A Statistical Analysis of Chemical and Mineralogic Data from the Tertiary Kootznahoo Formation in Southeastern Alaska, With Emphasis on Uranium and Thorium

By KENDELL A. DICKINSON and CHARLES T. PIERSON

U.S. GEOLOGICAL SURVEY BULLETIN 1851

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1988

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data
Dickinson, Kendell A., 1931–

A statistical analysis of chemical and mineralogic data from the Tertiary Kootznahoo Formation in southeastern Alaska, with emphasis on uranium and thorium.

(U.S. Geological Survey bulletin ; 1851)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1851
1. Geology, Stratigraphic—Tertiary. 2. Geology—Alaska—Kootznahoo Inlet Region. 3. Geochemistry—Alaska—Kootznahoo Inlet Region. 4. Kootznahoo Formation (Alaska) I. Pierson, Charles Thomas, 1918– . II. Title III. Series.
QE75.B9 no. 1851 557.3 s [553'.09798'2] 88-600197

CONTENTS

FIGURES

TABLES

TABLES

A Statistical Analysis of Chemical and Mineralogic Data From the Tertiary Kootznahoo Formation in Southeastern Alaska, with Emphasis on Uranium and Thorium

By Kendell A. Dickinson *and* Charles T. Pierson

ABSTRACT

Statistical analysis of chemical and mineralogic data from the Tertiary Kootznahoo Formation and related rocks in southeastern Alaska suggests regional geochemical and petrologic trends and sedimentary processes. Three data sets were analyzed. Data set I contains chemical data including uranium and thorium values and X-ray diffraction mineralogic data from 41 samples of the Tertiary Kootznahoo Formation, Data set II contains chemical data including uranium and thorium from Tertiary igneous intrusive and extrusive rocks associated with the Kootznahoo Formation. Data set III contains chemical data from samples of the Kootznahoo Formation in the Petersburg quadrangle area. The samples used for data sets I and II were collected from four Kootznahoo outcrop areas; the Zarembo Island area, which includes California Bay on the northern end of Prince of Wales Island; the Keku Strait area, which includes parts of Kuiu and Kupreanof Islands; the Pybus Bay area in the southeastern part of Admiralty Island; and the Kootznahoo Inlet area along the western shore of Admiralty Island. Data set III was taken from published data for the Alaska Mineral Resource Appraisal Program of the Petersburg 1° by 2° quadrangle.

R-mode factor analysis suggests that much of the distribution of the elements and minerals in data set I can be explained by a six-factor model. The first factor contains siderite, iron, and vanadium in a positive association and the elements Al, K, Ba, Sr, and Na as a negative association. The iron-vanadium association probably represents alteration and the aluminum-potassium association probably represents the detrital feldspar and mica-illite minerals. The second factor contains uranium and lead representing epigenetic mineralization as one association and titanium, and chromium that are common in resistate minerals together with scandium in an opposite association. The third factor contains the detrital minerals quartz and plagioclase together with calcite as one association and the chalcophile elements—Co, Ni, and Cu—as the other. The fourth factor includes the cations Mn, Mg, Y, and Ca that are expected in general to represent the carbonates. A positive association in the fifth factor includes Zr, La, Th, and Ga. Except for gallium, this association probably represents heavy mineral assemblages. A negative association that includes only dolomite is also present in factor five. The sixth factor includes chlorite and illite-mica as a positive association and kaolinite and potassium feldspar as a negative association. The latter minerals in factor six appear to have formed, at least in part, from the former. Dolomite also shows a moderate negative association in factor six and it may be an alteration product. Similar interpretations can be made for the other two data sets.

Scatterplots are a necessary complement to factor analysis for an adequate explanation of uranium and thorium. Uranium and thorium are distributed in three groups, one representing uranium enrichment, one representing thorium enrichment, and one representing detrital sediments enriched in neither uranium nor thorium.

INTRODUCTION

The Tertiary Kootznahoo Formation is a Paleocene through Miocene nonmarine clastic unit that crops out in southeastern Alaska. The main outcrop areas are found in a belt that stretches from the north end of Prince of Wales Island and Zarembo Island, in the south, to the Kootznahoo Inlet area on west-central Admiralty Island, in the north (fig. 1). The formation consists mostly of

Publication approved by the Director, U.S. Geological Survey April 6, 1988.

arkosic conglomerate and sandstone. The purpose of this report is to present statistical analyses of geochemical and mineralogic data from samples collected during the summers of 1979, 1980, and 1984, and to interpret the analyses in terms of regional trends and sedimentary and diagenetic processes. The data for sets I and II was originally collected as a part of a uranium-potential study of the area. The data for set III was taken from a study by Karl and others (1985).

Methods

Samples of the Kootznahoo Formation collected from four different areas were analyzed chemically and mineralogically. Uranium and thorium contents were determined by the delayed-neutron method (Millard, 1976); abundances of other elements were determined by six-step semiquantitative spectroscopy (SQS) (Myers and

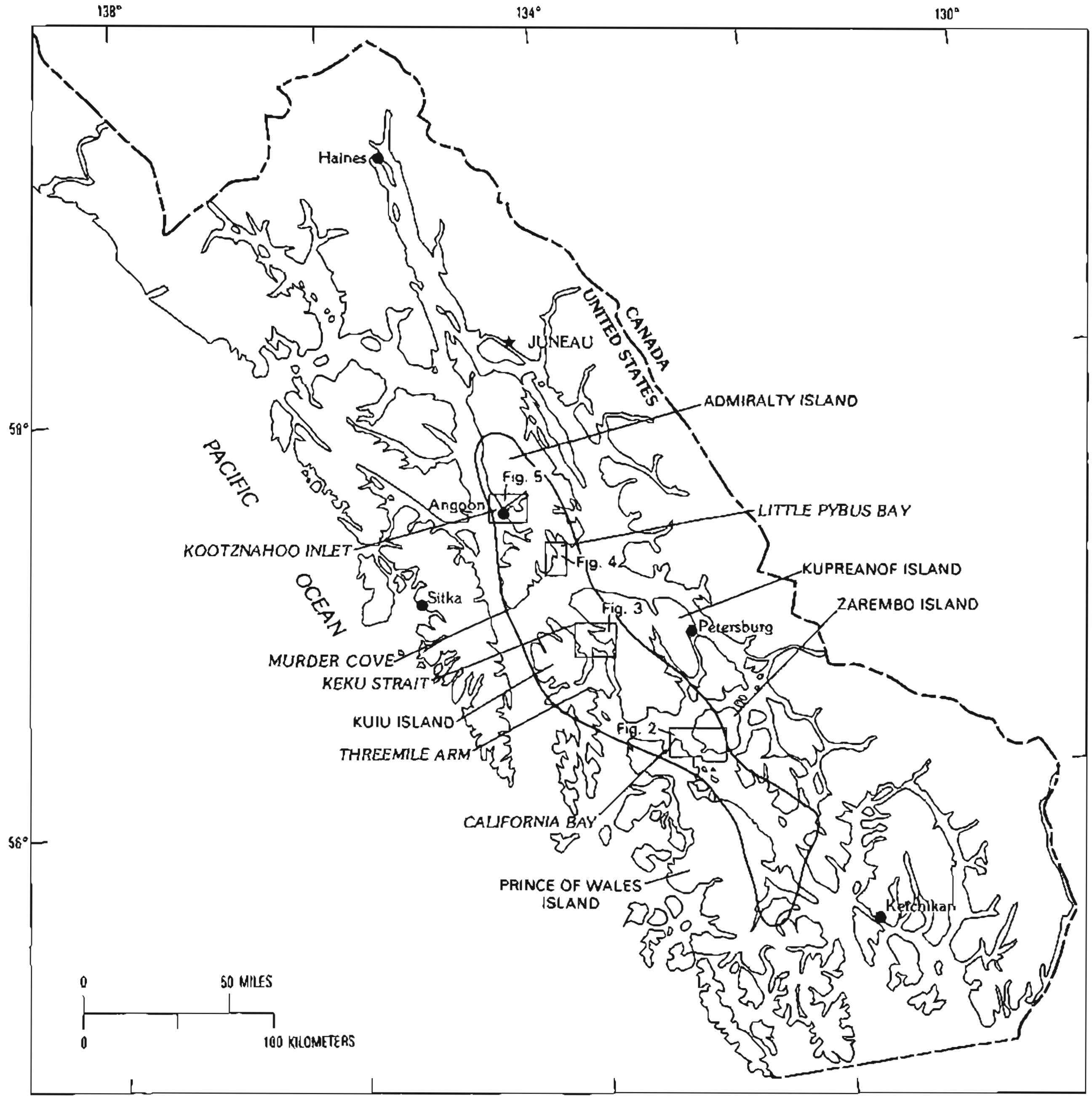


Figure 1. Map of southeastern Alaska showing study areas. Outlined area represents Admiralty Trough. Boxes are areas of figures 2 through 5.

Table 1. X-ray diffractogram peaks ($CuK\alpha$ radiation) measured for the Kootznahoo samples, data set I (Appendix 1-B)

Mineral	X-ray diffraction peak (degrees 2θ)	Crystallographic indices
Siderite..........................	32.1	104
Dolomite..........................	31.0	104
Calcite..........................	29.4	104
Plagioclase......................	27.9	002
Orthoclase		
and Microcline (K-feldspar)....	26.9-27.2	220, 202
Quartz..........................	26.7	101
Kaolinite........................	12.3	001
Chlorite..........................	12.5	002
Illite..........................	8.8	001

others, 1961) or by inductively coupled plasma spectroscopy (ICP) (Crock and others, 1983). Mineralogic determinations were by whole-rock X-ray diffraction (XRD).

Three sample sets were examined for this study. The first (data set I) contains both chemical and mineralogic data from 41 samples of the Kootznahoo Formation from areas shown in figure 1 (data listed in Appendix 1). Data set II (see Appendix 2) contains chemical data from 18 samples of dikes and sills that intruded the Kootznahoo Formation and of ash flows and volcanic conglomerates overlying the Kootznahoo. Data set III contains chemical data from 38 samples of the Kootznahoo Formation from the Petersburg Quadrangle that was published by Karl and others (1985). Data sets II and III were included mainly for comparison with data set I.

In the data sets numerical estimates were substituted for values that were reported below the lower limit of detection for the each analytical method. For values reported as "N" (not detected), one-half of the value for the lower detection limit was used, for "L's" and other less-than values, three-fourths of the value for the lower detection limit was used. Statistics are not presented for a given element if more than 20 percent of its values are qualified. The U.S. Geological Survey STATPAC programs (Grundy and Miesch, 1987) were used for the factor analysis.

In data set I, 34 samples from the Zarembo Island area, the Keku Strait area, and the Little Pybus Bay area were analyzed for 22 elements by SQS, and seven samples from the Kootznahoo Inlet area were analyzed for the same elements except zirconium by ICP. All samples in data set I were analyzed for uranium and thorium by neutron-activation. Rather than deleting zirconium because of the missing data, we estimated values of zirconium for the Kootznahoo Inlet samples from the thorium values in the other 34 samples by using regression analysis (Zielinski and others, 1987). The correlation coefficient (r) between thorium and the log of zirconium is +0.56. This procedure strongly biased the relation between thorium and zirconium but not the relations between zirconium and other variables.

No attempt was made to calculate actual quantities of minerals from the samples in data set I. Instead, XRD diffractogram peak heights measured in centimeters from $CuK\alpha$ radiation were used as an indication of relative mineral content. Peak heights were used rather than peak areas because the crystallinity of the clay minerals appears uniform based on peak height to width ratios and because the heights can be more uniformly measured than the areas for small or interfering peaks. For a few peaks that went off scale the heights were arbitrarily increased by 10 percent. The 2θ position of peak heights used to represent each mineral is given in table 1.

R-mode factor analysis (Harman, 1960) was performed on all three data sets in an attempt to reduce variance in these sets to the lowest number of factors that results in an adequate explanation. Appropriate factor models were used for each data set as discussed below. For the statistical calculations in data set I original units (raw data) were used a priori for uranium, thorium, and XRD mineral data. Log transformations were used for the other elemental abundances in data set I because the SQS data (34 of 41 samples) is reported in logarithmic determination intervals. In data sets II and III log transformations were used for all the data in the factor analysis calculations.

The results of these studies suggest many interesting relationships and the data can be interpreted to reflect regional geochemical and petrological trends, sedimentary processes, and mineralization. Some of the results, however, seem to defy interpretation, which probably reflects inadequacies in the methods, inaccuracies in the data, or various degrees of departure from normality of data distribution.

GEOLOGY

The Kootznahoo Formation consists mostly of nonmarine poorly sorted arkosic and lithic sandstone, conglomerate, and lesser amounts of shale. It was deposited primarily in fluvial environments in the Admiralty Trough, an elongate depression about 320 km long and 50 km wide (fig. 1; Miller and others (1959). Only scattered erosional remnants of the original formation remain, and it is not known whether Kootznahoo sediments were deposited in smaller basins in segments of the trough as suggested by Brew and others (1984) or whether deposition was in a single continuous basin as suggested by Buddington and Chapin (1929). Four main outcrop areas are known: (1) The Zarembo Island area which includes the California Bay area on northern Prince of Wales Island (figs. 1, 2); (2) The Keku Strait area, which includes the Port Camden area on Kuiu Island and the Hamilton Bay area on northwestern Kupreanof Island (figs. 1, 3); (3) The Little Pybus Bay area on the southern end of Admiralty Island (figs. 1, 4); and (4) The Kootznahoo Inlet area near Angoon on west-central Admiralty Island (figs. 1, 5). Smaller areas of Kootznahoo exposure (not sampled for this study) are found at Murder Cove on the southernmost tip of Admiralty Island, at Threemile Arm at the southern end of Port Camden, and at additional isolated localities listed by Buddington and Chapin (1929, p. 261).

In the Zarembo Island-California Bay area (fig. 2), the Kootznahoo consists of brown-weathering conglomerate, lithic and arkosic sandstone, and smaller amounts of mudstone and coal. The chief lithologies of the conglomerate pebbles are dark-gray phyllite and white chert. Kaolinite is a common constituent of the sandstone of California Bay, and chlorite is common on Zarembo Island. The base of the Kootznahoo is not exposed on Zarembo Island, but at California Bay the Kootznahoo unconformably overlies Paleozoic sedimentary rock, primarily the Silurian Heceta Limestone. On Zarembo Island the Kootznahoo is intruded by felsic and mafic dikes and sills, and it is overlain by volcanic flows and volcanic conglomerates that range from rhyolite to basalt in composition (Dickinson and Campbell, 1984). No datable fossils have been collected from the Zarembo Island area rocks.

In the Keku Strait area the Kootznahoo Formation consists mostly of poorly sorted light-brown or arkosic gray hard sandstone and small amounts of dark gray shale that generally dips about 10° southeastward (Buddington and Chapin, 1929; Muffler, 1967). The sandstone contains abundant carbonized wood fragments, spotty calcareous concretions and cement, and kaolinite. It ranges from silty fine-grained thin-bedded sandstone to medium- and coarse-grained, partly conglomeratic, medium- and thick-bedded sandstone. The shale is platy and contains abundant plant fossils and chlorite (Dickinson, 1979). In the Keku Strait area (fig. 3) the Kootznahoo overlies Triassic volcanic rock, is intruded by Tertiary gabbro, microgabbro, and basalt, and is overlain by Tertiary volcanic flows and volcaniclastic rock. The reported thickness of the Kootznahoo in this area is 1350 feet (Buddington and Chapin, 1929). The age of the Kootznahoo in Keku Strait area is Paleocene and correlates with the Little Pybus Bay section (Wolfe, in Lathram and others, 1965). Upper parts of the Kootznahoo may be somewhat younger in this area, however (Muffler, 1967).

In the western Pybus Bay and in the Little Pybus Bay areas (fig. 4) the Kootznahoo Formation consists of gently dipping conglomerate, arkosic and lithic sandstone, and minor amounts of shale. In this area the conglomerate to sandstone ratio is about three. The rounded cobbles of the conglomerate are composed mainly of argillite and plutonic rock. The matrix of the conglomerate is sandstone. The sandstone is characterized by an abundance of chlorite-bearing phyllite fragments, and it generally contains less than 15 percent quartz (Lathram and others, 1965). Carbonized wood fragments are common in the sandstone. The 2000-foot-thick Kootznahoo sequence unconformably overlies strongly deformed beds of the Upper Jurassic and Lower Cretaceous Seymour Canal Formation and the Devonian and Mississippian Cannery Formation. It is overlain by basaltic and andesitic flows of the Eocene and Oligocene Admiralty Island Volcanics and was intruded by felsic to mafic dikes and sills. Fossil leaves suggest a Paleocene age for the Kootznahoo in this area (Wolfe, in Lathram and others, 1965).

In the Kootznahoo Inlet area, the type locality of the Kootznahoo Formation, the formation is comprised of a conglomerate facies to the north and west and a finer grained facies to the east. The conglomerate contains pebbles and cobbles of chert, quartz, argillite, graywacke, slate, schist, and plutonic rocks. The matrix is partly calcareous arkosic to lithic sandstone. The conglomerate is massive to indistinctly bedded and contains a few thin interbeds of sandstone and shale. The sandstone in the finer grained facies is light brown to light gray, poorly sorted, conglomeratic, lithic to arkosic and crossbedded. The shale is gray and carbonaceous. Lenses of coal as

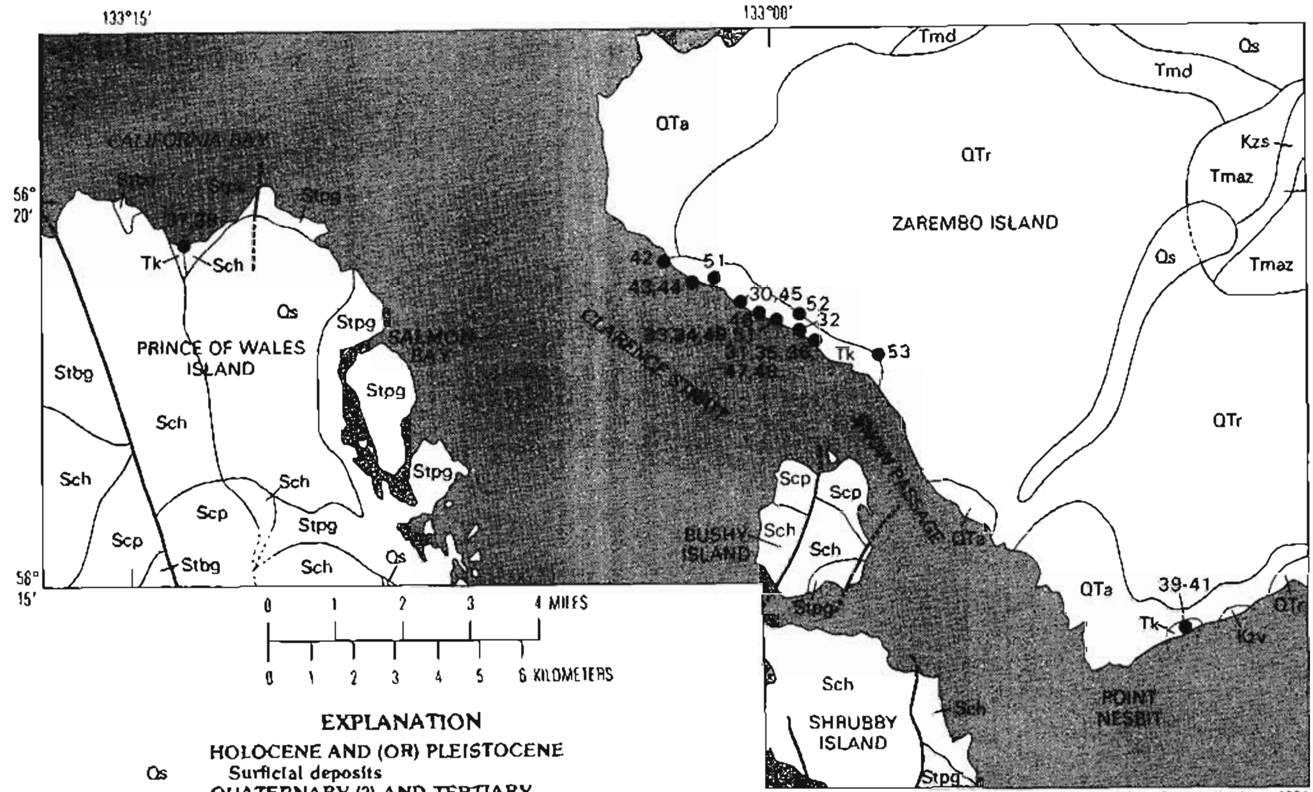


Figure 2. Geologic map of the Zarembo Island area, including northern Prince of Wales Island, showing sample localities.

thin as 1 inch and as thick as 4 feet are present in the finer grained facies. Siderite is abundant as concretions, thin layers, and cement in the finer grained facies. Chlorite is abundant as a detrital constituent in the sandstone and shale, and kaolinite is present in those samples that lack chlorite (Appendix 1–B) In the Kootznahoo Inlet area (fig. 5) the Kootznahoo overlies deformed plutonic and metamorphic Paleozoic and Mesozoic rocks. Beds of the Kootznahoo dip 30°–45° to the southeast. In this area the fossil flora indicate an Eocene to early Miocene age (Wolfe, in Lathram and others, 1965).

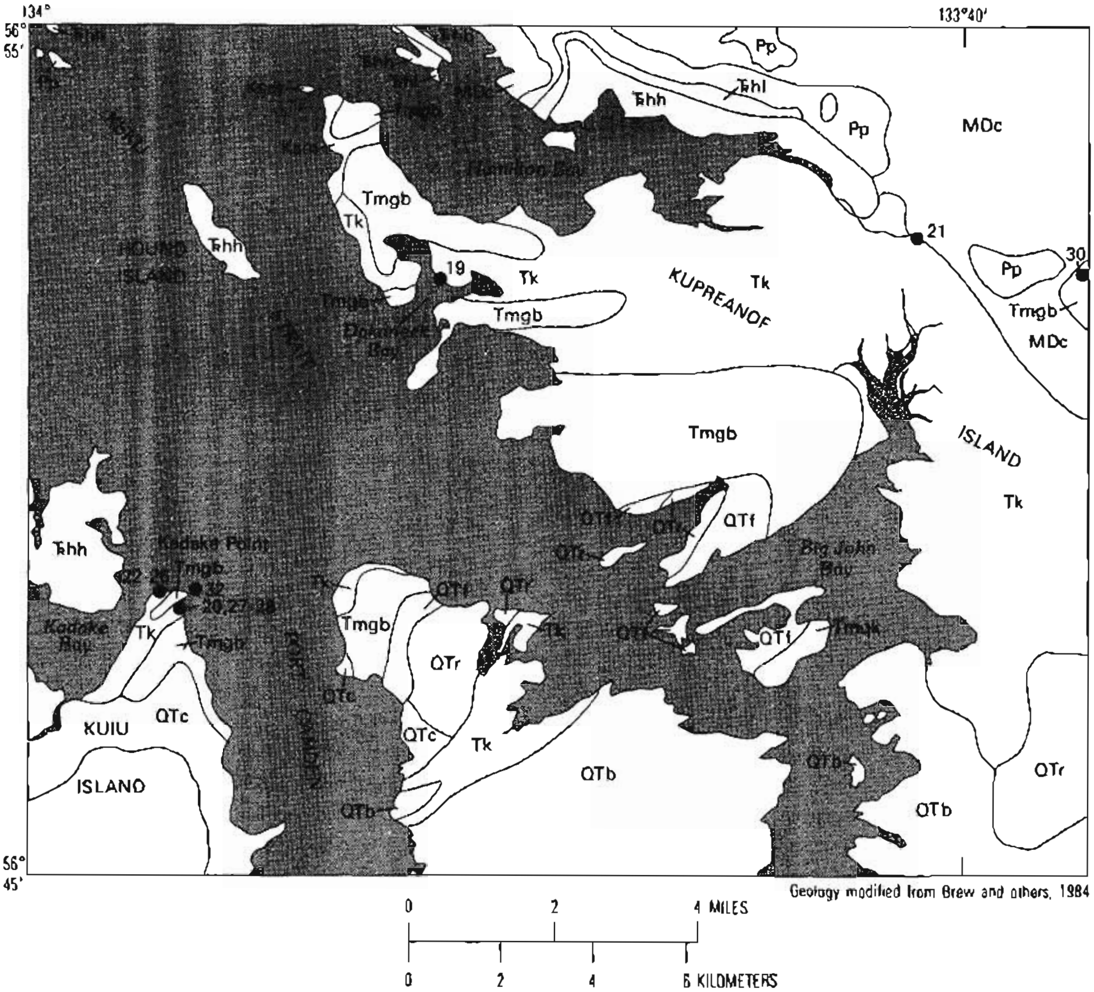
STATISTICAL ANALYSIS

The means and standard deviations for chemical contents for samples from all three data sets are given in table 2. *R*-mode factor analyses were also calculated for the three data sets.

Data Set I

The chemical contents with means and standard deviations for each of the four geographic areas for data set I are given in Appendix 1–A and mineral contents as represented by XRD peak heights are given in Appendix 1–B.

Rocks of the Kootznahoo Formation in the Little Pybus Bay area are relatively high in barium and low in siderite, dolomite, K-feldspar, and kaolinite. Kaolinite, dolomite, and siderite, which are believed to be



EXPLANATION

QUATERNARY AND TERTIARY
QT — QTr, Rhyolite, rhyodacite, and related siliceous intrusive rocks; QTf, altered dellenite extrusive rocks; QTb, basalt and other mafic intrusive rocks; QTc, volcaniclastic deposits including felsic to mafic tuff.

TERTIARY
Tmgb — Gabbro and microgabbro
Tmgk — Heterogeneous granitic rocks including granite quartz syenite, quartz monzonite and quartz monzodiorite
Tk — Kootznahoo Formation (Paleocene) continental arkosic sandstone and shale.

CRETACEOUS
Ksm — Lithic sandstone

TRIASSIC
Ћhh — Basaltic pillow breccia and pillow lava flows
Ћhl — Hamilton Island Limestone
Ћhb — Burnt Island Conglomerate

PERMIAN
Pp — Pybus Formation, limestone, dolomite, and chert

MISSISSIPPIAN AND DEVONIAN
MDc — Cannery Formation, thin-bedded gray volcanic argillite
●30 — Sample locality
——— Formation boundary

Figure 3. Geologic map of the Keku Strait area, Kuiu and Kupreanof Islands, showing sample localities.

associated with alteration, are low in the Little Pybus Bay area. Kootznahoo samples from the Kootznahoo Inlet area are also low in uranium, thorium, lead, and calcite. In the Keku Strait area the rocks appear to be high in uranium, thorium, lead, siderite, dolomite, and kaolinite and low in calcite, plagioclase, chlorite, and illite. In this area, however, the samples were biased toward high uranium by the sampling technique that was directed toward evaluation of uranium potential. Kootznahoo samples in the Zarembo Island area are low in siderite, dolomite, and illite and high in K-feldspar and calcite (Appendix 1–B).

Factor models for two through nine factors were computed for original units, logs of original units, and for the mixed units data set. The varimax six-factor model based on the mixed unit data set was chosen as the

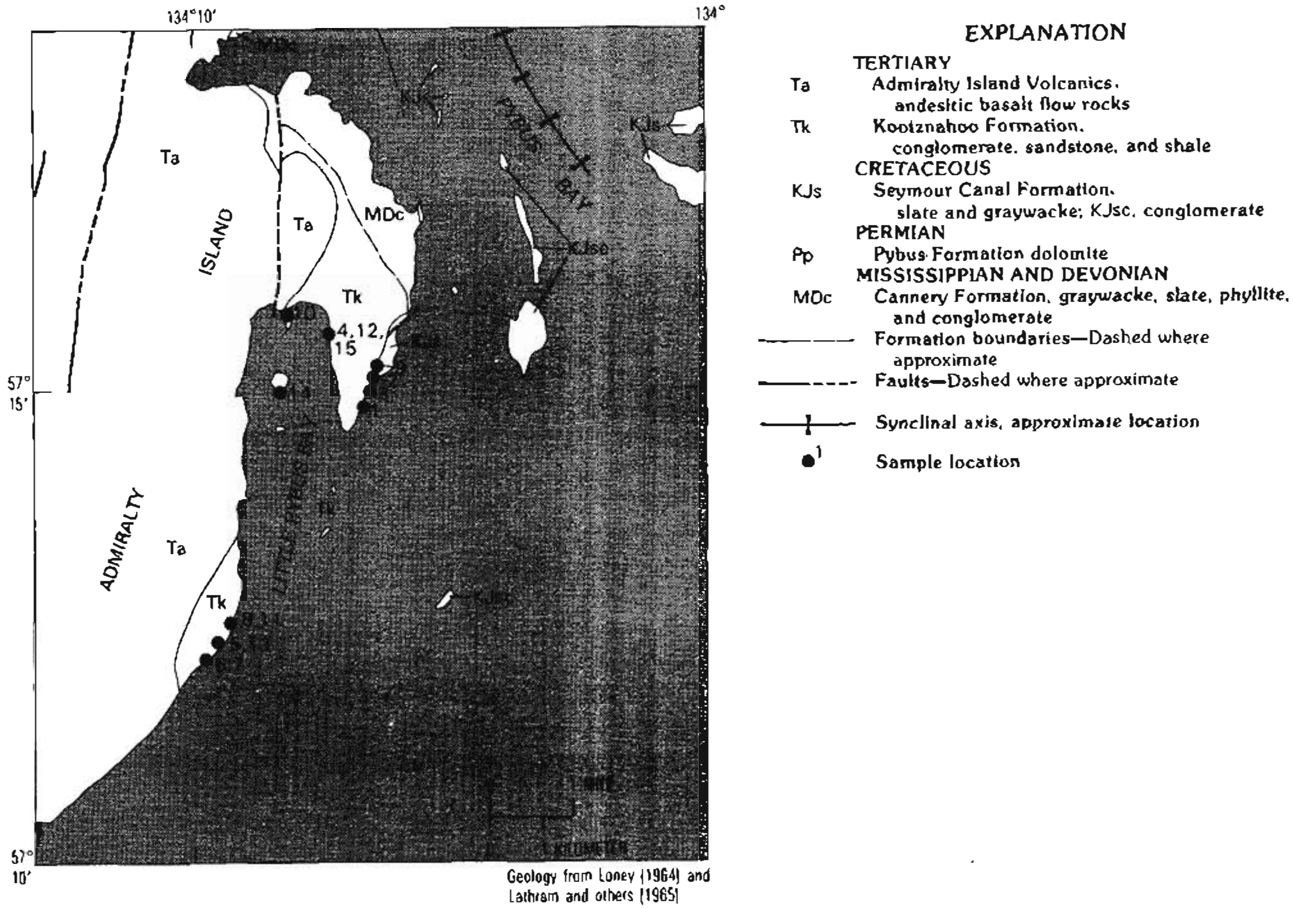


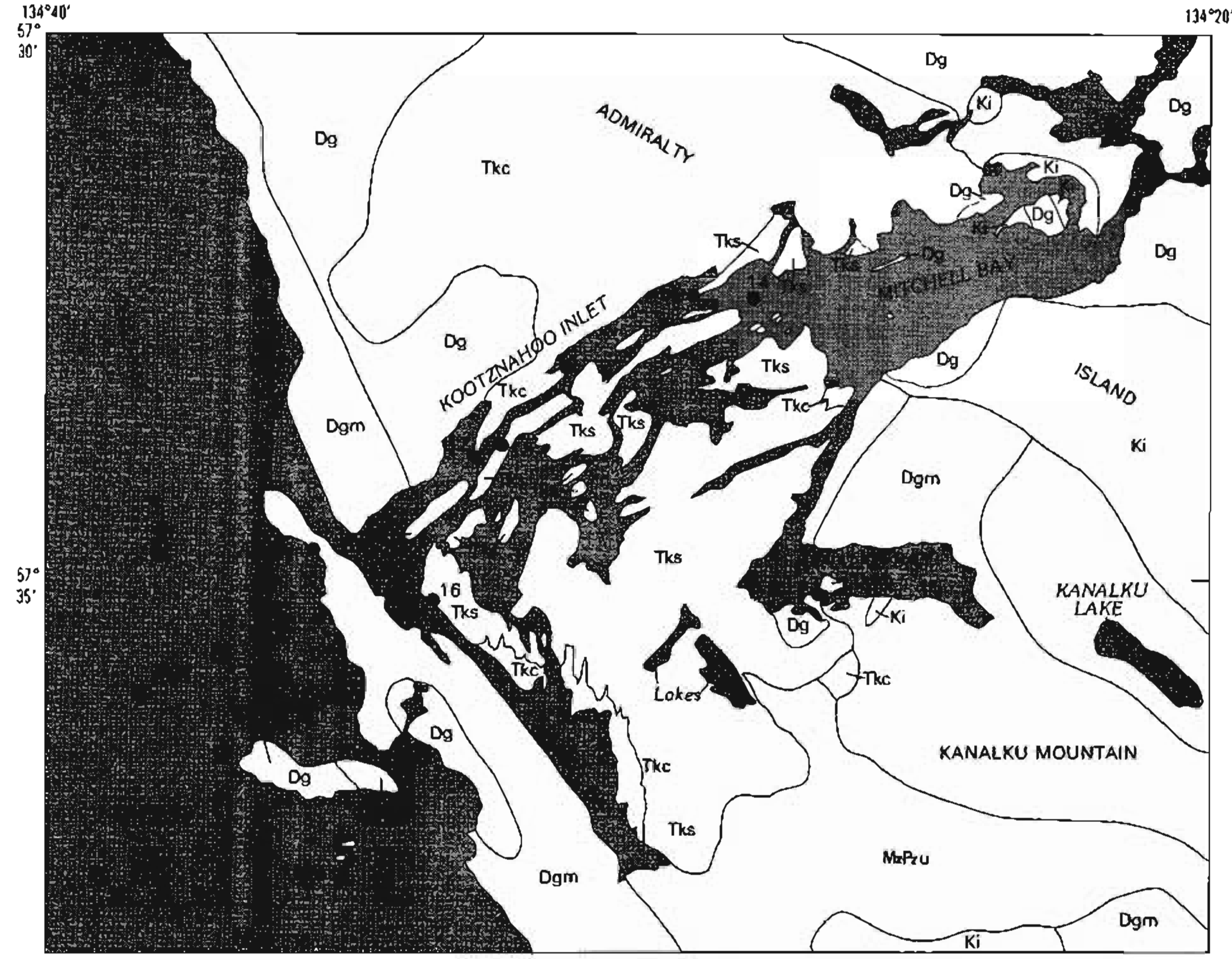
Figure 4. Geologic map of the Little Pybus Bay area, Admiralty Island, showing sample localities.

optimum explanation of the variance in data set I with emphasis on uranium and thorium (table 3). The six-factor model was chosen because the communality for uranium increases abruptly between factors five and six (fig. 6). A five-factor model adequately explains the variance in thorium but an extra factor is needed to account for additional variability in uranium that may result from alteration. The factors and the factor loadings are shown in table 3.

In general the number of factors required to explain the variance of a given element or mineral depends on the complexity of distribution for that element or mineral. In the Kootznahoo Formation the complexity of distribution of each element and mineral could depend on (1) composition of the source area, (2) sorting of elements and minerals during erosion, transportation, and deposition of the sedimentary rocks, and (3) post-depositional alteration (diagenesis and authigenesis). The variation of an element or a mineral that is uniformly distributed in the source areas and is uninfluenced by depositional processes and post-depositional alteration, is defined by fewer factors. Consequently its communality (C), the proportion of variability defined by various factor models, is higher for fewer factors. In the two-factor model for data set I, the communalities of Al ($C=0.82$), Cr ($C=0.70$), and Ti ($C=0.66$) are examples of these unaffected or slightly affected elements. On the other hand, the communalities for complexly distributed minerals, such as quartz, plagioclase, and dolomite, are below 0.5 even for the six-factor model. In general, a six-factor model describes the variance of the less complex chemical elements (average $C=0.75$) better than for the more complex minerals (average $C=0.5$).

Factor One

Factor one consists of both positive and negative groups that indicate where one group occurs the other will tend to be absent (table 3). The positive group in factor one consists of siderite, vanadium, and iron. The relation between siderite and iron is obvious because siderite ($FeCO_3$) contains iron. Vanadium and iron commonly occur together in iron deposits and are in the



EXPLANATION

TERTIARY
Tk Kootznahoo Formation
TKs, sandstone, siltstone, shale, and minor amounts of conglomerate and coal; TKc, conglomerate and minor amounts of sandstone and shale
CRETACEOUS
Ki Intermediate plutonic rocks

MESOZOIC AND PALEOZOIC
MzPzu Metamorphic rocks undifferentiated
DEVONIAN
Dg Gambier Bay Formation; schist; Dgm, thick marble lenses
——— Approximate formation boundaries
•16 Sample localities

Figure 5. Geologic map of the Kootznahoo Inlet area, Admiralty Island, showing sample localities.

same factor in all three data sets analyzed here. The other group consisting of Al, K, Ba, Na, and Sr are cations that have, except for aluminum, fairly large ionic radii, ranging from 0.97 Å for sodium to 1.34 Å for barium. They occur together probably representing a detrital mineral group composed mostly of feldspars.

Factor Two

In factor two uranium and lead are positively associated. Both elements are commonly solubilized in oxidizing ground water and transported to other areas where deposition (epigenetic mineralization) occurs. In addition they may be linked because lead is a radiogenic alteration product of uranium. Chromium, scandium, and titanium make up a negative association in this factor. Titanium and chromium are common in resistate minerals found in placer concentrations of heavy minerals. The inclusion of scandium in this group is, however, not totally understood because scandium is generally found in the silicate minerals. These latter elements have high communalities when analyzed for fewer factors and would, perhaps, be adequately explained by a lower numbered factor model.

Factor Three

The minerals—quartz, plagioclase, and calcite—are positively associated in factor three. Calcium, Na, and Sr are also associated, but to a lesser degree, in this

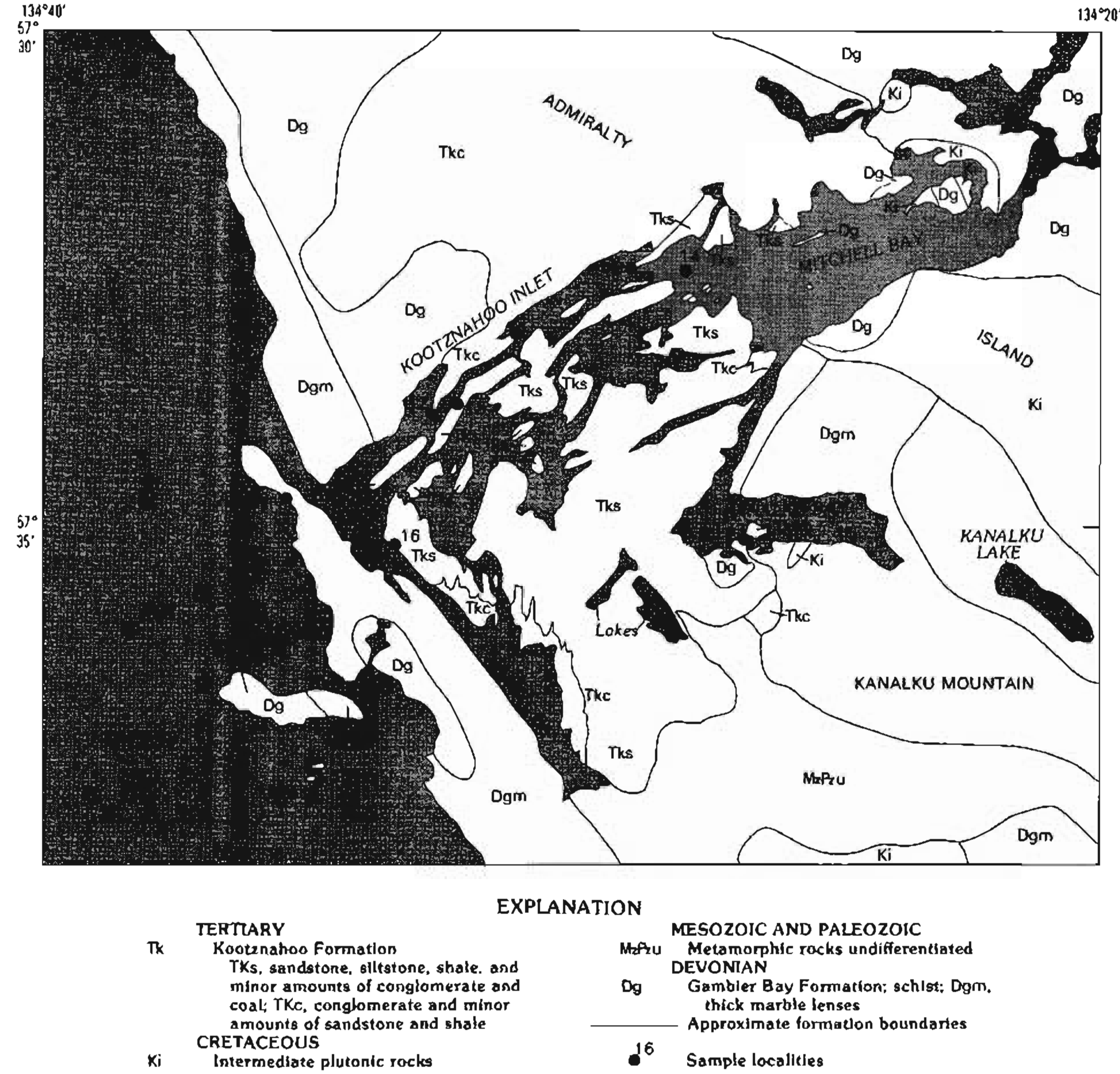


Figure 5. Geologic map of the Kootznahoo Inlet area, Admiralty Island, showing sample localities.

same factor in all three data sets analyzed here. The other group consisting of Al, K, Ba, Na, and Sr are cations that have, except for aluminum, fairly large ionic radii, ranging from 0.97 Å for sodium to 1.34 Å for barium. They occur together probably representing a detrital mineral group composed mostly of feldspars.

Factor Two

In factor two uranium and lead are positively associated. Both elements are commonly solubilized in oxidizing ground water and transported to other areas where deposition (epigenetic mineralization) occurs. In addition they may be linked because lead is a radiogenic alteration product of uranium. Chromium, scandium, and titanium make up a negative association in this factor. Titanium and chromium are common in resistate minerals found in placer concentrations of heavy minerals. The inclusion of scandium in this group is, however, not totally understood because scandium is generally found in the silicate minerals. These latter elements have high communalities when analyzed for fewer factors and would, perhaps, be adequately explained by a lower numbered factor model.

Factor Three

The minerals—quartz, plagioclase, and calcite—are positively associated in factor three. Calcium, Na, and Sr are also associated, but to a lesser degree, in this

Table 2. Means and standard deviations of elements in samples from all three data sets before log transformation

[*, indicates missing values or more than 20% qualified values. Means in parts per million unless otherwise noted]

	Data set I		Data set II		Data set III	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
U......	10.5	19.6	4.11	2.64	*	*
Th.....	13.6	225	6.69	6.42	*	*
Fe.....	5.11%	6.12	4.36%	2.43	3.83%	2.49
Mg.....	1.43%	0.84	1.59%	1.02	1.16%	0.85
Ca.....	2.58%	2.03	2.95%	1.93	2.70%	4.24
Ti.....	0.23%	0.13	0.50%	0.33	0.33%	0.20
Mn.....	976	892	897	434	1097	812
Ba.....	979	1080	581	629	1130	585
Co.....	15.5	15.7	15.5	10.0	13.9	9.46
Cr.....	44.4	35.5	33.0	48.4	56.0	41.9
Cu.....	32.0	35.3	19.8	16.2	22.9	27.1
La.....	23.0	15.8	*	*	*	*
Ni.....	23.0	26.7	*	*	22.9	13.4
Pb.....	17.6	30.6	*	*	31.6	27.6
Sc.....	11.7	6.91	20.6	16.7	15.9	6.95
Sr.....	406	326	342	230	443	234.9
V......	136	98.6	145	126	145	72.7
Y......	16.4	6.23	27.5	8.04	26.1	17.5
Zr.....	69.5	109	120	31.6	108	89.9
Al.....	6.18%	2.49	7.5%	1.12	*	*
Na.....	1.82%	0.92	2.47%	0.89	*	*
K......	1.70%	0.79	1.51%	0.79	*	*
Ga.....	15.6	5.60	15.6	2.29	*	*
Zn.....	*		*		68.0	34.6
Be.....	*		*		1.65	0.86

factor. Quartz and plagioclase are common detrital components in the clastic rocks and expected to occur together, but calcite is believed to be introduced during diagenesis. Calcium and strontium probably relate to the feldspars and calcium to the calcite. The negatively associated variables in this factor, Co, Ni, and Cu, are chalcophile elements that are expected to be associated. They are low or absent when quartz, plagioclase, and calcite are present.

Factor four

Manganese, magnesium, yttrium, and calcium and to a lesser extent strontium are associated in factor four. These elements are commonly found together in carbonates. The Mg, Ca, and, possibly, the Sr are in the dolomite, and the Mn probably substituted for Fe in the siderite. Mn, Mg, and Ca have a 2^+ oxidation state, and yttrium has a 3^+ oxidation state. Yttrium (atomic

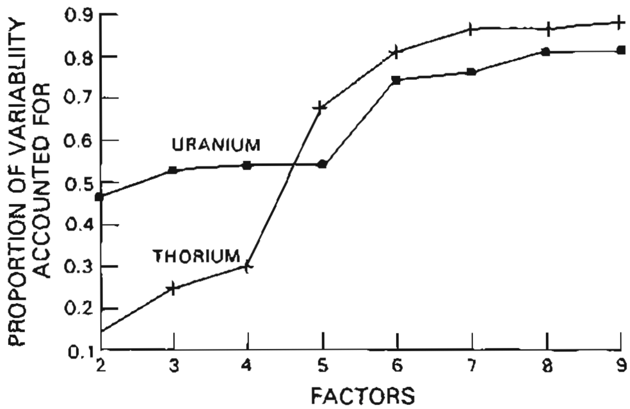


Figure 6. Scatterplot relating communalities of uranium (squares) and thorium (crosses) to number of factors analyzed in data set I.

during deposition. Sample 20 (Appendix 1) is from a placer in Kootznahoo sandstone and is high in these elements with the exception of gallium. Both thorium and gallium are partitioned between factors five and one. Thorium is associated with uranium in factor one but not in factor five. In factor one, gallium is associated with aluminum, a geochemically parallel element. The negative association between dolomite and calcium is consistent with the occurrence of dolomite as an authigenic product; it may have formed, at least in part, from alteration of the rocks containing the heavy-mineral assemblage. The loading for dolomite, however, is nearly as high in factor six (table 3), where it is associated with the other alteration minerals.

Factor six

The positively associated components of factor six are chlorite and illite, and the negatively associated components are kaolinite and K-feldspar. The minerals that formed the negatively associated group could have resulted from alteration of the minerals that formed the positive association. Or, the relation between these two groups could also be explained by differences in provenance areas, except that in the Kadake Point area the only clay mineral in the sandstone is kaolinite, and in the nearby Hamilton Bay and Dakaneek Bay areas the primary clay mineral in both shale and sandstone is chlorite (fig. 3). No other evidence was found, however, to indicate that the potassium feldspar is an alteration product. The alteration of chlorite probably also supplied the iron for authigenic siderite (factor one) and the magnesium for authigenic dolomite (dominant in factor five but also in factor six).

A four-factor model based only on chemical elements from data set I is given in table 4. A four-factor model was chosen to represent variance in these data because in a five-factor model one factor is reduced to only one element. In the four-factor model factor one, which includes V, Fe, Cu, Y, Mg, Sc, Ni, and Co generally represents the mafic minerals. Factor two contains Sr, K, Al, Na, and Ba and apparently represents the feldspars. The positively associated elements in factor three, which include Zr, Ga, Cr, La, Ti, and Th, appear to represent the heavy minerals; and the two negatively associated elements, manganese and calcium may represent calcite although manganese also has a minor association in factor one. Lead and uranium in factor four again apparently represent mineralization as discussed below.

Table 4. Varimax factor matrix for four-factor model for the chemical elements only in data set I

Element	Factor 1	Factor 2	Factor 3	Factor 4
V..........	-0.53	+0.49	+0.22	+0.01
Fe..........	-0.55	+0.41	-0.06	-0.30
Cu..........	-0.63	-0.00	+0.35	+0.54
Y..........	-0.63	-0.11	-0.13	+0.06
Mg..........	-0.66	-0.21	-0.27	-0.21
Sc..........	-0.69	-0.17	+0.25	-0.40
Ni..........	-0.72	+0.20	+0.27	+0.21
Co..........	-0.77	+0.29	+0.05	+0.26
Sr..........	+0.07	-0.68	-0.39	+0.01
K..........	+0.09	-0.69	+0.34	+0.41
Al..........	+0.04	-0.85	+0.27	-0.22
Na..........	+0.11	-0.86	-0.23	-0.10
Ba..........	-0.08	-0.87	+0.18	-0.07
Zr..........	-0.05	-0.05	+0.67	-0.42
Ga..........	-0.19	-0.42	+0.64	+0.02
Cr..........	-0.49	+0.04	+0.58	-0.47
La..........	-0.05	-0.13	+0.57	+0.02
Ti..........	-0.37	-0.52	+0.54	-0.36
Th..........	+0.07	+0.16	+0.43	+0.24
Mn..........	-0.46	+0.03	-0.60	-0.26
Ca..........	+0.01	-0.19	-0.91	-0.09
Pb..........	+0.03	-0.09	+0.02	+0.90
U..........	-0.11	+0.20	+0.04	+0.70

Data Set II

Mean contents of elements for the intrusive and extrusive igneous rock set (data set II) are given in table 2. The chemical composition of these younger igneous rocks is remarkably similar to the Kootznahoo Formation sedimentary rocks in data sets I and III. A three-factor model of the elements in data set II is given in table 5. A four-factor model included a factor with only one element, gallium. Factor one in data set II contains Th, Mn, Cr, Cu, Mg, Ca, Ti, Fe, V, and Sc. This group, except for thorium which is of opposite sign, generally represents the mafic and heavy minerals. Thorium also has a fairly high association in factor three, which, together with Y, K, Zr, and U, may represent the felsic minerals. Factor two contains Al, Na, Ba, Sr, and Ga and for the most part represents feldspars. Uranium, like thorium, also has a fairly high loading in factor one.

Table 5. Varimax factor matrix for three-factor model for data set II

Element	Factor 1	Factor 2	Factor 3
Th..........	+0.61	-0.29	+0.55
Mn..........	-0.69	+0.33	-0.43
Cr..........	-0.70	-0.35	-0.08
Cu..........	-0.81	-0.21	-0.21
Mg..........	-0.84	+0.16	-0.44
Ca..........	-0.86	+0.10	-0.20
Ti..........	-0.87	+0.22	-0.01
Fe..........	-0.91	+0.24	-0.07
V..........	-0.92	-0.04	-0.14
Sc..........	-0.98	+0.10	-0.03
Al..........	-0.16	+0.86	-0.09
Na..........	+0.16	+0.75	+0.10
Ba..........	+0.30	+0.72	+0.46
Sr..........	-0.25	+0.70	-0.42
Ga..........	-0.22	+0.60	-0.14
Y..........	-0.34	-0.12	+0.80
K..........	+0.55	-0.01	+0.73
Zr..........	+0.25	+0.11	+0.72
U..........	+0.50	-0.47	+0.56

Table 6. Varimax factor matrix for four-factor model for data set III

Element	Factor 1	Factor 2	Factor 3	Factor 4
Ti.......	+0.89	+0.01	-0.04	-0.23
Sc.......	+0.87	+0.16	+0.10	-0.04
Zr.......	+0.82	+0.04	+0.15	-0.36
V.......	+0.70	+0.07	+0.41	-0.19
Y.......	+0.69	+0.52	-0.05	-0.25
Cr.......	+0.69	-0.11	+0.11	+0.12
Fe.......	+0.66	+0.30	+0.36	-0.32
Mg.......	-0.07	+0.86	+0.16	-0.13
Ca.......	+0.09	+0.84	-0.12	+0.35
Mn.......	+0.28	+0.72	+0.08	-0.00
Be.......	-0.00	+0.25	+0.78	-0.29
Pb.......	+0.30	-0.03	+0.73	-0.20
Ni.......	+0.53	-0.08	+0.66	-0.08
Ba.......	-0.35	+0.41	+0.46	+0.46
Sr.......	-0.01	+0.19	-0.01	+0.72
Co.......	+0.44	+0.16	+0.32	-0.60
Cu.......	+0.34	-0.03	+0.45	-0.67
Zn.......	+0.20	+0.11	+0.19	-0.76

Data Set III

The average chemical contents for data set III (table 2) correspond approximately to those for data set I. A four-factor model chosen to represent variance in data set III (table 6) is also somewhat similar to a four-factor model for the element-only part of data set I (table 4). The two analyses are different partly because data set III lacks K, Al, Na, Ga, La, Th, and U that are in data set I and contains zinc and beryllium that are lacking in data set I. As would be expected, similarities between these sets are found in the factor loadings. In data set III factor one consists of Ti, Sc, Zr, V, Y, Cr, and Fe and seems to represent a combination of detrital oxides and heavy minerals. Factor two, which includes Mg, Ca, and Mn, probably represents carbonate minerals. Factor three contains Be, Pb, Ni, and Ba. Except for nickel this group could represent late stage magmatic minerals if lead substitutes for potassium in the feldspar. Barium could also be from the feldspars, but in addition it has a minor association with strontium in factor four. There seems to be no explanation for nickel in this group, although it has a subordinate association in factor one. Factor four contains the chalcophile elements—Co, Cu, and Zn—in a negative association.

URANIUM

Uranium and Thorium

The relation between uranium and thorium, which is generally simple in igneous rocks, is complex in sedimentary rocks, such as those of the Kootznahoo Formation. The complex relation between uranium and thorium in sedimentary rocks is indicated in the factor analysis of data set I. Uranium is partitioned between factor two where it is more dominant and associated with lead but not thorium and factor one where it is associated with thorium but not lead. Thorium, on the other hand, is most dominant in factor five where it is strongly associated zirconium and lanthanum but not with uranium.

The scatterplots of uranium versus thorium (fig. 7), offer considerable insight in this relation. They show that the samples can be placed into one of three populations, a population enriched in thorium ()13 ppm Th) and containing moderate amounts of uranium, a population enriched in uranium ()8 ppm U) but not thorium, and a population probably representing unaltered detrital minerals that are enriched in neither uranium nor thorium.

The samples enriched in thorium are believed to be those containing thorium minerals, such as monazite and thorianite. No thorium minerals were identified by XRD, however, even in the heavy-mineral-enriched sandstone sample 20 (appendix 1). That sample contains 144 ppm thorium and is also rich in lanthanum and zirconium, elements common in resistate, heavy-mineral concentrates. Th, La, and Zr together with gallium are associated in factor five for data set I (table 3). The Th/U ratio is about 5.7 in the thorium-enriched rocks, considerably higher than is generally found in igneous rock or that is average for the Earth's crust (Wedepohl, 1971, p. 65). Judging from the scatterplot, (fig. 7*A*) a slight amount of uranium enrichment is also found in the thorium-enriched rocks.

Samples in which uranium is enriched apparently are not enriched in thorium. These samples contain abundant carbonaceous material and represent epigenetic enrichment of uranium in a chemically reducing environment.

Among sedimentary rock samples that were not enriched in either uranium or thorium, the simpler relation probably reflects the population of elements in the igneous source rocks. A simpler relation between uranium and thorium is also shown in the igneous rocks (data set II). Even in these rocks, however, uranium and thorium are not strongest in the same factor in the three-factor model (table 5). They are, however, both strongly loaded in factors one and three. Uranium is more dominant in factor three where it is related to elements associated with felsic rocks, and thorium is more dominant in factor one where it occurs in opposition to the elements associated with mafic rocks. This simpler igneous rock relation between uranium and thorium is also indicated in a scatterplot (fig. 8).

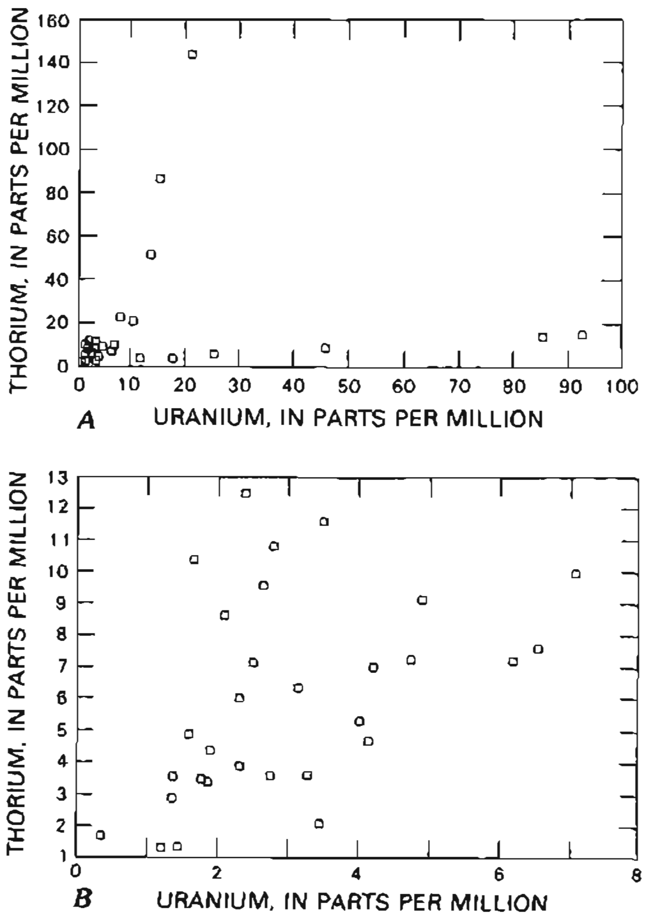


Figure 7. Scatterplots of uranium and thorium from samples of sedimentary rocks of the Kootznahoo Formation (data set I) . *A*, All samples; *B*, only samples with less than 8 ppm uranium and 13 ppm thorium.

Uranium and other elements

Uranium is related to lead in the sedimentary rocks (data set I) as shown in factor two (table 3). The uranium-lead association may result from the higher values of both lead and uranium in more felsic parts of the igneous source rock or from similar enrichment under reducing chemical conditions in the sedimentary environment of Kootznahoo deposition. This relationship could not be confirmed in data set II because that data set lacks uranium. In data set II, however, lead is related to beryllium ($r = +0.62$,). The amount of beryllium in data set I (Appendix 1) was too small for a reliable statistical comparison, and a relationship between uranium and beryllium must be left in doubt based on this data.

CONCLUSIONS

Several conclusions with varying degrees of certainty could be drawn from the statistical analyses presented here. Three of the more certain ones are presented below.

(1) Uranium and thorium are not well explained by the factor analysis or correlation coefficients. A scatter-

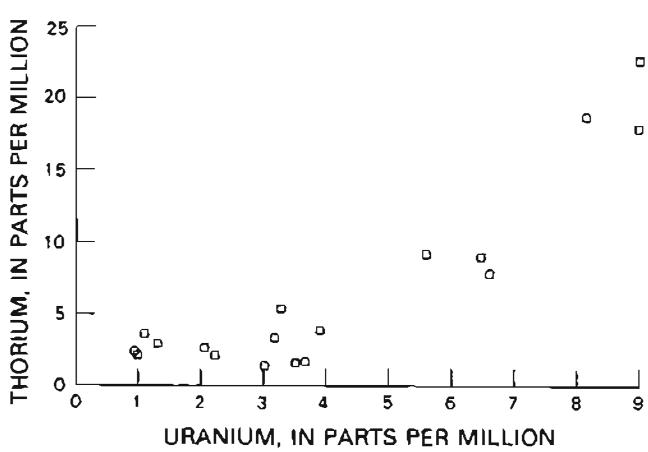


Figure 8. Scatterplot of uranium and thorium from samples of intrusive and extrusive igneous rocks that are younger than the Kootznahoo Formation (data set II).

plot indicates that uranium and thorium occur in three different populations. One population represents samples enriched in thorium that apparently represent placer concentration, one population that represents samples enriched in uranium probably by epigenetic processes, and one population in which neither the thorium nor the uranium is enriched, representing the relation in the detrital rock-forming minerals.

(2) Uranium is grouped with lead in the factor analysis in data set I. They may be linked because the are both concentrated by epigenetic enrichment or because lead is a radiogenic alteration product of uranium.

(3) Chlorite and illite form a positive association in a factor that includes kaolinite and K-feldspar as a negative association. It is concluded from this that the kaolinite and possibly the K-feldspar are alteration products of the decomposition of chlorite and illite, although no authigenic feldspar was seen in thin sections. The alteration of chlorite may provide magnesium for the authigenic dolomite and iron for the authigenic siderite, and the alteration of mica-illite minerals may provide potassium for the formation of K-feldspar.

REFERENCES CITED

Brew, D.A., Ovenshine, T.A., Karl, S.M., and Hunt, S.J., 1984, Preliminary reconnaissance geologic map of the Petersburg and parts of the Port Alexander and Sumdum 1:250,000 quadrangles: U.S. Geological Survey Open-File Report 84–405, 2 maps, 43 p. text.

Buddington, A.F., and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U.S. Geological Survey Bulletin 800, 398 p.

Crock, J.G., Lichte, F.E., and Briggs, P.H., 1983, Determinations of elements in National Bureau of Standards' geological reference materials SRM 278 obsidian and SRM 688 basalt by inductively coupled argon plasma-atomic emission spectrometry: Geostandards Newsletter, v. 7, no. 2, p. 335–340.

Dickinson, K.A., 1979, A uranium occurrence in the Tertiary Kootznahoo Formation on Kuiu Island, southeast Alaska: U.S. Geological Survey Open-File Report 79–1427, 5 p.

Dickinson, K.A., and Campbell J.A., 1978, Epigenetic mineralization and areas favorable for uranium exploration in Tertiary continental sedimentary rock in south-central Alaska—A preliminary report: U.S. Geological Survey Open-File Report 78-757, 13 p.

______ 1984, Uranium geology of the Tertiary Kootznahoo Formation of the Admiralty Trough, southeastern Alaska: Journal of the Alaskan Geological Society, v. 4, p. 1–11.

Grundy, W.D., and Miesch, A.T., 1987, Brief descriptions of STATPAC and related statistical programs for the IBM Personal Computer: U.S. Geological Survey Open-File Report 87–411A, 35 p.

Harman, H.H., 1960, Modern factor analysis: University of Chicago Press, Chicago, Illinois, 2nd Revised edition, 471 p.

Karl, S.M., Koch, R.D., Hoffman, J.D., Gay, G.W., Sutley, S.J., McDanal, S.K., 1985, Trace element data, for rock samples from Petersburg, and parts of the Port Alexander and Sumdum Quadrangles, southeastern Alaska: U.S. Geological Survey Open-File Report 85–146. 698 p.

Lathram, E.H., Pomeroy, J.S., Berg, H.C., and Loney, R.A., 1965, Reconnaissance geology of Admiralty Island, Alaska: U.S. Geological Survey, Bulletin 1181–R, 48 p.

Loney, R.A., 1964, Stratigraphy and petrography of the Pybus-Gambier area, Admiralty Island, Alaska: U.S. Geological Survey Bulletin 1178, 103 p.

Millard, D.J., Jr., 1976, Determinations of uranium and thorium in USGS Standard rocks by the delayed neutron technique: U.S. Geological Survey Professional Paper 840, p. 61–65.

Miller, D.J., Payne, T.G., and Gryc, G., 1959, Geology of possible petroleum provinces in Alaska with an annotated bibliography by E. H. Cobb: U.S. Geological Survey Bulletin 1094, 131 p.

Muffler, L.J.P., 1967, Stratigraphy of the Keku Islets and neighboring parts of Kupreanof Islands, southeastern Alaska: U.S. Geological Survey Bulletin 1241–C, 52 p.

Myers, A.T., Havens, R.G., and Dunton, P.J., 1961, A spectrochemical method for the analysis of rocks, minerals, and ores: U.S. Geological Survey Bulletin 1084-I, p. 1207–1229.

Wedepohl, K.H., 1971, Geochemistry: New York, Holt, Rinehart, and Winston, 231 p.

Zielinski, R.A., Otton, J. K., Wanty, R. B., and Pierson, C. T., 1987, The geochemistry of water near a surficial organic-rich uranium deposit, northeastern Washington State, U.S.A.: Chemical Geology, v. 62, n. 3/4, p. 263–289.

APPENDICES 1 AND 2

APPENDIX 1

Chemical and mineralogic data for the Kootznahoo Formation sedimentary rocks

1–A. Chemical data

[*, statistic not calculated; **, missing value; N, not detected; L, detected, but not determined. Elemental contents are given in parts per million unless otherwise noted. Uranium and thorium were determined by the neutron-activation technique, and other elements were determined by six-step semiquantitative or inductively coupled plasma spectroscopy]

Sample No.	Lithology	U	Th	Fe%	Mg%	Ca%	Ti%	Mn	Ba	Be	Co	Cr	Cu
						Little Pybus Bay area							
1..........	Cgl	2.1	8.6	1.5	1.0	5.0	0.15	1500	700	<1	7	30	10
2..........	Ss	3.1	6.3	3.0	1.5	2.0	.20	700	1000	<1	10	30	20
3..........	Ss	1.8	3.5	3.0	2.0	1.5	.50	700	7000	<1	15	15	30
4..........	Ss	1.6	4.9	1.5	1.5	3.0	.15	1500	3000	1.5	3	15	7
5..........	Ss	2.6	9.6	3.0	1.0	1.5	.20	1000	500	<1	5	30	7
6..........	Ss	1.9	4.4	3.0	1.0	1.5	.15	700	300	<1	7	20	15
7..........	Ss	2.3	6.0	3.0	1.0	5.0	.15	1500	700	<1	7	30	10
8..........	Ss	14	51	3.0	1.5	.3	.70	1500	700	1.5	15	70	70
9..........	Sh	2.3	3.9	3.0	3.0	1.5	.30	300	1000	1.5	15	30	50
10.........	Sh	4.0	5.3	3.0	2.0	.15	.30	300	1500	1.5	20	150	70
11.........	Sh	4.2	7.0	5.0	3.0	.07	.50	300	1500	1.5	7	150	70
Mean...............		3.59	10.1	2.91	1.68	1.96	.300	909	1630	*	10	51.8	33
Std. deviation....		3.43	13.8	.92	.75	1.73	.187	515	1930	*	5.3	50.1	27
						Kootznahoo Inlet area							
12.........	Ss	3.5	<2.8	3.5	2.10	4.0	0.18	820	490	<1	6	64	16
13.........	Ss	1.2	<1.8	3.6	1.40	5.5	.20	960	460	<1	10	64	14
14.........	Ss	1.4	2.9	2.5	2.10	7.8	.20	1400	900	<1	11	61	14
15.........	Ss	1.4	<1.8	20	1.40	4.1	.23	2100	330	<1	55	90	25
16.........	Ss	1.9	3.4	4.4	1.80	1.4	.30	550	680	<1	15	110	22
17.........	Mdst	.35	1.7	32	1.50	4.6	.09	5000	220	<1	35	30	9
18.........	Sh	1.4	3.6	22	3.20	1.8	.24	3500	740	2.0	29	94	33
Mean...............		1.58	*	12.6	1.93	4.17	.206	2050	546	*	23	73.3	19
Std. deviation....		1.46	*	11.0	.94	2.49	.130	1570	642	*	17	41.6	19
						Keku Strait area							
19.........	Sh	4.9	9.1	7.0	3.00	3.0	0.30	500	1000	N	20	70	7
20.........	Ss	21	144	10	.70	.7	.30	1500	300	N	20	70	15
21.........	Ss	4.1	4.7	1.5	.15	.07	.10	70	200	N	70	70	150
22.........	Ss	1.6	10	3.0	.20	1.5	.20	200	1000	N	7	30	10
23.........	Ss	12	<5.2	3.0	.70	3.0	.20	700	1000	N	15	30	20
24.........	Ss	2.8	11	5.0	.70	1.5	.50	700	1500	L	20	50	70
25.........	Ss	93	<20	7.0	3.00	7.0	.30	1500	300	N	15	15	30
26.........	Ss	85	<19	3.0	1.50	3.0	.02	1000	30	N	10	5	15
27.........	Ss	46	<12	5.0	1.50	5.0	.10	1500	1500	N	70	7	150
28.........	Ss	25	<8.3	3.0	1.50	5.0	.10	700	1000	N	20	7	100
29.........	Ss	2.4	13	2.0	.50	3.0	.20	700	1000	N	5	20	15
Mean...............		27.0	*	4.96	1.22	2.98	.210	825	803	*	25	34	53
Std. deviation...		33.4	*	3.81	1.00	2.06	.135	503	513	*	23	27	56
						Zarembo Island area							
30.........	Ss	2.5	7.1	1.5	0.70	1.5	0.15	300	1000	N	L	15	3
31.........	Ss	3.5	12	3.0	.70	2.0	.15	700	1000	N	7	15	7
32.........	Ss	18	<5.1	1.5	.70	7.0	.15	1000	700	N	7	20	15
33.........	Cgl	15	86	5.0	.70	.70	.15	700	700	N	7	30	15
34.........	Sh	7.0	10	3.0	3.00	.70	.30	700	1500	1.0	15	70	70
35.........	Sh	4.7	7.3	3.0	2.00	1.5	.30	700	1000	N	15	30	30
36.........	Ss	2.8	3.6	1.5	.70	3.0	.15	500	1000	N	L	7	5
37.........	Ss	6.2	7.2	7.0	.07	.15	.15	30	500	N	7	30	15
38.........	Ss	3.3	3.6	1.5	.70	3.0	.15	300	700	N	N	15	7
39.........	Sh	6.5	7.6	3.0	1.50	.15	.30	300	700	N	15	70	50
40.........	Cgl	11	21	3.0	1.50	1.0	.15	700	300	N	7	30	15
41.........	Cgl	8.9	23	2.0	1.00	1.5	.30	700	500	N	5	30	7
Mean...............		7.34	16.0	2.92	1.11	1.85	.200	553	800	*	*	30	20
Std. deviation....		4.87	23.9	1.66	.81	1.96	.075	269	327	*	*	21	21

1-A. Chemical data—Continued

Sample No.	Lithology	La	Ni	Pb	Sc	Sr	V	Y	Zr	Al%	Na%	K%	Ga
						Little Pybus Bay area							
1..........	Cgl	30	15	<10	7	500	50	15	30	3.0	3.0	1.5	15
2..........	Ss	30	20	10	7	300	70	15	70	5.0	3.0	1.5	15
3..........	Ss	<30	7	10	15	1500	150	15	150	10	3.0	.70	15
4..........	Ss	30	5	15	7	700	50	10	30	7.0	3.0	1.5	15
5..........	Ss	30	7	30	10	300	70	15	30	7.0	1.5	1.5	15
6..........	Ss	<30	10	15	7	300	70	<10	30	5.0	1.5	1.5	15
7..........	Ss	30	7	10	7	1000	70	15	30	7.0	3.0	2.0	15
8..........	Ss	100	15	10	20	150	150	30	100	7.0	1.0	1.5	15
9..........	Sh	<30	30	<10	10	300	150	15	70	10	3.0	1.5	20
10.........	Sh	<30	70	15	15	150	90	15	70	10	1.5	3.0	30
11.........	Sh	50	20	<10	30	150	300	10	100	10	1.0	3.0	30
Mean................		*	19	*	12	486	111	14.8	64.5	7.36	2.23	1.75	18.2
Std. deviation......		*	19	*	7.3	426	74.1	6.75	39.8	2.42	.91	.69	6.03
						Kootznahoo Inlet area							
12.........	Ss	11	13	9	12	190	120	15	**	5.9	1.4	0.95	11
13.........	Ss	10	23	8	10	270	110	14	**	6.0	1.9	.97	12
14.........	Ss	12	20	4	10	370	94	11	**	6.0	1.8	1.2	11
15.........	Ss	11	64	<4	24	210	190	24	**	3.9	1.1	.64	10
16.........	Ss	17	33	4	15	320	130	12	**	7.4	2.5	.75	15
17.........	Mdst	9	9	<4	6	83	95	11	**	1.7	.47	.27	10
18.........	Sh	16	77	<4	37	230	240	28	**	4.3	.57	.73	12
Mean................		12	34	*	16	239	140	16.4	*	5.03	1.39	.787	11.6
Std. deviation......		14	.24	*	11	150	84.9	7.89	*	2.98	.804	.830	7.71
						Keku Strait area							
19.........	Sh	N	30	N	20	700	150	30	70	7.0	3.0	1.5	30
20.........	Ss	50	15	15	7	150	500	15	700	.70	.30	N	30
21.........	Ss	N	150	30	7	30	150	10	30	1.5	.07	1.5	15
22.........	Ss	N	7	15	10	1500	150	20	50	10	1.0	3.0	20
23.........	Ss	N	10	15	10	700	200	15	50	7.0	3.0	2.0	20
24.........	Ss	N	20	15	15	700	150	15	100	10	2.0	3.0	20
25.........	Ss	N	10	10	7	500	150	20	20	2.0	1.0	1.5	10
26.........	Ss	N	10	20	7	200	500	20	15	.10	.15	N	5
27.........	Ss	N	50	150	7	500	100	20	10	5.0	2.0	2.0	15
28.........	Ss	N	30	150	5	300	70	15	15	5.0	3.0	3.0	15
29.........	Ss	N	5	10	10	500	70	10	50	7.0	2.0	1.5	15
Mean................		*	31	*	9.5	525	199	17.3	94.5	5.03	1.59	1.79	18
Std. deviation.......		*	42	*	4.4	398	154	5.64	203	3.55	1.15	.95	7.5
						Zarembo Island area							
30.........	Ss	N	3	N	7	300	70	10	70	7.0	3.0	1.5	10
31.........	Ss	30	3	10	7	700	150	20	70	7.0	3.0	1.5	15
32.........	Ss	N	7	10	7	700	70	30	70	7.0	3.0	3.0	15
33.........	Cgl	30	7	N	7	300	150	15	100	5.0	1.5	1.5	15
34.........	Sh	30	30	20	15	300	150	20	150	7.0	3.0	3.0	15
35.........	Sh	30	20	10	15	300	70	20	100	7.0	1.5	3.0	15
36.........	Ss	N	3	10	7	300	70	10	30	7.0	2.0	2.0	10
37.........	Ss	N	15	20	N	150	70	N	70	7.0	1.5	1.5	15
38.........	Ss	N	3	N	7	300	30	15	70	7.0	1.5	1.5	15
39.........	Sh	30	30	10	20	150	150	30	150	7.0	.70	3.0	15
40.........	Cgl	30	15	N	15	150	150	15	70	7.0	1.5	1.5	15
41.........	Cgl	30	10	N	15	200	70	15	150	7.0	.70	1.5	10
Mean................		*	12	*	10	321	100	17.1	91.7	6.83	1.91	2.04	13.8
Std. deviation......		*	10	*	5.4	197	46.5	7.51	40.4	.601	.85	.73	2.1

1–B. Mineralogic data

[X-ray diffractogram peak heights measured in centimeters for powdered whole-rock (bulk) samples in cell mounts. CuKα radiation was used. An arbitrary 10% was added to peaks (underlined) that were off the chart]

Sample No.	Lithology	Siderite	Dolomite	Calcite	Plagioclase	K-spar	Quartz	Kaolinite	Chlorite	Illite
					Little Pybus Bay area					
1..........	Cgl	0.0	0.0	22	12	0.0	3.6	0.0	2.9	0.9
2..........	Ss	.0	.0	9.3	21	.0	7.7	.0	5.9	2.0
3..........	Ss	.0	.0	.0	24	.0	4.0	.0	3.5	.0
4..........	Ss	.0	18	.0	23	.0	6.6	.0	.0	1.4
5..........	Ss	.0	.0	7.1	24	.0	11	.0	7.2	2.0
6..........	Ss	.0	.0	8.9	13	.0	8.3	.0	14	2.3
7..........	Ss	.0	.0	24	12	.0	9.0	.0	7.5	1.5
8..........	Ss	.0	.0	.0	6.5	.0	2.4	.0	4.4	1.2
9..........	Sh	.0	.0	3.4	15	9.4	4.3	.0	2.1	.7
10..........	Sh	.0	.0	.0	7.3	.0	2.9	.0	11.2	5.1
11..........	Sh	.0	.0	.0	6.2	.0	2.0	.0	14	6.9
Mean...............		.00	1.7	6.8	14.9	.86	5.64	.00	6.3	2.2
Std. deviation.....		.00	5.5	8.8	7.04	2.8	3.07	.00	5.0	2.0
					Kootznahoo Inlet area					
12..........	Ss	5.0	22	0.0	19	4.0	12	2.9	0.0	1.3
13..........	Ss	2.8	24	.0	24	.0	8.8	3.0	.0	1.5
14..........	Ss	.0	13	.0	22	.0	7.8	.0	2.3	.3
15..........	Ss	.0	.0	.0	14	.0	8.0	.0	4.0	1.9
16..........	Ss	.0	.0	3.2	24	.0	8.0	.0	6.0	1.7
17..........	Mdst	5.5	9.2	.0	6.9	.0	4.5	.0	1.8	1.7
18..........	Sh	9.5	.0	.0	5.0	.0	4.1	2.4	.0	1.5
Mean.............		3.3	7.9	.46	16.4	.57	7.60	1.2	2.0	1.5
Std. deviation....		3.4	9.4	3.3	8.68	1.4	3.59	1.3	4.4	1.8
					Keku Strait area					
19..........	Sh	0.0	0.0	0.0	11	0.0	1.9	0.0	3.0	0.0
20..........	Ss	15	.0	.0	5.2	.0	9.3	2.5	.0	.0
21..........	Ss	.0	.0	.0	24	.0	.0	.0	3.0	.0
22..........	Ss	.0	4.5	2.0	.0	9.3	12	12	.0	.0
23..........	Ss	.0	7.9	1.5	11	22	3.6	4.9	.0	.0
24..........	Ss	.0	2.6	.0	5.7	6.0	6.2	4.7	.0	1.5
25..........	Ss	.0	13.7	.0	4.0	6.1	4.9	3.3	.0	.0
26..........	Ss	5.9	16	.0	1.0	.0	1.2	.0	.0	.0
27..........	Ss	.0	5.3	.0	.0	6.0	1.8	1.7	.0	.0
28..........	Ss	.0	21	.0	13	23	4.6	3.0	.0	.0
29..........	Ss	.0	3.5	.0	24	6.2	5.0	5.0	.0	.0
Mean..............		1.9	6.8	.32	8.9	7.1	4.6	3.4	.55	.14
Std. deviation....		4.7	7.2	.72	8.6	8.2	3.6	3.5	1.2	.45
					Zarembo Island Area					
30..........	Ss	0.0	0.0	4.0	24	0.0	12	1.6	0.0	0.8
31..........	Ss	.0	.0	4.0	23	19	10	.0	1.5	.6
32..........	Ss	.0	.0	22	16	11	.0	.0	1.8	.6
33..........	Cgl	.0	.0	.0	23	5.3	9.4	.0	3.9	1.0
34..........	Sh	.0	.0	.0	14	4.6	4.9	.0	2.4	.6
35..........	Sh	.0	.0	.0	12	7.7	5.2	.0	4.5	.7
36..........	Ss	.0	.0	9.1	22	14	7.5	1.9	.0	.8
37..........	Ss	.0	.0	.0	9.2	5.5	6.7	3.3	.0	.0
38..........	Ss	.0	8.2	9.4	16	17	5.3	4.5	.0	.7
39..........	Sh	.0	.0	.0	7.0	.0	10	.0	3.8	3.5
40..........	Cgl	.0	.0	5.5	10	.0	8.2	.0	4.6	1.3
41..........	Cgl	.0	.0	5.8	18	.0	12	.0	4.2	1.5
Mean...............		.00	.68	5.0	16.2	6.95	8.1	.94	2.2	1.0
Std. deviation.....		.00	2.46	6.7	5.62	6.75	2.4	1.6	1.9	.91

APPENDIX 2

Data set for ash-flows and volcanic conglomerates deposited above the Kootznahoo Formation and igneous rocks that intruded it or were extruded above it.

Samples are from the study areas indicated in figures 1-5. Elemental contents are given in parts per million unless otherwise noted. %, indicates elemental contents given in weight percent. *, statistic not calculated. N, not detected. L, detected but not determined.

Lithology abbreviations:

- Ignfg. = Fine-grained igneous
- Volflo. = Volcanic flow rock
- Ashflo. = Ash flow
- Volcgl. = Volcanic conglomerate
- Rhy. = Rhyolite
- Bas. = Basalt
- Felsdik. = Felsic dike
- Basdik. = Basic dike
- And. = Andesite

Area–Sample No.	Lithology	U	Th	Fe%	Mg%	Ca%	Ti%	Mn	Ba	Be	Co	Cr	Cu
PB12......	Ignfg.	2.1	2.7	5.0	1.5	2.0	0.50	1500	3000	1.5	7	<1	2
PB13......	Ignfg.	1.3	3.0	3.0	2.0	3.0	.50	1500	700	<1	15	10	20
PB14......	Ignfg.	0.99	2.2	7.0	2.0	3.0	1.0	1000	200	<1	30	7.0	30
PB15......	Ignfg.	1.1	3.7	3.0	1.5	2.0	.30	700	300	<1	15	7.0	15
KU30......	Ignfg.	3.2	3.5	7.0	3.0	7.0	.50	700	200	N	30	7.0	15
KU32......	Ignfg.	.94	2.4	10	3.0	7.0	.70	1000	500	N	30	200	70
ZE42......	Volflo.	3.5	<2.3	7.0	1.5	3.0	.70	700	300	1.0	20	30	30
ZE43......	Ashflo.	6.6	8.0	3.0	.70	3.0	.30	700	700	1.0	15	30	15
ZE44......	Volcgl.	6.5	9.1	3.0	1.5	1.5	.30	1000	300	1.0	7	70	30
ZE45......	Rhy.	3.7	<2.4	3.0	.70	3.0	.30	700	500	N	7	1.5	7
ZE46......	Ashflo.	8.2	19	1.5	.30	1.0	.15	300	700	1.0	5	7.0	7
ZE47......	Rhy.	9.0	23	1.5	.15	.15	.15	150	700	1.0	N	3.0	2
ZE48......	Bas.	2.2	2.2	7.0	3.0	5.0	.70	1500	300	N	30	70	30
ZE49......	Felsdik.	3.0	<2	3.0	3.0	3.0	.30	1500	150	N	15	70	30
ZE50......	Basdik.	3.9	4.0	7.0	3.0	5.0	1.5	1500	300	N	30	70	15
ZE51......	And.	5.6	9.3	3.0	.70	3.0	.70	700	1000	N	10	7.0	30
ZE52......	And.	3.3	5.6	3.0	.70	.70	.30	700	300	N	7	1.0	5
ZE53......	And.	9.0	18	1.5	.30	.70	.15	300	300	1.0	L	3.0	3
Mean..............		4.11	6.70	4.36	1.59	2.95	0.503	897	581	*	16	33.0	20
Std. deviation....		2.72	6.60	2.50	1.05	1.98	0.344	447	647	*	10	50.0	17

Area–Sample No.	Lithology*	La	Ni	Pb	Sc	Sr	V	Y	Zr	Al%	Na%	K%	Ga
PB12......	Ignfg.	30	7	<10	15	1000	30	30	150	10	5.0	1.5	20
PB13......	Ignfg.	<30	<3	<10	15	500	150	15	100	10	3.0	1.0	15
PB14......	Ignfg	<30	7	<10	30	300	300	30	70	7.0	1.5	.70	20
PB15......	Ignfg	<30	<3	<10	10	200	70	20	70	7.0	3.0	1.5	15
KU30......	Ignfg.	N	7	N	30	150	300	30	100	7.0	3.0	.70	15
KU32......	Ignfg.	N	20	N	70	700	500	30	100	10	3.0	.70	20
ZE42......	Volflo.	N	7	N	30	150	150	50	150	7.0	3.0	1.5	15
ZE43......	Ashflo.	N	15	10	15	300	70	30	150	7.0	1.5	1.5	10
ZE44......	Volcgl.	N	15	10	15	200	100	30	150	7.0	2.0	1.5	15
ZE45......	Rhy.	N	N	N	7.0	300	70	15	150	7.0	2.0	1.5	15
ZE46......	Ashflo.	30	5	10	7.0	150	30	30	150	7.0	2.0	3.0	15
ZE47......	Rhy.	30	2	10	N	150	15	30	100	7.0	3.0	3.0	15
ZE48......	Bas.	N	30	N	30	300	200	30	100	7.0	1.5	.70	15
ZE49......	Felsdik.	N	30	N	15	700	70	15	70	7.0	2.0	N	15
ZE50......	Basdik.	30	15	N	50	300	300	30	100	7.0	1.5	1.5	15
ZE51......	And.	30	7	N	15	300	150	30	150	7.0	3.0	3.0	15
ZE52......	And.	N	N	N	7.0	300	70	20	150	7.0	3.0	1.5	15
ZE53......	And.	30.00	3	10	7.0	150	30	30	150	7.0	1.50	2.0	15
Mean................		*	*	*	20.6	342	145	27.5	120	7.50	2.47	1.51	15.6
Std. deviation......		*	*	*	17.1	236	130	8.27	32.5	1.15	.915	.809	2.36

★ U.S. GPO: 1989 673-047/86,057