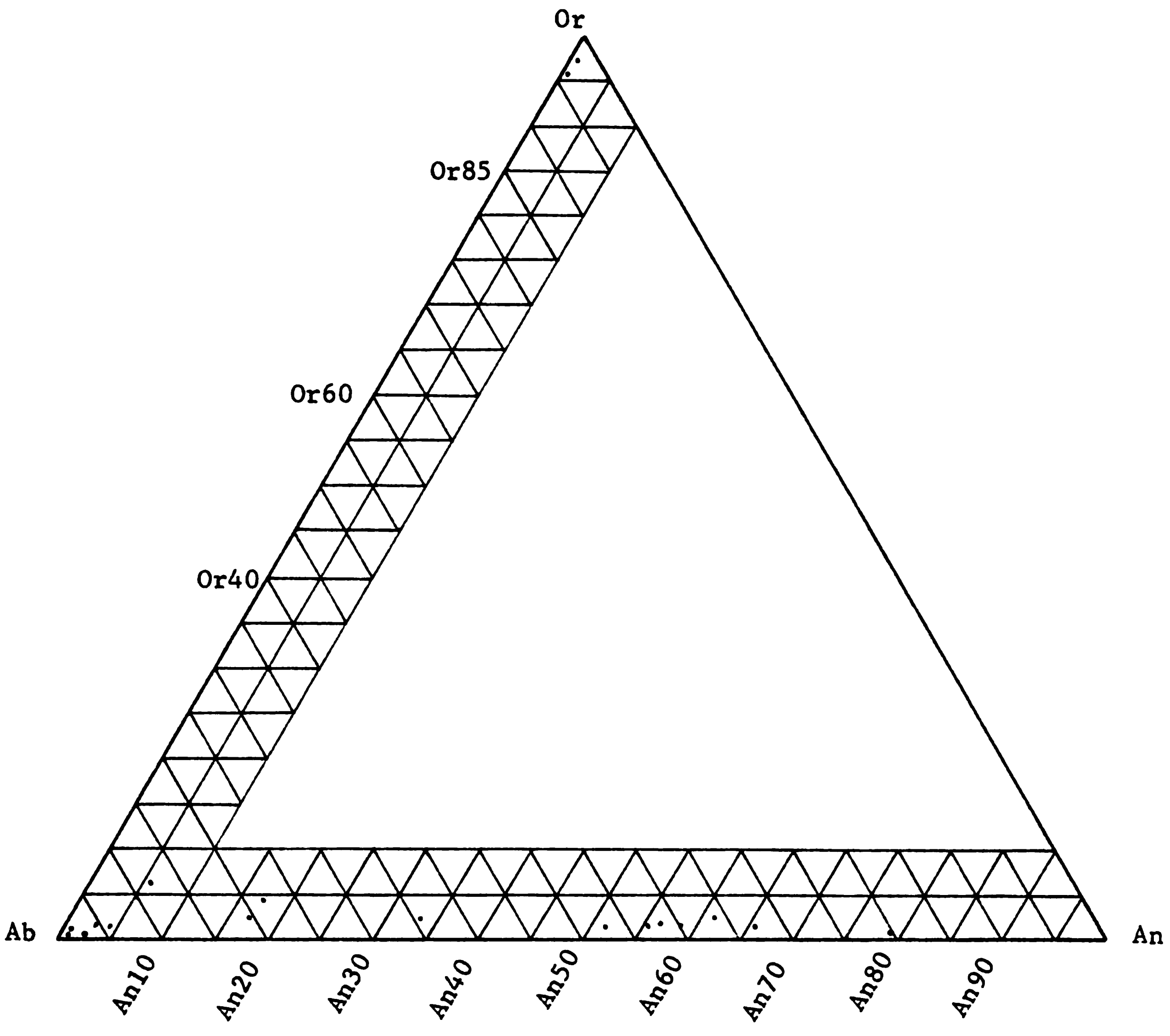


Figure A-28. Compositional plot of 18 feldspar grains in sample 30.

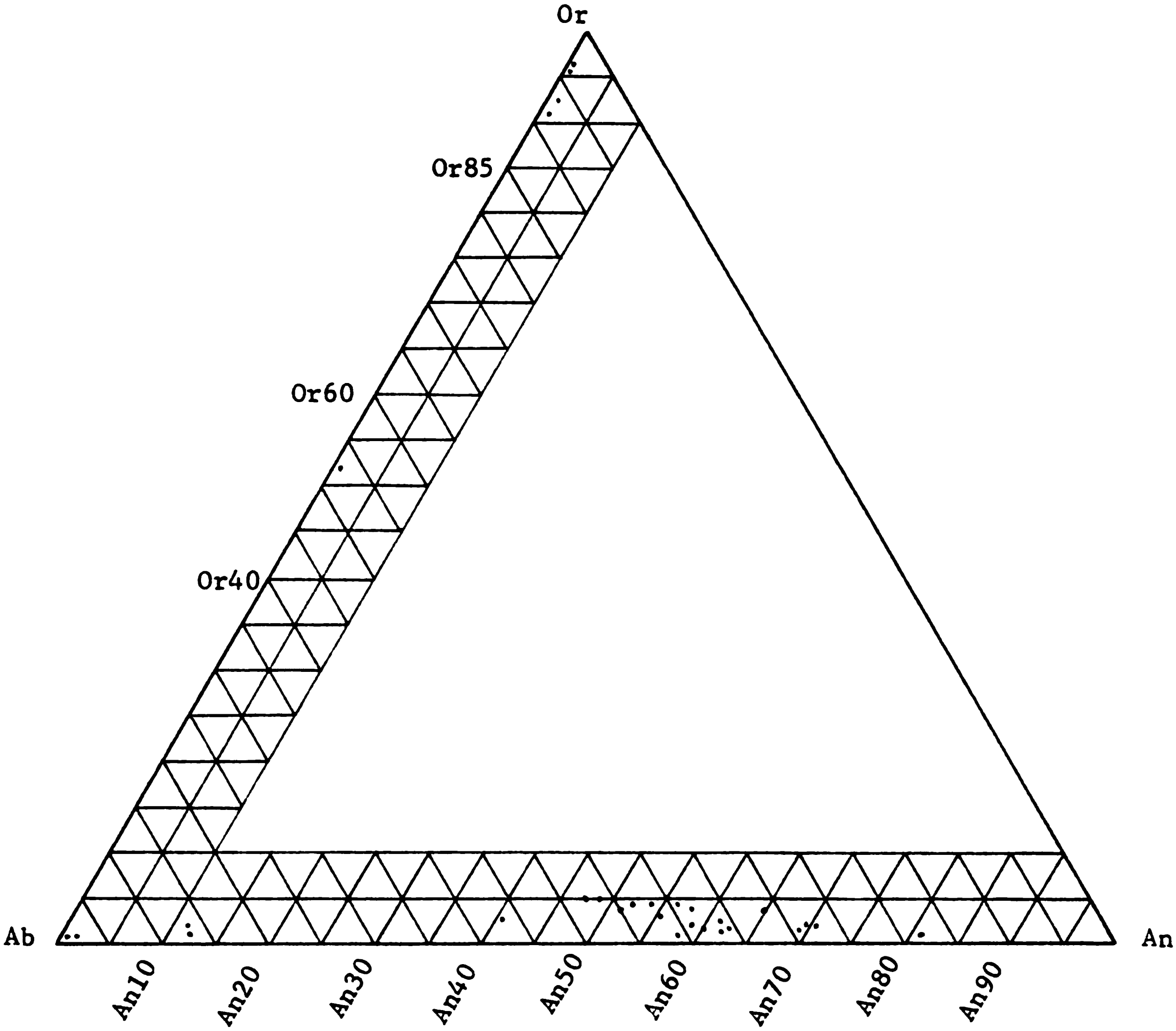


Figure A-29. Compositional plot of 29 feldspar grains in sample 31.

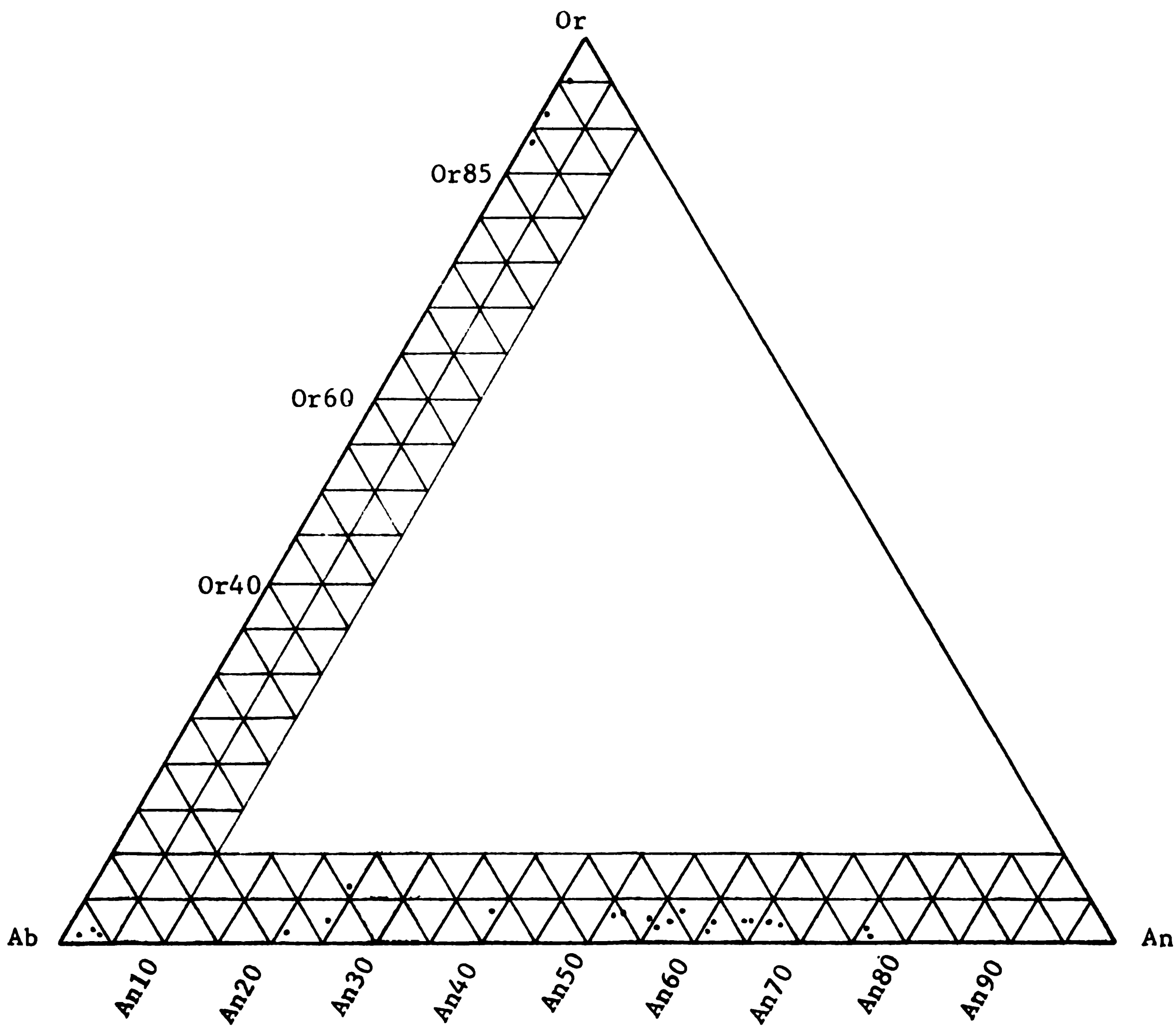


Figure A-30. Compositional plot of 24 feldspar grains in sample 32.

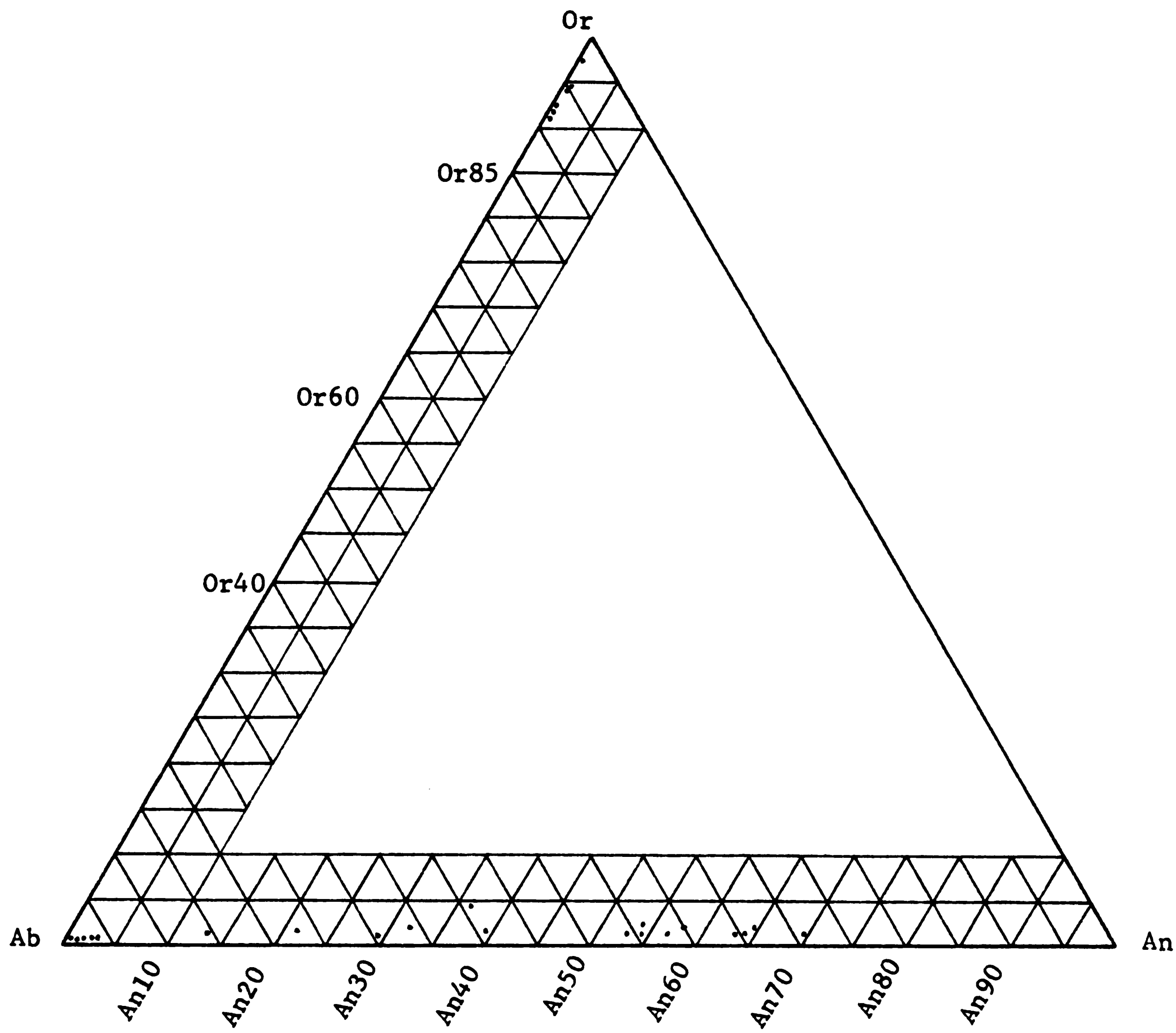


Figure A-31. Compositional plot of 26 feldspar grains in sample 33.

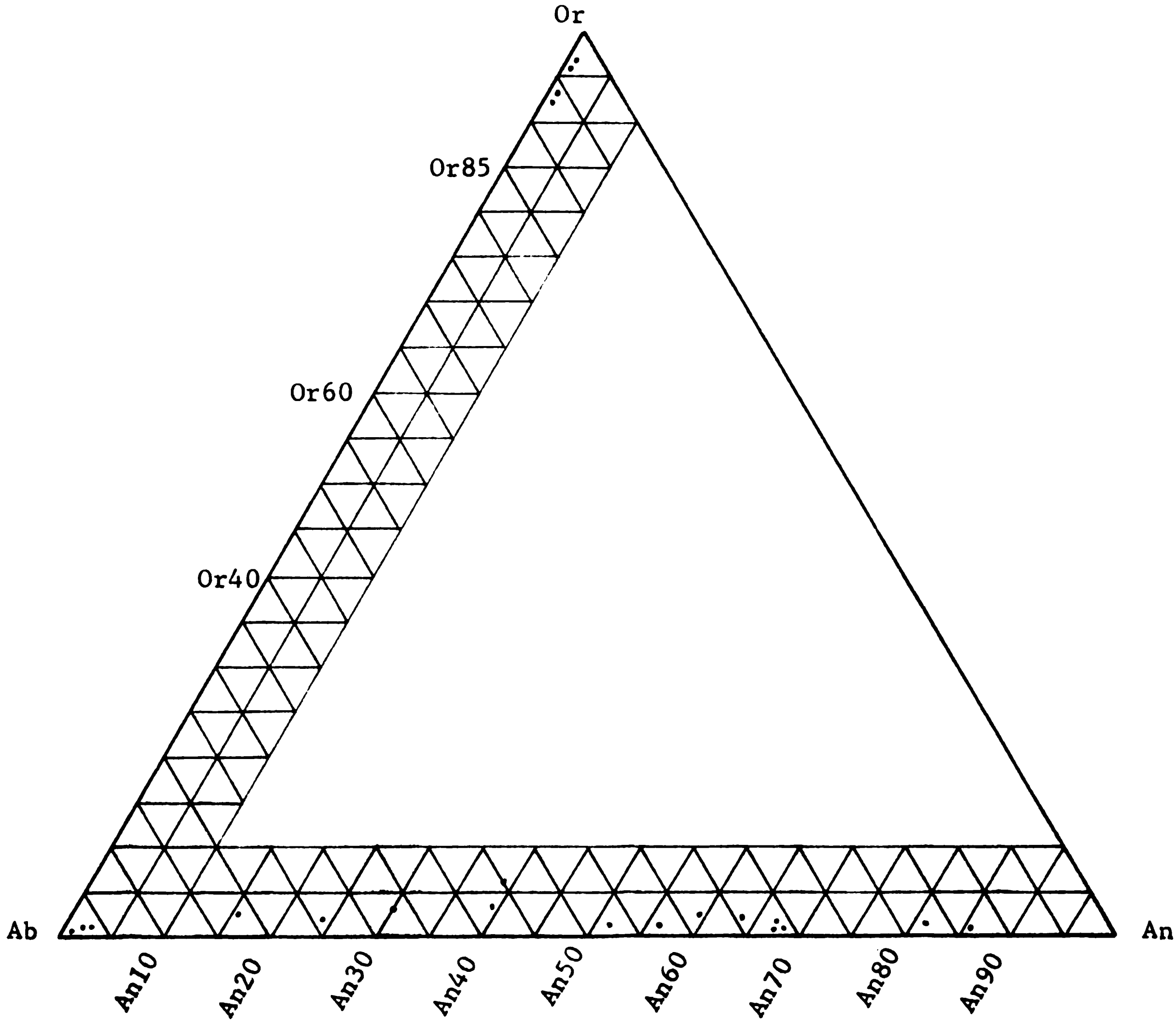


Figure A-32. Compositional plot of 21 feldspar grains in sample 35.

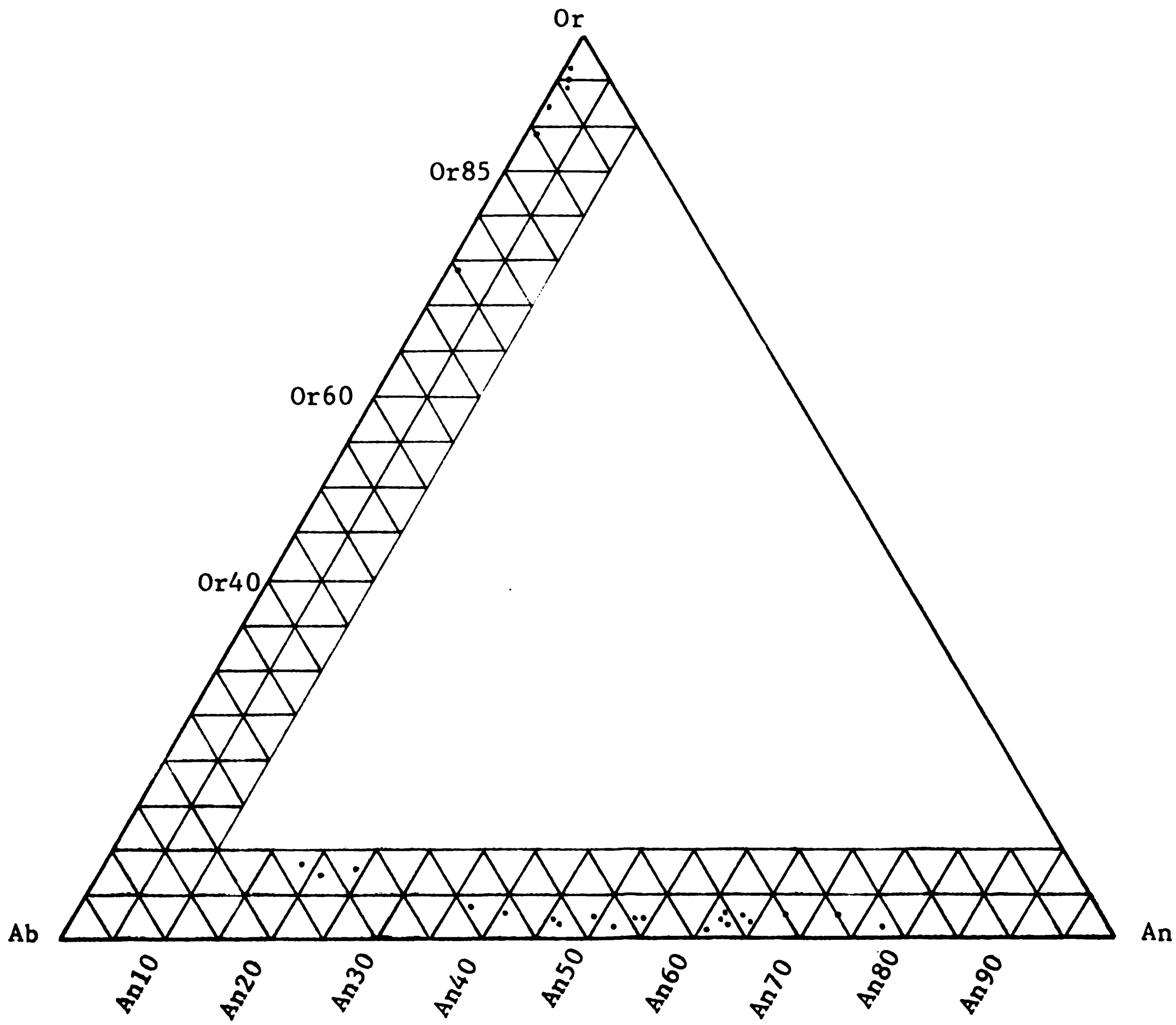


Figure A-33. Compositional plot of 26 feldspar grains in sample 36.

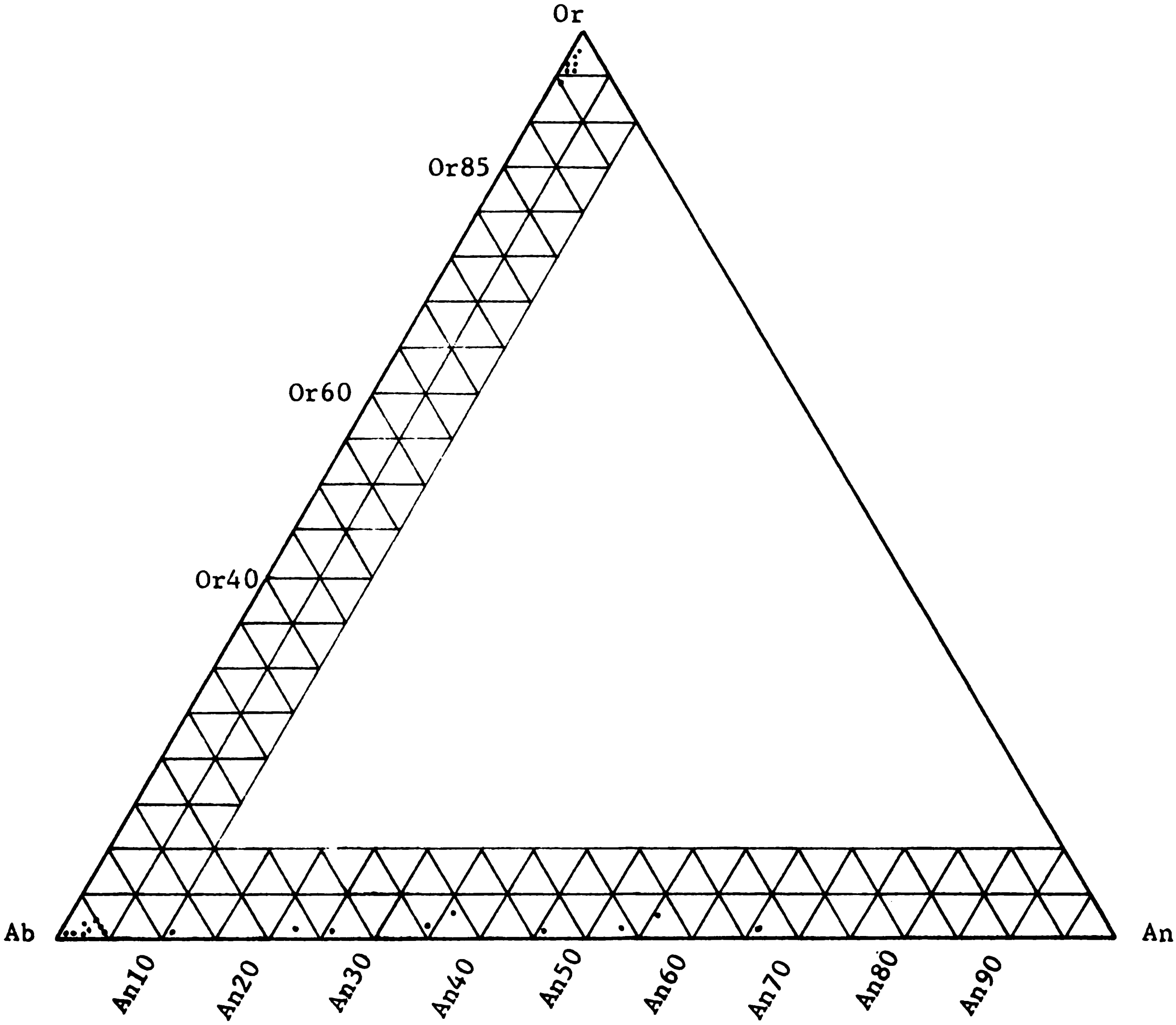


Figure A-34. Compositional plot of 24 feldspar grains in sample 37.

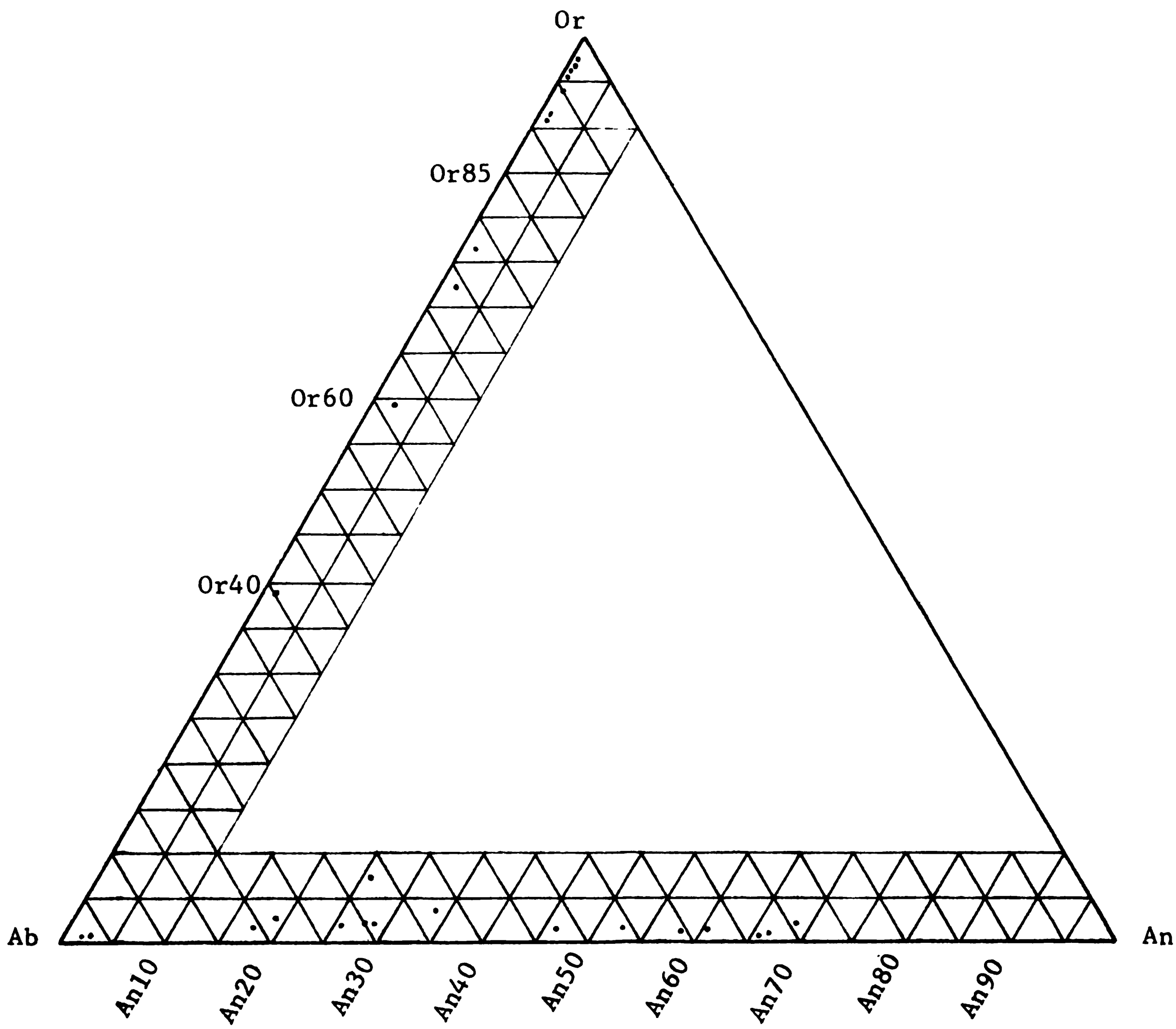


Figure A-35. Compositional plot of 27 feldspar grains in sample 38.

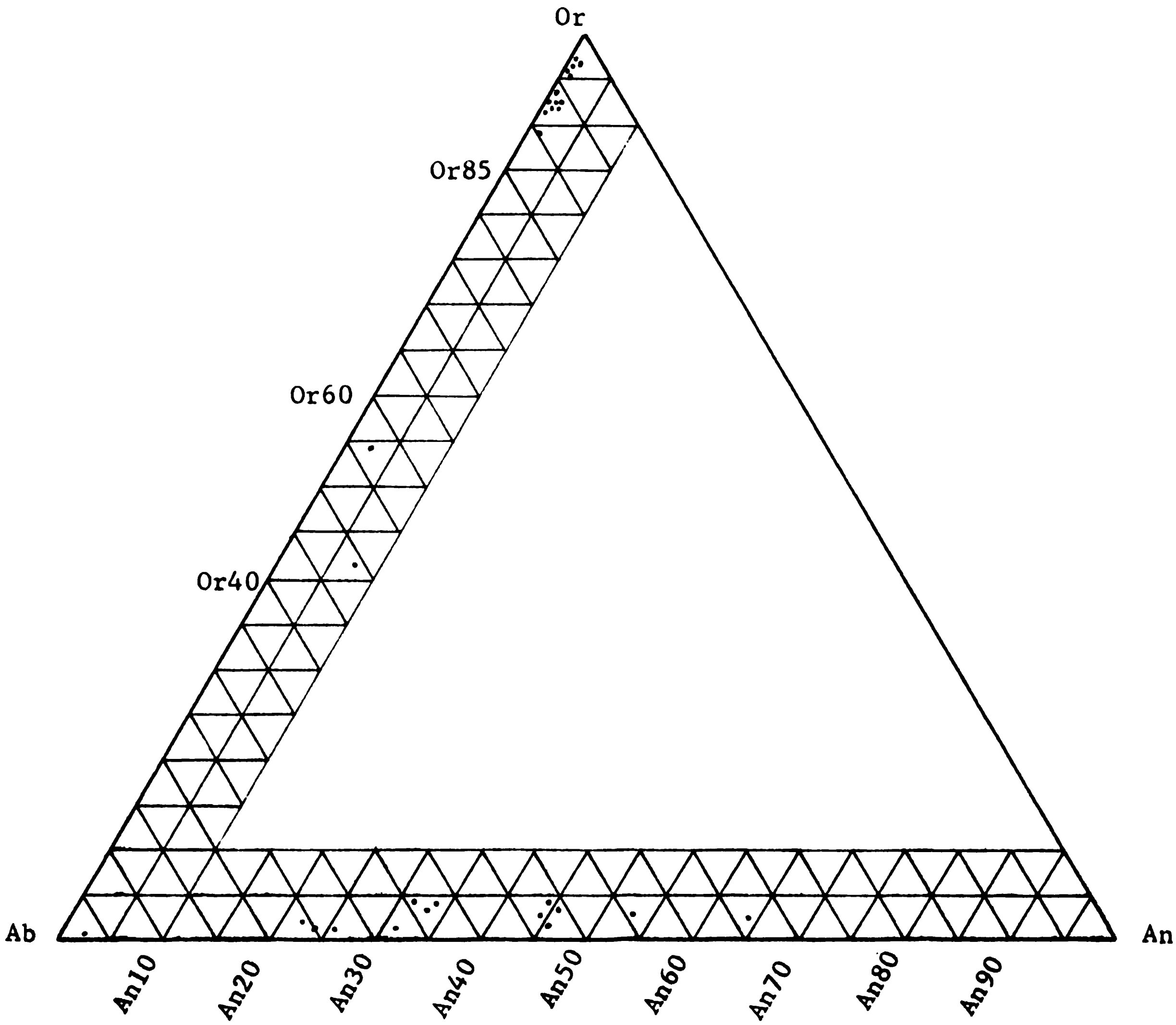


Figure A-36. Compositional plot of 29 feldspar grains in sample 41.

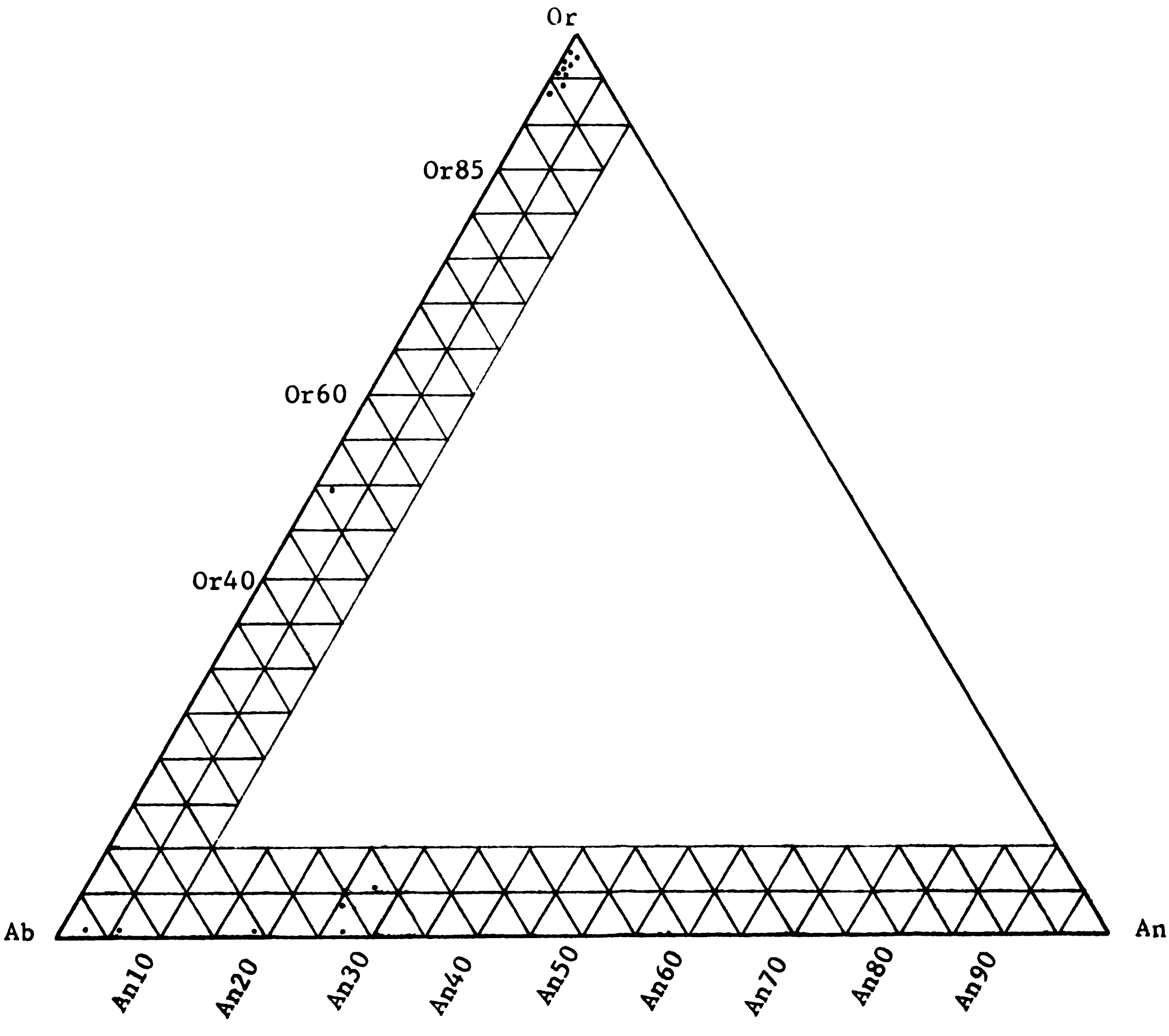


Figure A-37. Compositional plot of 16 feldspar grains in sample 42.

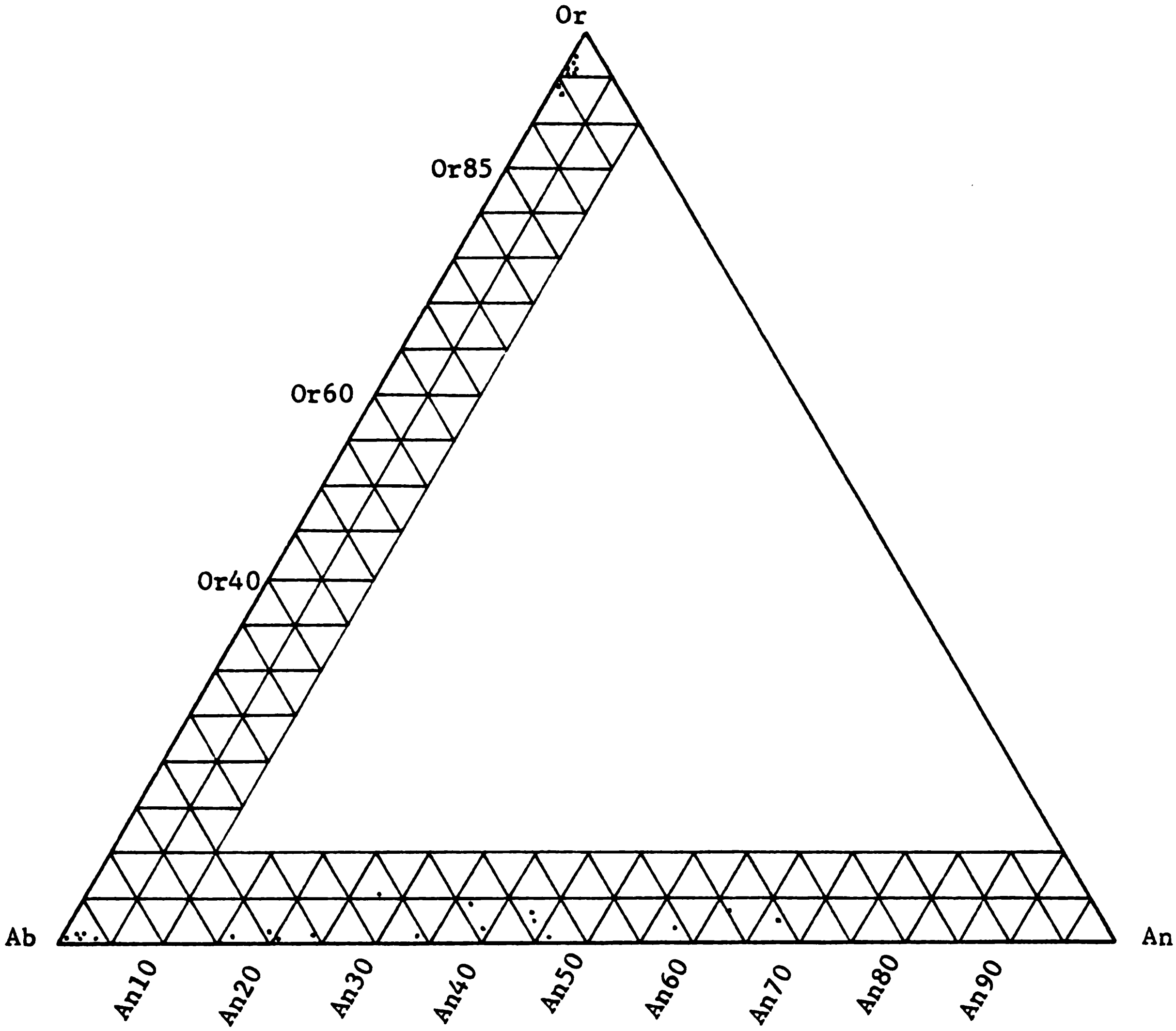


Figure A-38. Compositional plot of 27 feldspar grains in sample 43.

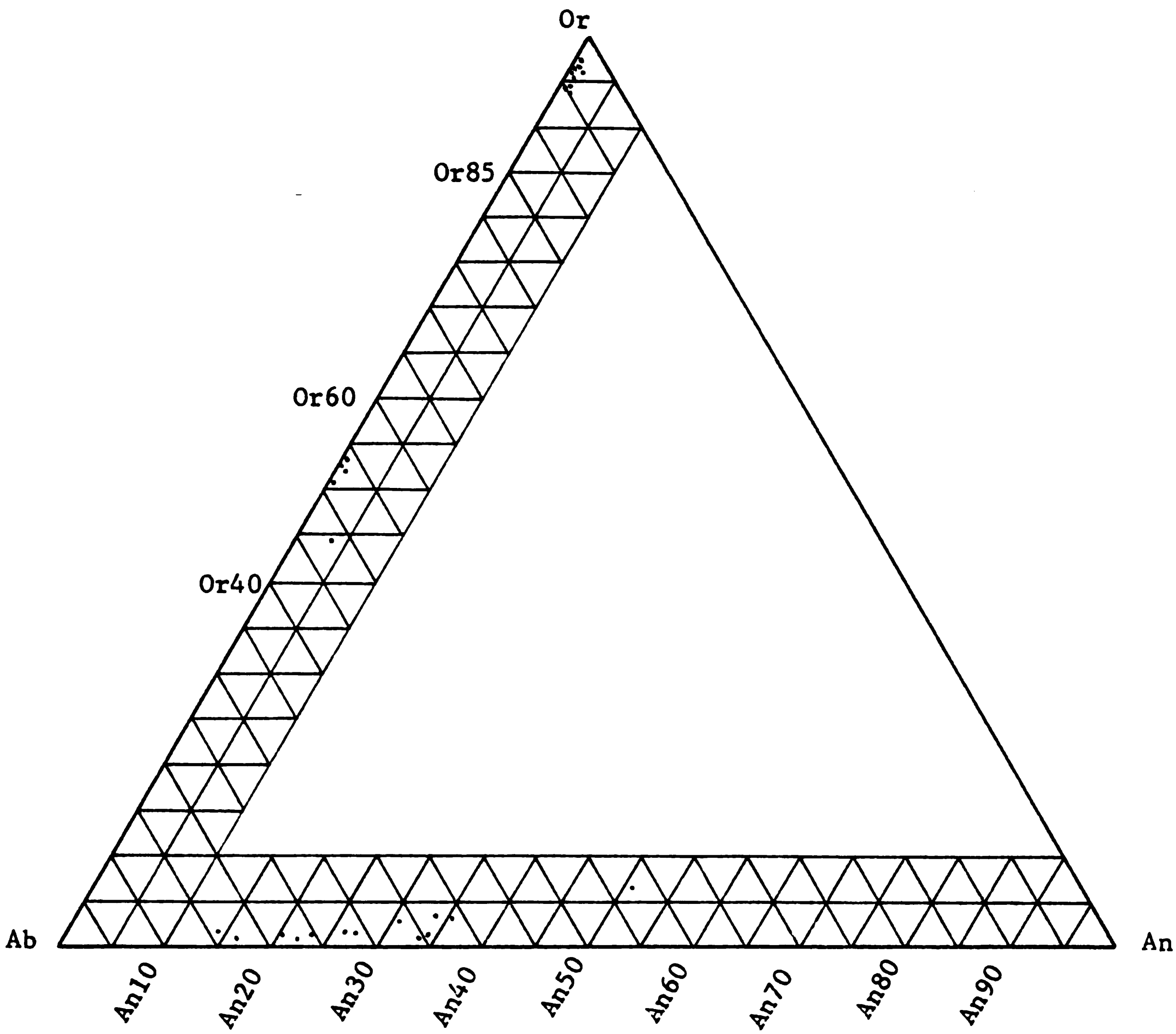


Figure A-39. Compositional plot of 27 feldspar grains in sample 44.

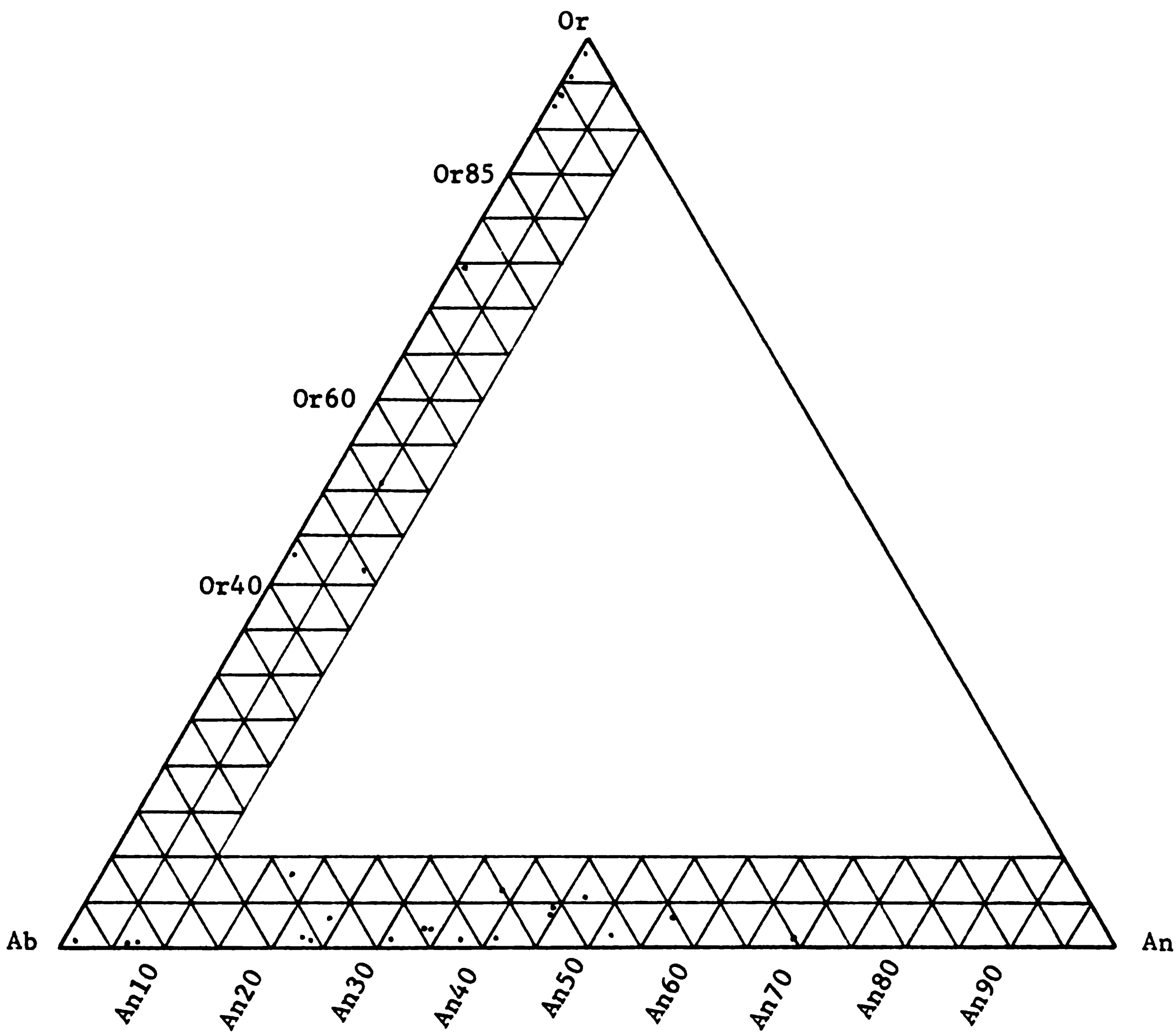


Figure A-40. Compositional plot of 27 feldspar grains in sample 45.

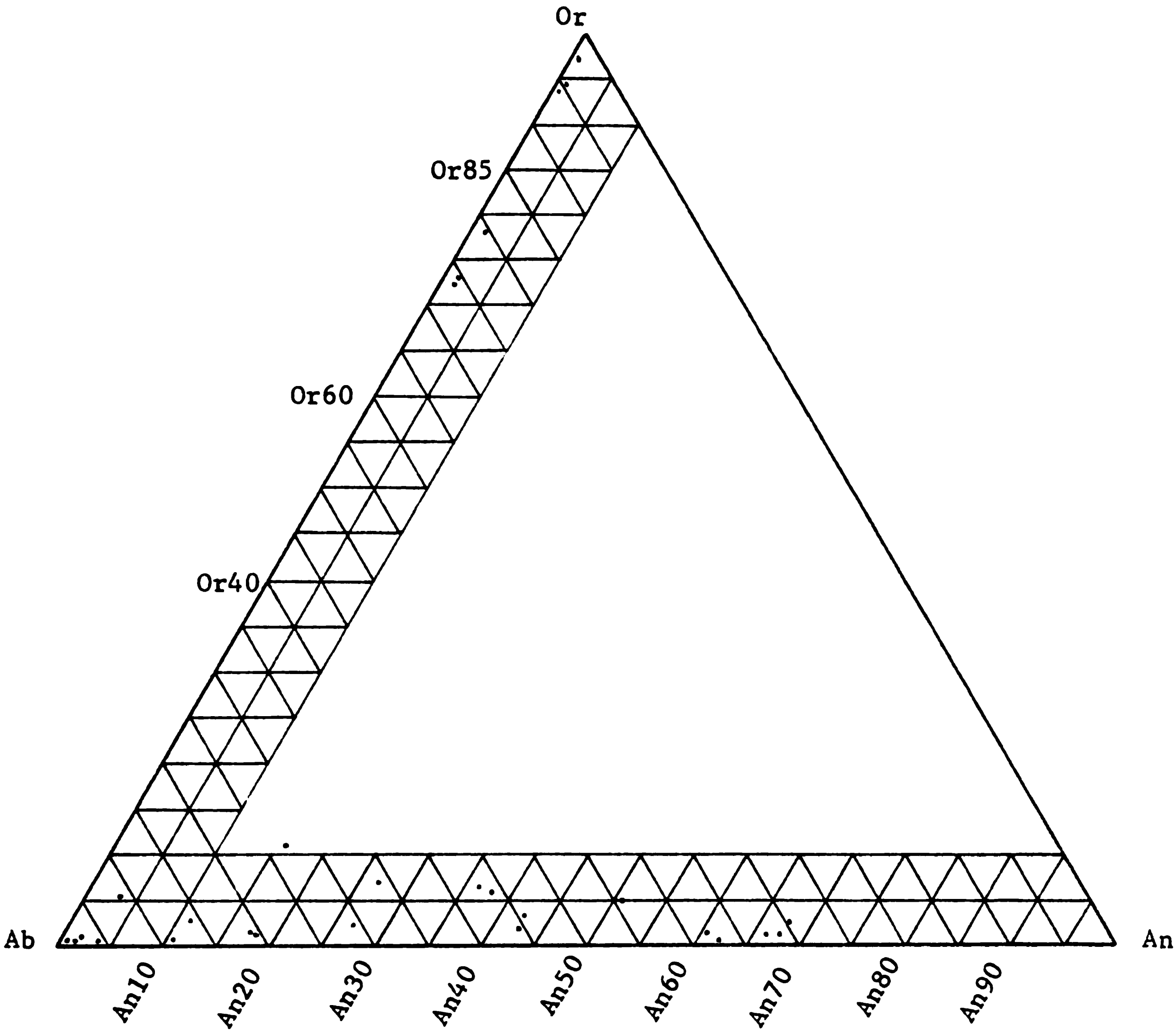


Figure A-41. Compositional plot of 28 feldspar grains in sample 48.

REFERENCES

REFERENCES

Ataman, G., and S. L. Gökçen, 1975, Determination of source and paleoclimate from the comparison of grain and clay fractions in sandstones: a case study, Sed. Geol., v. 13, p. 81-107.

Beloussov, V. V., 1968, Some problems of development of the earth's crust and upper mantle of oceans, In Knopoff, L., et al. (eds.), The crust and upper mantle of the Pacific area, Amer. Geophys. Union, Washington, p. 449-459.

Blatt, H., and B. Sutherland, 1969, Intrastratal solution and nonopaque heavy minerals in shales, Jour. Sed. Petrology, v. 39, p. 591-600.

Bokman, J., 1953, Lithology and petrology of the Stanley and Jackfork formations, Jour. Geology, v. 61, p. 152-170.

Bouma, A. H., 1962, Sedimentology of some flysch deposits, Elsevier, Amsterdam, 168 p.

_____ and C. D. Hollister, 1973, Deep ocean basin sedimentation, In Middleton, G. V., and A. H. Bouma (eds.), Turbidites and deep-water sedimentation, Short course notes, SEPM Pacific section, Anaheim, p. 79-118.

_____ and J. C. Moore, 1975, Physical properties of deep-sea sediments from the Phillipine Sea and the Sea of Japan, In Karig, D. E., J. C. Ingle et al., Initial reports of the Deep Sea Drilling Project, v. 31, U. S. Govt. Printing Office, Washington, p. 535-568.

Campbell, J. S., and D. L. Clark, 1977, Pleistocene turbidites of the Canada abyssal plain of the Arctic Ocean, Jour. Sed. Petrology, v. 47, p. 657-670.

Chayes, F., 1962, Numerical correlation and petrographic variation, Jour. Geology, v. 70, p. 440-452.

Cook, H. E., I. Zemmels and J. C. Matti, 1975, X-ray mineralogy data, far western Pacific, leg 31, Deep Sea Drilling Project, In Karig, D. E., J. C. Ingle et al., Initial reports of the Deep Sea Drilling Project, v. 31, U. S. Govt. Printing Office, Washington, p. 883-895.

Cummins, W. A., 1962, The greywacke problem, Liverpool Manchr. Geol. Jour., v. 3, p. 51-72.

Dickinson, W. R., and E. I. Rich, 1972, Petrologic intervals and petrofacies in the Great Valley sequence, Sacramento Valley, California, Geol. Soc. Amer. Bull., v. 83, p. 3007-3024.

Duncan, J. R., and L. D. Kulm, 1970, Mineralogy, provenance and dispersal history of Late Quaternary deep-sea sands in Cascadia Basin and Blanco fracture zone off Oregon, Jour. Sed. Petrology, v. 40, p. 874-887.

Eisbacher, G. H., 1976, Sedimentology of the Dezadeash flysch and its implications for strike-slip faulting along the Denali Fault, Yukon Territory and Alaska, Can. Jour. Earth Sci., v. 13, p. 1495-1513.

Fan, Pow-Foong, 1976, Recent silts in the Santa Clara River drainage basin, Southern California: a mineralogical investigation of their origin and evolution, Jour. Sed. Petrology, v. 46, p. 802-812.

Geological Survey of Japan, 1956, Geological map of Japan, T. Semba, Tokyo, Scale 1:2,000,000.

_____, 1964, Geological map of Japan, Kokudo Chizu Co., Ltd., Scale 1:2,000,000.

Gilbert, W. G., 1973, Franciscan rocks near Sur Fault Zone, northern Santa Lucia range, California, Geol. Soc. Amer. Bull., v. 84, p. 3317-3328.

_____, and W. R. Dickinson, 1970, Stratigraphic variations in sandstone petrology, Great Valley sequence, central California coast, Geol. Soc. Amer. Bull., v. 81, p. 949-954.

Gnibidenko, H. S., V. V. Argentov and S. V. Potapyev, 1977, Geology and deep structure in Primorye (South-western Sikhote-Alin, USSR), Pacific Geol., v. 12, p. 71-98.

Graham, S. A., R. V. Ingersoll and W. R. Dickinson, 1976, Common provenance for lithic grains in carboniferous sandstones from Ouachita Mountains and Black Warrior Basin, Jour. Sed. Petrology, v. 46, p. 620-632.

Grossgeym, V. A., 1972, Structure and conditions of formation of flysch, Geotectonics, no. 1, p. 22-25.

Harrold, P. J., and J. C. Moore, 1975, Composition of deep-sea sands from marginal basins of the northwestern Pacific, In Karig, D. E., J. C. Ingle et al., Initial reports of the Deep Sea Drilling Project, v. 31, U. S. Govt. Printing Office, Washington, p. 507-514.

Hasebe, K., N. Fujii and S. Uyeda, 1970, Thermal processes under island arcs, Tectonophysics, v. 10, p. 335-355.

Heezen, B. C., et al., 1966, Shaping of the continental rise by deep geostrophic contour currents, Science, v. 152, p. 502-508.

Hein, J. R., 1973, Increasing rate of movement with time between California and the Pacific plate: from Delgada submarine fan source areas, Jour. Geophys. Research, v. 78, p. 7752-7762.

Hilde, T. W. C., and J. M. Wageman, 1973, Structure and origin of the Japan Sea, In Coleman, P. J. (ed.), The western Pacific, Crane, Russak and Co., New York, p. 415-434.

Hubert, J., and P. F. Neal, 1967, Mineral composition and dispersal patterns of deep sea sands in the western North Atlantic petrologic province, Geol. Soc. Amer. Bull., v. 78, p. 749-772.

Karig, D. E., 1971, Origin and development of marginal basins in the western Pacific, Jour. Geophys. Research, v. 76, p. 2542-2561.

_____, J. C. Ingle et al., 1975, Initial reports of the Deep Sea Drilling Project, v. 31, U. S. Govt. Printing Office, Washington, 927 p.

_____ and G. F. Moore, 1975, Tectonically controlled sedimentation in marginal basins, Earth and Planetary Sci. Letters, v. 26, p. 233-238.

Keighin, C. W., G. B. Morey and S. S. Goldich, 1972, East-central Minnesota, In Sims, P. K., and G. B. Morey (eds.), Geology of Minnesota: a centennial volume, Minnesota Geol. Survey, St. Paul, p. 240-255.

Lajoie, J., Y. Heroux and B. Mathey, 1974, The Precambrian shield and the lower Paleozoic flysch sandstones and conglomerates of the Appalachians between Beaumont and Bic, Quebec, Can. Jour. Earth Sci., v. 11, p. 951-963.

Ludwig, W. J., S. Murauchi and R. E. Houtz, 1975, Sediments and structure of the Japan Sea, Geol. Soc. Amer. Bull., v. 86, p. 651-664.

Matsuda, T., and S. Uyeda, 1971, On the Pacific-type orogeny and its model -- extension of the paired belts concept and possible origin of marginal seas, Tectonophysics, v. 11, p. 5-27.

McBride, E. F., 1962, Flysch and associated beds of the Martinsburg formation (Ordovician), central Appalachians, Jour. Sed. Petrology, v. 32, p. 39-91.

Minato, M., 1973, The origin of "deep sea basins" in the marginal seas behind the island arcs of the western Pacific, Pacific Geol., v. 6, p. 95-99.

Moore, J. C., 1973, Cretaceous continental margin sedimentation, southwestern Alaska, Geol. Soc. Amer. Bull., v. 84, p. 595-614.

Murray, M., and K. C. Condie, 1973, Post-Ordovician to Early Mesozoic history of the Eastern Klamath subprovince, Northern California, Jour. Sed. Petrology, v. 43, p. 505-515.

Nelson, C. H., and T. H. Nilson, 1974, Depositional trends of modern and ancient deep-sea fans, In Dott, Jr., R. H., and R. S. Shaver (eds.), Modern and ancient geosynclinal sedimentation, SEPM Spec. Pub. 19, Tulsa, p. 69-91.

Ojakangas, R. W., 1968, Cretaceous sedimentation, Sacramento Valley, California, Geol. Soc. Amer. Bull., v. 79, p. 973-1008.

_____, 1972, Archean volcanogenic greywackes of the Vermilion district, Northeastern Minnesota, Geol. Soc. Amer. Bull., v. 83, p. 429-442.

Shaw, D. B., and C. E. Weaver, 1965, The mineralogical composition of shales, Jour. Sed. Petrology, v. 35, p. 213-222.

Shideler, G. L., A. Ślaczka, R. Unrug and M. Wendorff, 1975, Textural and mineralogical sorting relationships in Krosno formation (Oligocene) turbidites, Polish Carpathian mountains, Jour. Sed. Petrology, v. 45, p. 44-56.

Siegel, S., 1956, Nonparametric statistics for the behavioral sciences, McGraw-Hill, New York, 312 p.

Steel, R. G. P., and J. H. Torrie, 1960, Principles and procedures of statistics, McGraw-Hill, New York, 481 p.

Stewart, R. J., 1976, Turbidites of the Aleutian abyssal plain: mineralogy, provenance and constraints for Cenozoic motion of the Pacific plate, Geol. Soc. Amer. Bull., v. 87, p. 793-808.

Swe, W., and W. R. Dickinson, 1970, Sedimentation and thrusting of Late Mesozoic rocks in the Coast Ranges near Clear Lake, California, Geol. Soc. Amer. Bull., v. 81, p. 165-188.

Sweatmen, T. R., and J. V. P. Long, 1969, Quantitative electron-probe microanalysis of rock-forming minerals, Jour. Petrology, v. 10, p. 332-379.

Sychev, P. M., and S. S. Snegovsky, 1976, Abyssal depressions of the Okhotsk, Japan and Bering Seas, Pacific Geol., v. 11, p. 57-80.

United Nations Economic Commission for Asia and the Far East (UNECAFE), 1971, Geological map of Asia and the Far East, 2nd ed., Scale 1:5,000,000.

Uyeda, S., and A. Miyashiro, 1974, Plate tectonics and the Japanese islands: a synthesis, Geol. Soc. Amer. Bull., v. 85, p. 1159-1170.

Vallier, T. L., P. J. Harold and W. A. Girdley, 1973, Provenances and dispersal patterns of turbidite sand in the Escabana trough, northeastern Pacific Ocean, Marine Geol., v. 15, p. 67-87.

Woodbury, J. L., and T. A. Vogel, 1970, A rapid, economical method for polishing thin sections for microprobe and petrographic analyses, Amer. Mineralogist, v. 55, p. 2095-2102.