INORGANIC CHEMICAL ANALYSES OF BLACK SHALE FROM WELLS IN THE NATIONAL PETROLEUM RESERVE IN ALASKA

by

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ABSTRACT

Inorganic chemical analyses of Mississippian to Cretaceous black lutites from NPRA wells show that these rocks do not differ markedly in trace element content from the average shale worldwide. A few stratigraphic differences in abundance of trace elements may be significant. Cretaceous orogenic and post orogenic deposits, derived from the ancestral Brooks Range, are richer than others in base metals, while the older and more mature deposits derived from a source north of Barrow are richer in the suite of elements commonly associated in deposits of phosphate and thorium.

INTRODUCTION

Core samples of Mississippian through Upper Cretaceous black shale, siltstone, and lime mudstone from 24 test wells in the National Petroleum Reserve in Alaska (Figs. 1 and 2) have been analyzed for trace elements in order to provide regional background for geochemical explorations.

The study was made because several of the rock units cored in the subsurface are associated with surface geochemical anomalies or small deposits in the areas where they crop out. In southwestern NPRA the heavy concentrates from stream sediments in a large area of shale and graywacke of the Lower Cretaceous Fortress Mountain and Torok Formations are unusually rich in lead, arsenic and silver (Churkin and others, 1978). Southeast of NPRA, in the foothills of the Philip Smith Mountains, stream sediments in areas of Permian to Lower Cretaceous shale locally contain anomalous amounts of zinc and thorium (Cathrall and others, 1978; Reiser and others, 1983). Barite concretions are common in the shale and chert of the Pennsylvanian to Lower Triassic Siksikpuk Formation (Patton and Tailleur, 1964; Churkin and others, 1978) and locally in shale of the Permian to Lower Triassic Sadlerochit Group (Detterman, 1976; Bundtzen and Henning, 1978). Phosphate rock occurs in the Triassic Shublik Formation and in the Mississippian part of the Lisburne Group (Patton and Matzko, 1959). In addition, the high organic carbon content of the Shublik Formation, Jurassic Kingak Shale, and lowest Cretaceous "pebble shale" where they occur in the subsurface in the Prudhoe Bay area (Morgridge and Smith, 1972; Seifert and others, 1979) suggest that they may be rich in trace metals. Outcrops of the Shublik in the Brooks Range locally do contain much copper, molybdenum, vanadium, and rare earths (Tourtelot and Tailleur, 1971), and the high gamma radiation characteristic of the pebble shale in the subsurface shows that it is rich in uranium and thorium (Carman and Hardwick, 1983). The shales with the most important known metal deposits are the Mississippian shale and chert now assigned to the Kuna Formation (Mull and others, 1982). These rocks contain massive sulfide zinc deposits in southern NPRA (Nokleberg and Winkler, 1982) but were penetrated only by one well.

The distribution of vanadium and nickel may also be of interest in oil exploration. Hughes and others (1983) found higher V/Ni ratios in the Prudhoe-Barrow family of oils than in the Umiat-Simpson oils and attributed them to sources in the Shublik Formation and Jurassic Kingak Shale.

ROCK UNITS SAMPLED

Most of the samples are from the 10 major stratigraphic units penetrated by the wells in the coastal plain and northern foothills that are shown in figure 1. Almost all of the stratigraphic assignments of samples are based on the formation boundaries for wells in that area listed by Bird (1982); a few are based on his revised stratigraphy for the East Simpson 2 well (Bird, written communication, 1983). Formation assignments for the

Lisburne well are by Tailleur. We differ with Bird on the assignment of only four of the samples from the other wells. Two of these are from the Shublik Formation at depths of 7572 ft and 7572.5 ft in the Drew Point well where we differ from Bird's contact by only 2 1/2 ft. We have assigned the core at 6070 ft in Simpson 1 to the Kingak Shale rather than to the Sag River Sandstone, and the core at 1763 ft in Square Lake 1 to the Colville Group rather than to the Nanushuk Group. Bird also lists references and notes for most of the sampled units. A brief description of each unit is given below with some remarks about the samples.

The rocks have been divided into two major sequences by Lerand (1973). The Brookian Sequence comprises the Upper Jurassic (Mayfield and others, 1983) to Tertiary (Molenaar, 1981 and 1983) post-orogenic deposits that were derived from an ancestral Brooks Range to the south, while the Ellesmerian sequence comprises the Mississippian through earliest Cretaceous deposits that were derived from the north. Carman and Hardwick (1983) recently have placed the locally derived lowest Cretaceous rocks in the Kuparuk oil field into a third sequence that they have named Barrovian. Part or all of the lowest Cretaceous rocks in northern NPRA may belong to the Barrovian Sequence rather than the Ellesmerian, so on figure 2 we have queried the sequence to which these rocks are assigned.

Colville Group: Upper Cretaceous (Turonian) and younger deltaic deposits with a basal marine shale and an upper, partly nonmarine sandy unit. The highest sample is from a coal-bearing nonmarine interval; the others are from the basal marine shale.

Nanushuk Group: Topset, foreset, and fluvial deposits of the Lower (Albian) to Upper (Cenomanian) Cretaceous deltaic system that preceded the Colville Group delta. The highest sample from each of the two wells is from nonmarine beds; the others are marine (Molenaar, 1981).

Torok Formation: Thick foreset and thin bottomset shale and sandstone deposits at the front of the Lower Cretaceous (Albian and Aptian?) deltaic system. Equivalent rocks in the southern foothills are the Fortress Mountain Formation which is composed of coarse polymict turbidites and some fluvial beds, and was derived from several local sources (Molenaar, 1981). Beneath the northern foothills, in the deeper parts of the Cretaceous basin, the Torok grades down into shale and sandstone that can be separated seismically from the rest of the Torok and have been informally assigned to the lower Torok and distal Fortress Mountain Formation, although Molenaar (1981) questions this correlation. The lower sample from the Awuna 1 well and the lowest 3 samples from Seabee 1 are from this lower unit.

"Pebble shale": An informally named unit only a few hundred feet thick that is composed of fissile carbonaceous shale with floating quartz grains and rests with erosional unconformity on Jurassic to pre-Mississippian rocks. It comprises the upper part of the "unnamed" subsurface unit of Robinson (1956) and Collins (1958) and is equivalent to the pebble shale member of the Kongakut Formation in outcrop (Detterman and others, 1975). In NPRA it seems to be mostly of Early Cretaceous (Hauterivian to Barremian) age. A highly radioactive zone, 20-150 ft thick, that usually occurs in the top of the unit, is separately identified from wire line logs as the Gamma Ray Zone (GRZ) and is so marked on table 2.

Okpikruak Formation: This oldest Brookian deposit occurs only in the Brooks Range and in the southern foothills where it was penetrated by the Lisburne 1 well. It consists of graywacke turbidite as much as 3000 feet thick that is of Late Jurassic to Early Cretaceous (Valanginian) age (Patton and Tailleur, 1964; Mayfield and others, 1983), so that most of it is slightly older than the pebble shale unit.

Kingak Shale: In its type area, and in the subsurface at Prudhoe Bay and Barrow, this unit is entirely of Jurassic age (Detterman and others, 1975; Carman and Hardwick, 1983). However in NPRA south of Barrow, a thick unit of previously unnamed lowest Cretaceous shales, that are similar to the Kingak, lies between the Jurassic Kingak and the unconformity at the base of the pebble shale, and progrades southward over the Jurassic shales. Molenaar (1981) and Bird (1982) have extended the term Kingak to include these Cretaceous beds as well as the underlying Jurassic. In classifying our samples we have distinguished the Cretaceous part of this extended Kingak from the Jurassic part by using the tops of paleontologic zones listed by Witmer and others (1981). According to them, the upper Kingak is Lower Cretaceous (Berriasian and Valanginian). It is therefore equivalent to the Okpikruak Formation. The entire Kingak, as well as the pebble shale, are part of the northerly derived Ellesmerian Sequence according to Bird (1981). Inasmuch as the upper Kingak is the same age as the locally derived Barrovian Sequence of Carman and Hardwick (1983) and, like it, contains some locally thick sandstones at Tunalik 1 well, the upper Kingak may be partly Barrovian rather than Ellesmerian. The question mark on figure 2 expresses this uncertainty.

Shublik and Sag River Formations: In the coastal plain the black shale, siltstone, and phosphatic limestone of the Middle to Upper Triassic Shublik Formation are overlain by 50 to 250 feet of glauconitic sandstone and siltstone of the Upper Triassic Sag River Formation (Jones and Speers, 1976). The core samples from this Triassic interval include two from the Sag River Formation (Simpson 1, 6240 and East Simpson 1, 6865). All three of the samples from Simpson 1 well are dark, fine grained limestone, as noted on table 4.

Otuk Formation: Mull and others (1982) have restricted the term Shublik Formation to rocks in the type area and in the subsurface. Lower to Upper Triassic rocks in the southern foothills and in most of the Brooks Range that were formerly called Shublik are now part of the Otuk Formation. Unlike the type Shublik, they contain much bedded chert and siliceous limestone. The Lisburne 1 well penetrated the Otuk Formation; the single core sample of black calcareous shale from the Otuk in that well is listed with the Shublik in table 4.

Etivluk Group: This group includes the Otuk Formation and the Siksikpuk Formation, a chert and siltstone unit of Pennsylvanian to Early Triassic age (Mull and others, 1982). It occurs only in the southern foothills and Brooks Range and was penetrated only by the Lisburne 1 well. The single core sample of Etivluk Group from that well is probably of the Siksikpuk Formation (table 5). This single sample cannot properly be grouped with samples from any other unit, so it has been omitted from the statistical summaries shown in tables 6, 7, and 8 and figures 3, 4, and 5.

Sadlerochit Group: This group comprises the Permian nearshore marine Echooka Formation and the Lower Triassic marine to fluvial Ivishak Formation (Detterman and others, 1975; Jones and Speers, 1976) that was deposited as a southward prograding delta system. The samples are all from the Triassic rocks: 3 from the upper siltstone member; 4 from the middle sandstone member; and 2 from the lower shale member. All are of marine rocks.

Lisburne Group: In the coastal plain and northern foothills, and in the series of thrust plates penetrated by the Lisburne 1 well, this unit is mostly carbonate rock of Mississippian to Permian age (Bird and Jordan, 1977; Bird, 1981). Shale is rare in the cores, and the samples are of mixed black clay mudstone and very fine grained argillaceous limestone as noted on table 5. The single core sample of the dominantly non-carbonate Kuna Formation (Mull and others, 1982) of the Lisburne Group that is listed in table 5 has been omitted from the statistical summaries shown in tables 6, 7, and 8 and figures 3, 4, and 5.

Endicott Group: These are Mississippian clastic rocks that rest unconformably on the basement rocks in the coastal plain. Interbedded shale and limestone in the upper part grade upward into the Lisburne Group. The lower part includes coarse clastics and is partly nonmarine and coal-bearing; all of the samples (table 5) are from this lower part of the unit.

SAMPLES

The sample set consists of 147 samples from conventional drill cores and 16 samples of cuttings. Although in some instances several samples were taken from one core, they are grab samples, not composite samples. Each consists of a semicircular chip about 1/2 to 1 inch thick taken from the longitudinally sliced core. Almost all samples are of black shale or siltstone; exceptions are a few samples of gray shale or argillaceous limestone. The limestone samples are noted on tables 4 and 5.

The distribution of samples among the various stratigraphic units is unequal. It was determined partly by the availability of suitable material and partly by our assessment of the importance of the units in terms of relative thickness and potential metal content. The Kingak Shale and pebble shale were sampled most intensely relative to their thickness.

CONTAMINATION

All of the samples were subject to contamination by barite drilling mud, but with 3 exceptions the cores seemed clean when sampled. We scraped mud from these cores: Kugrua 1, 7198 (pebble shale); Walakpa 1, 2112 (Jurassic Kingak Shale), and Drew Pt. 1, 6937.5 (Jurassic Kingak Shale). All of the core samples were further cleaned in the analytical laboratory.

Judging from the amount of barium reported in the analyses, most of the core samples were free of mud when analyzed. The median concentration of barium reported from the cores differs by only 4% from the worldwide median concentration of barium in shales (Rose, Hawkes, and Webb, 1979). However, the 16 samples of cuttings from Lisburne 1 well are certainly contaminated either by mud or by cuttings from the barium-rich Siksikpuk Formation, and the 2 core samples of Kuna Formation and Etivluk Group from that well may also be contaminated. The cuttings of Lisburne Group limestone from Lisburne 1 contain at least 10 times as much barium as do the core samples of the Lisburne Group from the same well. The Etivluk and Kuna core samples are also unusually high in barium, although this may simply reflect the inherently high barium content of the Siksikpuk Formation. Neither the cuttings shown in table 5 nor the 2 Kuna Formation and Etivluk Group cores shown in table 5 are included in the statistical summaries.

Inigok 1 well was intentionally contaminated when ZnO was added to the drilling mud at depth 17,570 ft in order to quell a strong blow of H_2S encountered in the Lisburne Group. However the zinc is not evident in the sample of the Endicott Group recovered farther down the hole. The density of the drilling mud was also increased by 50% below 17,570 ft. This might account for the anomalous amount of barium in the Endicott Group core from this well, but even more barium was found in some of the Endicott cores taken at shallower depths with normal mud weight in the East Simpson 2 well.

ANALYSES AND ACKNOWLEDGMENTS

All of the samples were analyzed by direct reader emission spectography in the U.S.G.S. Menlo Park, California laboratory. This method determined the concentrations of the 10 major elements and of 22 of the trace elements. It is quantitative for all of the silicate rocks, but only semi-quantitative for the non-silicates. For this reason, the samples consisting in part of limestone are separately noted in tables 1 to 5. In all of the rocks, zirconium values are subject to errors of more than 10%. The analysts were T. L. Fries, J. J. Consul, and R. W. Lerner.

All but four of the samples were analyzed for uranium and thorium in the USGS Lakewood, Colorado laboratory by delayed neutron determination. Single run determinations were made for 78 of the core samples. These include all of the samples from the Colville, Nanushuk, and Endicott Groups and the Jurassic part of the Kingak Shale; most of the samples from the Torok Formation and Sadlerochit Group; and a few from the pebble shale. The coefficients of variation expressed as percentages of the reported value, are from 5% to 11% for thorium, and from 1% to 4% for uranium. M. Coughlin, S. Danahey, J. M. Storey, and B. Vaughn made these analyses. High precision analyses of 5 or 6 runs were made on the 16 samples of cuttings from the Lisburne 1 well and on 65 core samples that include all of the samples from the Okpikruak Formation, the Cretaceous part of the Kingak Shale, the Etivluk Group, the Shublik, Sag River and Otuk Formations, and the Lisburne Group and Kuna Formation, as well as most of the samples from the pebble shale and a few from the Torok Formation. The coefficients of variation for thorium in the high precision analyses range from 2% to 15% and are generally less than 8%; for uranium they range from zero to 2%. B. A. Keaten, F. Loman, and H. T. Millard, Jr., made these analyses. At the suggestion of David McKown, these multiple run analyses were discontinued in favor of single runs when it became apparent that, for our purposes, they did not significantly improve the data.

Special analyses for P_2O_5 were made in the USGS Menlo Park laboratory by M. J. Cremer for 25 core samples and for all 16 of the samples of cuttings from the Lisburne 1 well. The core samples are from those units known to contain phosphate rock. They include all of the samples from the Shublik, Sag River, and Otuk Formations and from the Lisburne Group and Kuna Formation. They also include the single sample from the Etivluk Group and one of the samples from the Sadlerochit Group.

RESULTS

The analytical data for the 10 major elements (Fe, Mg, Ca, Ti, Mn, Si, Al, Na, K, P) and 24 trace elements are listed by stratigraphic interval in tables 1 to 5 for all of the samples. Cumulative frequency curves showing the number of samples (as a percent of 145 samples) that contain elemental concentrations less than or equal to each plotted concentration have been drawn for phosphorous and 18 of the trace elements (Figs. 3, 4, and 5). Curves cannot be drawn, nor medians calculated, for silver, cadmium, molybdenum, niobium, tin, and cerium because in most of the samples the concentration of these elements is below the limit of determination. Two Kuna Formation and Etivluk Group cores from Lisburne 1 well have been omitted from the calculations.

In order to judge the regional background information provided by the analytical data we have compared the median concentrations of most of the trace elements with their median or average values in shales in North America or worldwide (Table 6). In order to discover whether there may be any marked differences in trace element content between stratigraphic units we have compared the median concentrations found in each stratigraphic unit, and have also compared the distribution of anomalous values among the stratigraphic units.

Median concentrations: Medians were calculated from the frequency distribution histograms drawn for phosphorous and 18 of the trace elements in each of the stratigraphic units and in the whole group of 145 core samples. The median values, rather than average values, are presented because they are less affected by anomalously high values in a few samples.

Median concentration values for trace elements in shales worldwide are available only for Ba, Cu, Pb, Zn, and U. For the other elements only the average value is available. Comparison of median values with average values is not rigorous because the average is greater than the median in positively skewed distributions like those commonly found for trace elements. When the medians for the group are compared with an average shale, the group is:

> richer even than the average in scandium, vanadium, chromium, boron, phosphorus, thorium, and zirconium poorer than average in cobalt, nickel, and strontium; and has about the same content of gallium, beryllium, lanthanum, and yttrium.

When the medians for the group are compared with the median values worldwide, the group is poorer in lead and has about the same content of barium, copper, zinc, and uranium.

Inasmuch as the medians for only four of the elements differ from the worldwide medians or averages by more than 33% (Table 6), it is likely that most of the differences are within one or two standard deviations of the worldwide averages. When compared with the average values for 20 sets of U.S. black shales determined by Vine and Tourtelot (1970), the results are somewhat different because the Vine and Tourtelot average values are generally smaller than those used in Table 6. However, the only prominent differences between the medians for the group of 145 core samples and the Vine and Tourtelot averages are for scandium, beryllium, boron, barium, and zirconium. For these elements our medians are respectively 170%, 260%, 400%, 190%, and 370% of their averages. Our very high median values for zirconium may partly reflect the relatively low precision of the zirconium analyses. Thus, the sample group as a whole seems to consist of very ordinary shale and might serve as background anywhere.

Based on the median concentrations of elements in each stratigraphic unit (Table 6), a few of the units are richer than the others in a few of the elements as follows:

Torok Formation	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-
pebble shale	Cu	Zn	-	-	-	Ga	-	V	-	B	-	-	-	Th	-	Sr	-
gamma ray zone of the pebble shale	Cu	Zn	Co	-	-	-	-	V	-	B	-	Y	P	Th	U	Sr	-
Okpikruak Formation	Cu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cretaceous Kingak Shale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Zr
Shublik Formation	-	-	-	-	-	-	-	-	Cr	-	-	-	-	-	-	Sr	Zr
Sadlerochit Group	-	-	-	Ni	-	-	Be	V	Cr	-	Ce	-	P	Th	-	Sr	-
Lisburne Group	-	Zn	-	-	-	-	-	-	-	-	-	-	-	-	U	Sr	-
Endicott Group	-	-	-	-	Sc	Ga	-	V	Cr	B	La	-	-	Th	U	-	Ba

The two samples analyzed from the gamma ray zone of the pebble shale have a higher median concentration of uranium than any other unit and almost as high a median concentration of thorium as the Endicott Group.

By the same standards, the Lisburne Group is particularly poor in almost all of the trace elements, and the Shublik Formation is poor in cobalt, gallium, beryllium, thorium, and (surprisingly) phosphorous.

In addition, the median concentrations of copper, lead, cobalt, and phosphorous are generally higher in all of the post-orogenic Brookian deposits than in the Ellesmerian, and especially so in the Okpikruak Formation. Conversely, the median concentration of zirconium is generally lower in the Brookian deposits.

Anomalous concentrations: We picked anomalies at the 94th to 99th percentile in the frequency distribution histograms of each of the elements in the group of 145 core samples, and found 102 anomalies distributed among 40 of the samples. These anomalies are not evenly distributed among samples or among the stratigraphic units. Ten of the samples contain 57 of the anomalous concentrations, and these 10 samples come from only 5 of the 10 stratigraphic units: the Torok Formation, the pebble shale, the Shublik and Otuk Formations, the Sadlerochit Group, and the Endicott Group. The other 45 anomalies are distributed among 30 samples, most of which are also in the Torok Formation, pebble shale, Shublik and Sag River Formations, and Endicott Group. Of the 102 anomalous concentrations of individual elements, 83 are in the Torok Formation; the pebble shale; the Shublik, Otuk, and Sag River Formations; and the Endicott Group. Thus, both the distribution of samples that are anomalous for one or more elements and the distribution of the actual element anomalies shows a high concentration of anomalies in 4 of the stratigraphic units.

The number of anomalous samples from each stratigraphic unit is at least in part related to the total number of samples collected from that unit. The Torok Formation, the pebble shale, and the combined Shublik, Sag River, and Otuk Formations provide most of the total number of samples (26%, 16%, and 12% respectively), and also provide most of the anomalous samples (13%, 18%, and 30% respectively), as well as most of the individual anomalies (19%, 22%, and 27% respectively). Two-thirds of all of the samples from the Shublik, Sag River and Otuk Formations contain anomalies, so it is likely that the abundance of anomalous samples in that unit, as well as in the sparsely sampled Endicott Group, is significant.

Anomalies for each element tend to be concentrated in one or two stratigraphic units. Samples from the Endicott Group contain the cerium and gallium anomalies, most of the lanthanum anomalies and half of the barium and thorium anomalies.

Samples from the Shublik, Sag River, and Otuk Formations contain all of the phosphorous and tin anomalies, and most of the chromium, nickel, strontium, and zirconium anomalies. The metal anomalies are mainly in the Torok Formation and pebble shale, which contain most of the anomalous concentrations of copper, zinc, cadmium, cobalt, molybdenum, vanadium, uranium, and scandium.

The stratigraphic distribution of anomalies agrees with the distribution of high median values in that: the Torok Formation and pebble shale are relatively rich in copper and cobalt; the pebble shale is also relatively rich in zinc, vanadium and uranium; the Shublik Formation is relatively rich in chromium, strontium, and zirconium; the Endicott Group is relatively rich in gallium, lanthanum, barium, and thorium.

The anomalies and medians disagree in that: all of the phosphorous anomalies are in the Shublik Formation, but the median concentration of phosphorous in the Shublik is lower than that in almost all other units, suggesting that Shublik phosphate is concentrated in certain beds. Most lead anomalies are in the Shublik Formation and

Kingak Shale, but all of the higher median concentrations of lead are in the Brookian rocks. Half of the uranium anomalies are in the Torok Formation whereas all of the higher median concentrations of uranium are in the pebble shale and the Triassic and older rocks.

CONCLUSIONS

The rocks sampled are not significantly different from the average shale in trace element content, but certain stratigraphic units seem to be slightly favored as hosts for a few of the elements (Table 8). When the strongest evidence from anomalies and high median concentrations is combined it appears that:

1. The Brookian rocks, which were derived from the south, are richer than the other rocks in copper, cobalt, and cadmium.

2. The northerly derived (Ellesmerian or Barrovian) pebble shale and the included gamma ray zone are moderately rich in uranium, vanadium, and zinc.

3. The Triassic and older Ellesmerian rocks, particularly the coaly Endicott Group, are richer than the other rocks in uranium plus thorium.

4. The rocks that are richer than others in uranium are also richer in vanadium, particularly the coaly rocks of the Endicott Group. Except for the coaly Endicott Group, the highest ratios of vanadium to nickel are in the pebble shale, and the next highest in the Shublik Formation and Cretaceous Kingak Shale.

5. Despite a few lead anomalies, the Kingak Shale is not favored as a host for metals.

6. The deepest marine units, the pebble shale and Jurassic Kingak Shale, are richer than the other rocks in boron.

7. The northerly derived rocks, particularly those relatively rich in uranium, are richer than other rocks in rare earths.

8. The northerly derived rocks beneath the pebble shale unconformity are richer than others in zirconium.

9. The coaly Endicott Group is richer than other rocks in barium.

10. The Shublik Formation and Sadlerochit Group are richer than the other rocks in phosphorous, but the Brookian rocks are generally richer in phosphorous than the rest of the Ellesmerian or Barrovian rocks.

These few conclusions seem consistent with the regional geology. They suggest that the source of the Brookian deposits in the ancestral Brooks Range was richer in base metals than the unknown northern source of the Ellesmerian rocks and that the Brookian deposits are compositionally less mature than the Ellesmerian (Molenaar, 1983). The suite of elements associated with the Ellesmerian rocks may reflect either the character of their source, or the environment of their deposition, since most of the elements in this suite are commonly associated with each other in phosphate deposits (P, U, V, RE, Zr) (Cathcart and Gulbrandson, 1973; Klemic and others, 1973) or in monazite deposits (Th, RE, Zr) (Staats and Olson, 1973).

REFERENCES CITED

Bird, 1981, Petroleum exploration of the North Slope in Alaska, U.S.A.: U.S. Geological Survey Open-file Report 81-227, 43 p.

______1982, Rock unit reports of 228 wells drilled on the North Slope, Alaska: U.S. Geological Survey Open-file Report 82-278, 106 p.

Bird, K. J., and Jordan, D. F., 1977, Lisburne Group (Mississippian and Pennsylvanian), potential major hydrocarbon objective of Arctic Slope, Alaska: American Association of Petroleum Geologists Bulletin, v. 61, no. 9, p. 1493-1512.

Bundtzen, T. K., and Henning, W. W., 1978, Barite in Alaska: Alaska Division of Geological and Geophysical Surveys Mines and Geology Bulletin, v. 27, no. 4, p. 1-4.

Carman, G. J., and Hardwick, Peter, 1983, Geology and regional setting of Kuparuk oil field, Alaska: American Association of Petroleum Geologists Bulletin, v. 67, no. 6, p. 1014-1031.

Cathcart, J. B., and Gulbrandson, R. A., 1973, Phosphate deposits, in Brobst, D. A., and Pratt, W. D., eds., United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 515-525.

Cathrall, J. B., Detra, D. E., and O'Leary, R. M., 1978, Geochemical maps showing the distribution and abundance of zinc in the Philip Smith Mountains quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-879I, scale 1:250,000.

Churkin, Michael, Jr., Mayfield, C. F., Theobald, P. K., Barton, Harlan, Nokleberg, W. J., Winkler, G. R., and Huie, Carl, 1978, Geological and geochemical appraisal of metallic mineral resources, southern National Petroleum Reserve in Alaska: U.S. Geological Survey Open-file Report 78-70A, 82 p.

Collins, F. R., 1958, Test wells, Topagoruk area, Alaska: U.S. Geological Survey Professional Paper 305-D, p. 265-316.

Detterman, R. L., 1976, Lithofacies fence diagram of Sadlerochit Group for Philip Smith Mountains quadrangle and adjacent areas, northeastern Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-744.

Detterman, R. L., Reiser, H. N., Brosge, W. P., and Dutro, J. T., Jr., 1975, Post-Carboniferous stratigraphy, northeastern Alaska: U.S. Geological Survey Professional Paper 886, 46 p.

Hughes, W. B., Miller, D. E., and Holba, A. G., 1983, North Slope, Alaska oil-rock correlation study, in Magoon, L. B., and Claypool, G. E., eds., Alaska North Slope oil-rock correlation study - a compilation of abstracts: American Association of Petroleum Geologists Short Course, Dallas, Texas, April 17, 1983.

Jones, H. P., and Speers, R. G., 1976, Permo-Triassic reservoirs of Prudhoe Bay field, North Slope, Alaska, in Braunstein, Jules, ed., North American oil and gas fields: American Association of Petroleum Geologists Memoir 24, p. 23-50.

Klemic, Harry, Gottfried, David, Cooper, Margaret, and Marsh, S. P., 1973, Zirconium and hafnium, in Brobst, D. A., and Pratt, W. D., eds., United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 713-722.

Lerand, Monte, 1973, Beaufort Sea, in The future petroleum provinces of Canada - their geology and potential: Canadian Society of Petroleum Geologists Memoir 1, p. 315-386.

Mayfield, C. F., Tailleur, I. L., and Ellersieck, Inyo, 1983, Stratigraphy, structure and palinspastic synthesis of the western Brooks Range, northwestern Alaska: U.S. Geological Survey Open-file Report 83-779, 58 p.

Molenaar, C. M., 1981, Depositional history and seismic stratigraphy of lower Cretaceous reocks, National Petroleum Reserve in Alaska and adjacent areas: U.S. Geological Suvey Open-file Report 81-1084, 42 p.

_____1983, Depositional relations of Cretaceous and lower Tertiary rocks, northeastern Alaska: American Association of Petroleum Geologists Bulletin, v. 67, no. 7, p. 1066-1080.

Morgridge, D. L., and Smith, W. B., Jr., 1972, Geology and discovery of Prudhoe Bay field, eastern Arctic Slope, Alaska, in Stratigraphic oil and gas fields - classification, exploration methods and case histories: American Association of Petroleum Geologists Memoir 16, p. 489-501.

Mull, C. G., Tailleur, I. L., Mayfield, C. F., Ellersieck, Inyo, and Curtis, S., 1982, New upper Paleozoic and lower Mesozoic stratigraphic units, central and western Brooks Range, Alaska: American Association of Petroleum Geologists Bulletin, v. 66, no. 3, p. 348-362.

Nokleberg, W. J., and Winkler, G. R., 1982, Stratiform zinc-lead deposits in the Drenchwater Creek area, Howard Pass quadrangle, northwestern Brooks Range, Alaska: U.S. Geological Survey Professional Paper 1209, 22 p.

Norman, J. C., and Haskins, L. A., 1968, The geochemistry of Sc-A comparison to the rare earths and Fe: Geochimica and Cosmochimica Acta, v. 32, no. 1, p. 93-108.

Patton, W. W., Jr., and Matzko, J. J., 1959, Phosphate deposits in northern Alaska: U.S. Geological Suvey Professional Paper 302-A, p. 1-17.

Patton, W. W., Jr., and Tailleur, I. L., 1964, Geology of the Killik-Itkillik region, Alaska: U.S. Geological Survey Professional Paper 303-G, p. 409-500.

Reiser, H. N., Brosge, W. P., Hamilton, T. D., Singer, D. A., Menzie, W. D., II, Bird, K. J., Cady, J. W., LeCompte, J. R., and Cathrall, J. B., 1983, The Alaska Mineral Resource Assessment Program: guide to information contained in folio of geologic and mineral resource maps of the Philip Smith Mountains quadrangle, Alaska: U.S. Geological Survey Circular 759, 22 p.

Robinson, F. M., 1956, Core tests and test wells, Oumalik area, Alaska: U.S. Geological Survey Professional Paper 305-A, p. 1-70.

Rose, A. W., Hawkes, H. E., and Webb, J. S., 1979, Geochemistry in mineral exploration, second edition: Academic Press, 657 p.

Seifert, W. K., Moldowan, J. M., and Jones, R. W., 1979, Application of biological marker geochemistry to petroleum exploration: Tenth World Petroleum Congress, p. 425-440.

Staats, M. C., and Olson, J. C., 1973, Thorium, in Brobst, D. A., and Pratt, W. D., eds., United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 468-476.

Tourtelot, H. A., and Tailleur, I. L., 1971, The Shublik Formation and adjacent strata in northeastern Alaska: U.S. Geological Survey Open-file Report 462, 62 p.

Turekian, K. K., 1977, Geochemical distribution of elements, in Encyclopedia of Science and Technology, 4th edition: McGraw Hill, New York, p. 627-630.

Vine, J. D., and Tourtelot, E. B., 1970, Geochemistry of black shale deposits - a summary report: Economic Geology, v. 65, no. 3, p. 253-272.

Weeks, R. A., 1973, Gallium, germanium and indium, in Brobst, D. A., and Pratt, W. P., eds., United States Mineral Resources: U.S. Geological Suvey Professional Paper 820, p. 237-246.

Witmer, R. J., Haga, Hideyo, and Mickey, M. B., 1981, Biostratigraphic report of thirty-three wells drilled from 1975 to 1981 in National Petroleum Reserve in Alaska: U.S. Geological Survey Open-file Report 81-1166, 47 p.

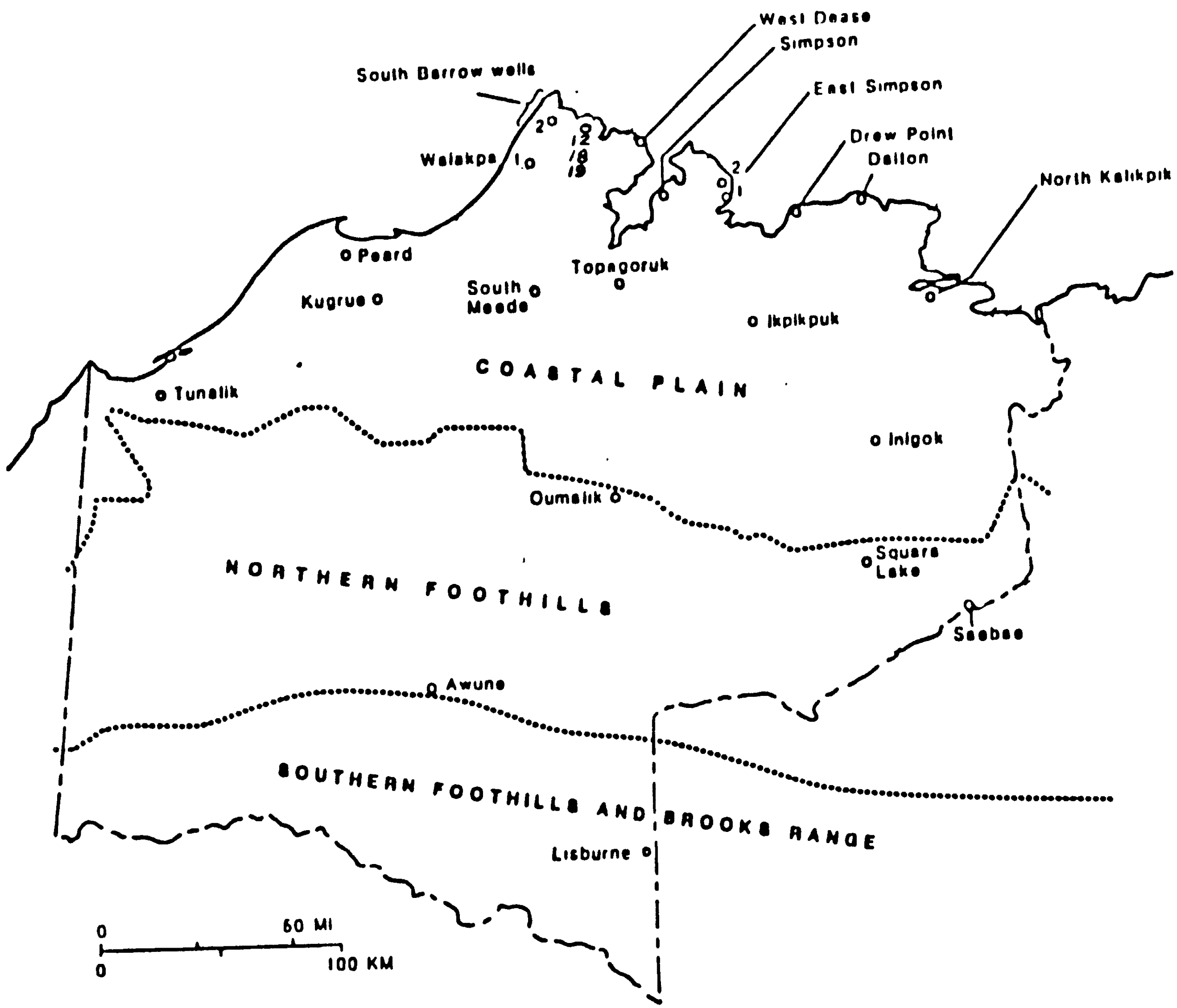


Figure 1. Index map of NPRA.

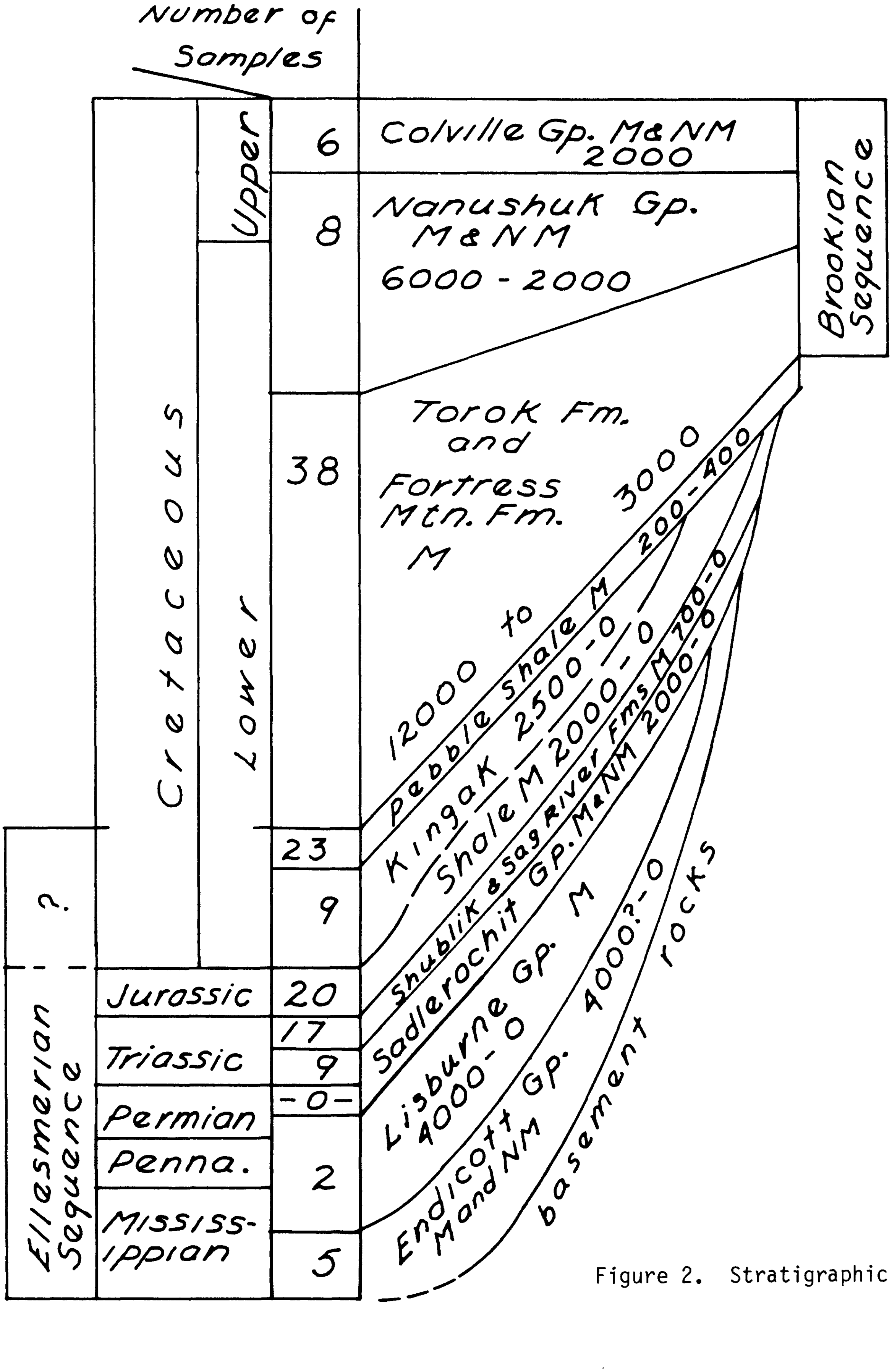


Figure 2. Stratigraphic diagram.

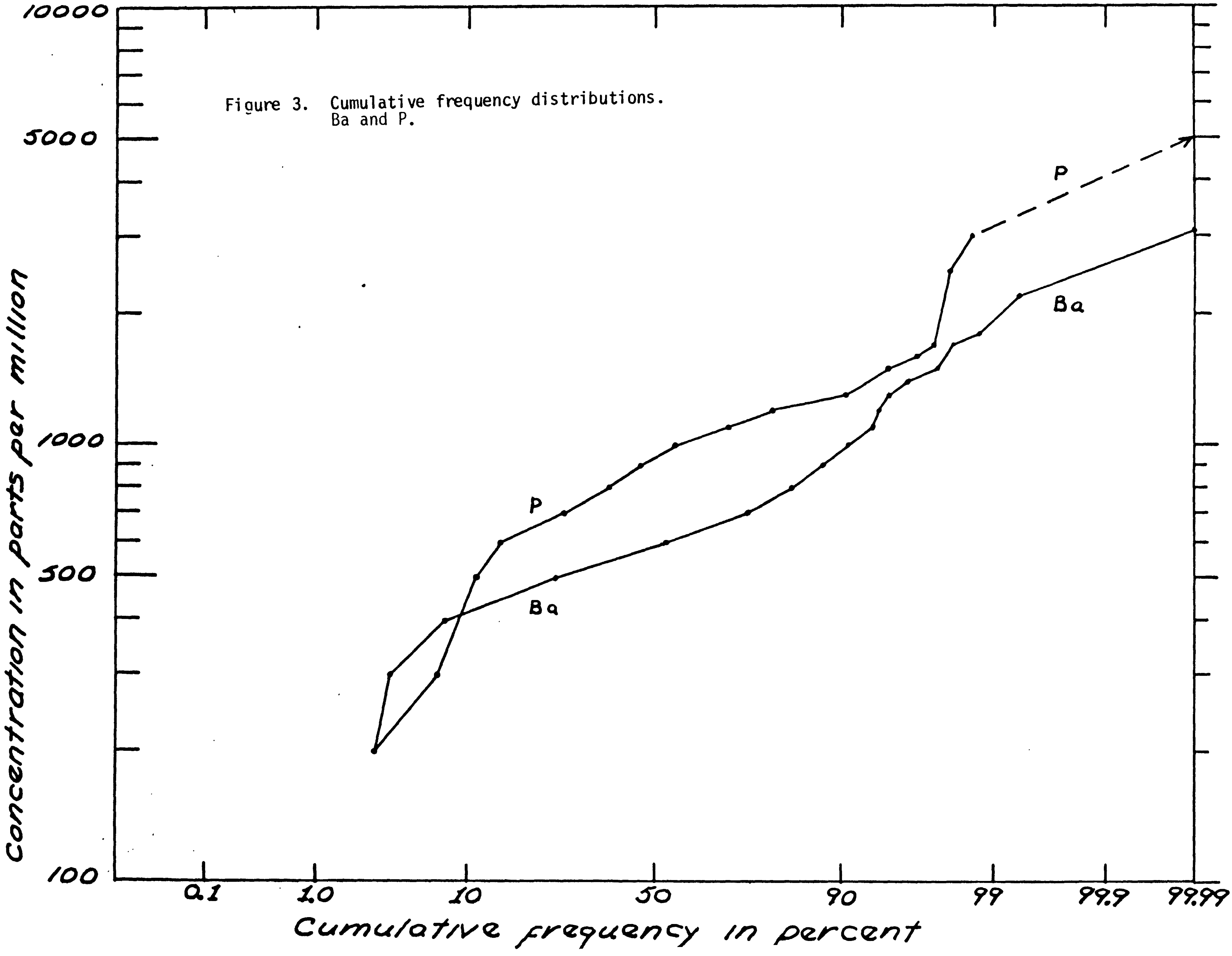
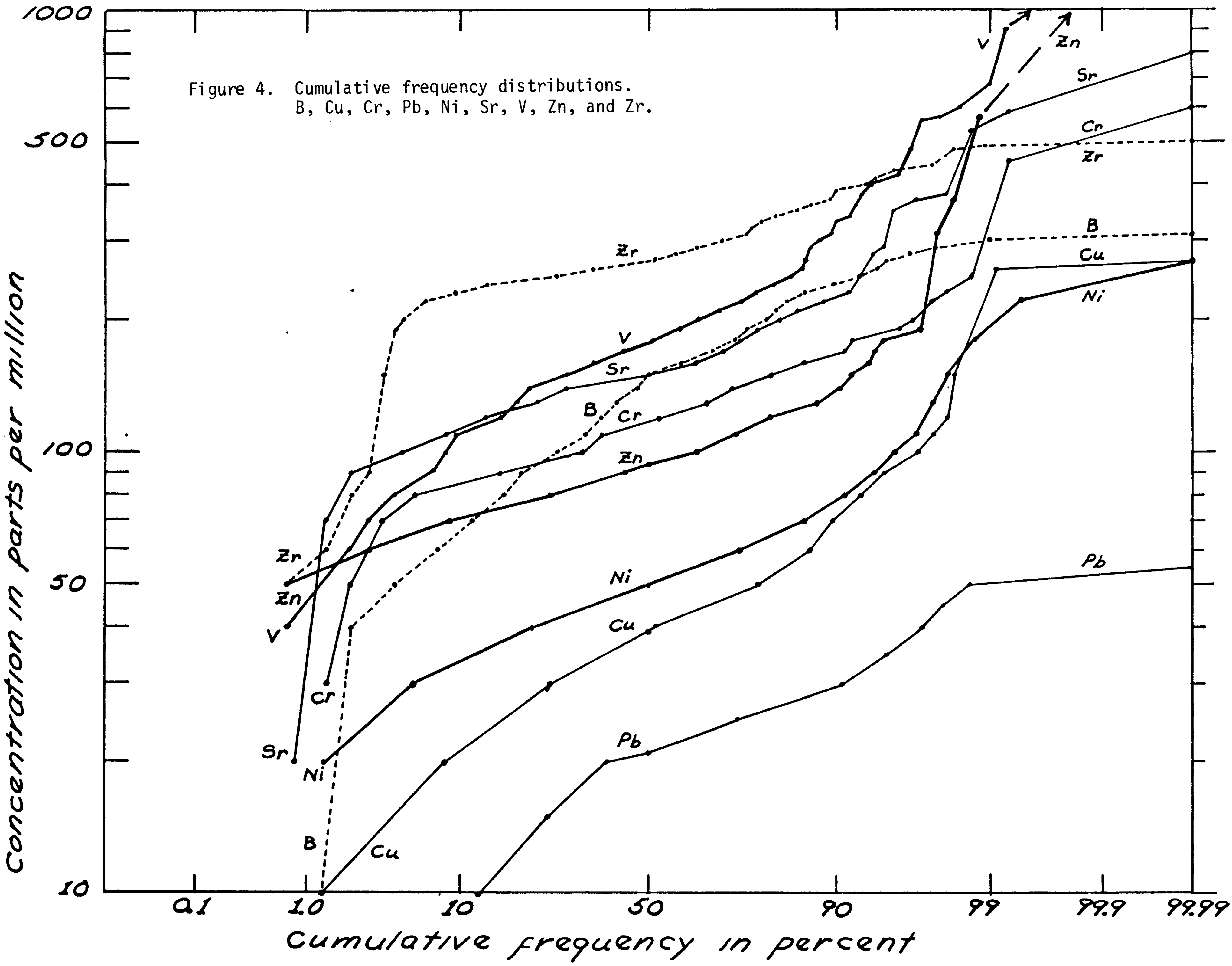


Figure 3. Cumulative frequency distributions.
Ba and P.

Figure 4. Cumulative frequency distributions. B, Cu, Cr, Pb, Ni, Sr, V, Zn, and Zr.



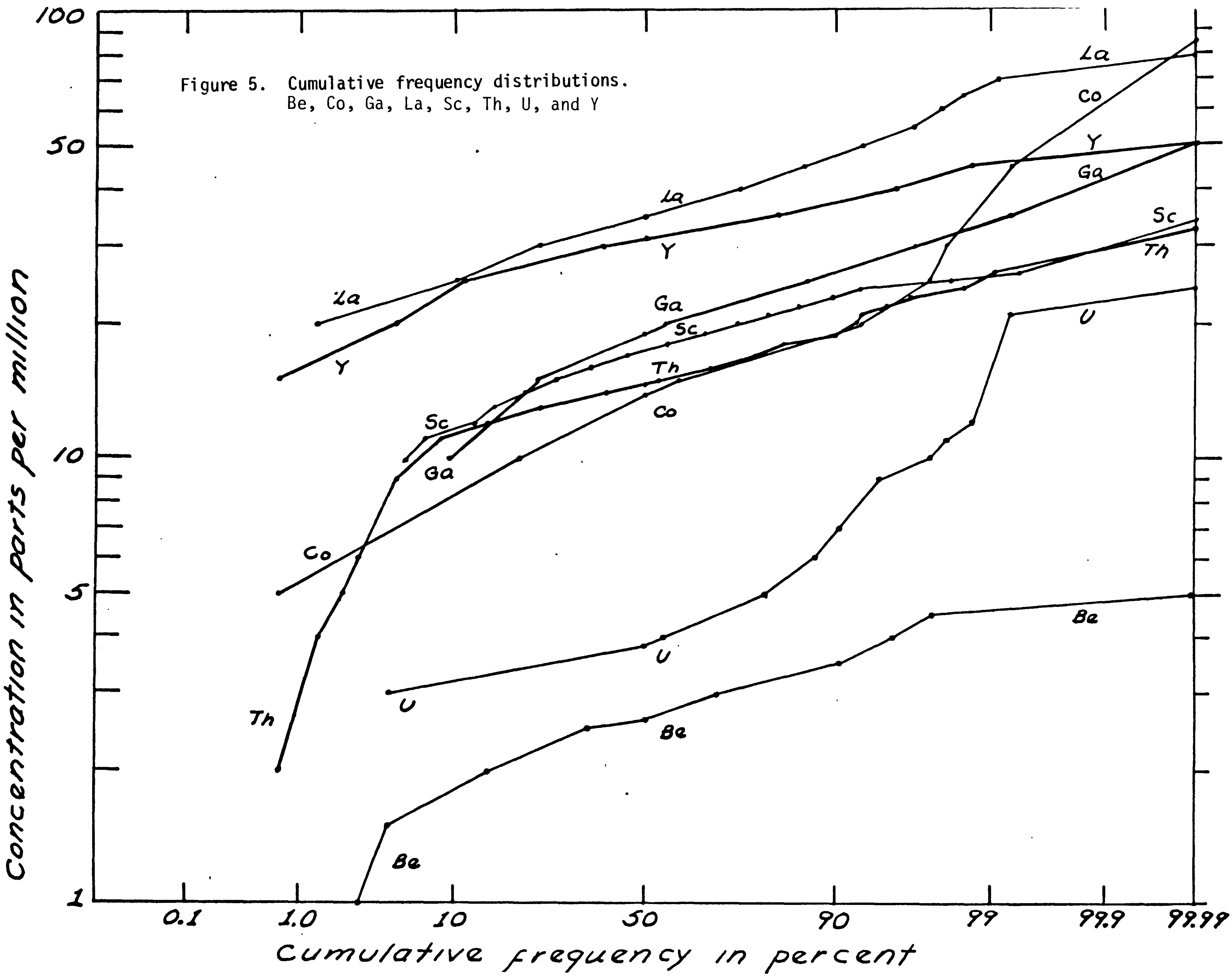


Figure 5. Cumulative frequency distributions.
Be, Co, Ga, La, Sc, Th, U, and Y

Table 1. Analyses of core samples from the Colville and Nanushuk Groups and Torok Formation. H = interference; X = no data; G = greater than the upper limit of determination; L = detected, but below the lower limit of determination. Values for G and L limits are indicated above columns where needed.

Sample	Fe %	Mg %	Ca %	Ti %	Mn ppm	Ag ppm	B ppm	Ba ppm	Be ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	La ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Sc ppm	Sn ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm	Si %	Al %	Na %	K %	P %	Ce ppm	Ga ppm	Th ppm	U ppm	
G			10					5000														1000				40				.45					
L					200	1	10		1	2				20	10	25		10	10	10				50		10		.15		.02	100	10			
Sq Lake 265	1.6	.57	.23	.16	L	L	38	1700	3	L	4.2	46	92	28	L	L	19	23	L	L	140	64	31	59	140	31	7.9	1.2	1.6	.02	L	20	15.3	6.86	Colville Gp.
Sq Lake 710	4.5	1.2	.73	.42	530	L	45	690	3.1	L	12	75	40	32	L	L	39	24	16	L	150	110	38	82	260	28	8.3	1.4	2.1	.11	L	24	18.1	4.80	
Sq Lake 942	4.4	1.1	.71	.43	430	L	45	640	2.6	L	13	83	49	34	L	L	41	26	16	L	150	130	34	72	260	28	7.8	1.5	2.3	.09	L	20	18.6	5.34	
Sq Lake 1287	4.1	.92	.35	.44	230	L	76	640	2.7	L	12	110	31	35	L	L	47	20	17	L	140	140	33	68	240	32	8.6	1.5	2.6	.09	L	23	14.5	4.16	
Sq Lake 1475	4.6	1.6	1.2	.49	440	L	93	620	2.5	L	17	120	70	31	L	L	71	26	22	L	120	200	31	98	260	27	8.7	.99	3.0	.08	L	21	15.8	3.82	
Sq Lake 1763	4.6	1.2	1.4	.38	650	L	55	660	2.4	L	12	86	36	23	L	L	49	24	17	L	130	120	31	89	280	28	7.1	1.1	2.1	.11	L	15	14.5	3.82	
Sq Lake 2051	3.8	.87	.24	.46	1400	L	51	680	2.3	L	18	140	41	31	L	L	65	20	17	L	89	140	34	110	260	32	7.9	1.2	2.0	.06	L	20	13.2	3.53	Nanushuk Gp.
Sq Lake 2344	3.2	.81	.12	.49	L	L	55	650	2.0	L	19	130	37	35	L	L	72	20	17	L	91	160	33	100	260	31	7.4	1.1	1.9	.05	L	20	12.8	4.34	
Sq Lake 2500	5.2	1.1	.23	.53	550	L	60	680	2.4	L	24	180	49	33	L	L	83	22	24	L	91	200	35	93	260	29	8.7	1.0	2.0	.06	L	22	12.1	3.78	
Sq Lake 2845	4.6	1.2	.25	.54	550	L	66	670	2.0	L	23	180	53	31	L	L	97	21	23	L	100	190	31	94	250	29	8.2	1.3	1.9	.08	L	21	10.5	3.54	
Sq Lake 3200	6.0	1.3	.49	.50	620	L	110	700	3.2	L	17	120	58	40	L	L	61	34	26	L	120	240	41	90	280	25	9.2	.97	2.6	.10	L	24	15.4	3.87	
Tunalik 3295	4.9	.98	.72	.49	700	L	78	570	2.8	L	10	110	44	39	L	L	42	25	22	L	140	180	36	78	230	28	9.0	1.1	2.3	.12	L	25	14.3	3.73	
Tunalik 3822	5.3	.94	.38	.44	570	L	110	640	2.9	L	13	110	37	46	L	L	47	26	22	L	160	200	34	120	250	26	9.7	.95	2.7	.12	L	31	15.1	3.36	
Tunalik 5553	5.3	1.2	1.1	.42	540	L	88	530	2.7	L	13	97	45	26	L	L	54	24	21	L	120	180	31	140	240	26	8.5	1.1	2.6	.10	L	21	15.0	4.02	
Awuna 2447	4.5	1.4	1.9	.44	440	L	77	420	2.7	L	13	91	37	29	L	L	46	26	17	L	140	150	31	88	270	28	8.0	1.4	2.0	.10	L	15	13.5	3.77	Torok Fm.
Awuna 3668	4.8	1.4	1.7	.44	470	L	95	480	2.9	L	14	97	36	32	L	L	54	24	21	L	140	170	33	100	260	27	8.4	1.2	2.3	.09	L	21	13.2	3.74	Kfm
Seabee 6548	5.4	1.4	.72	.50	390	L	110	720	2.9	L	14	110	44	34	L	L	52	25	22	L	120	210	33	95	240	28	9.5	1.1	2.8	.13	L	22	15.4	3.60	
Seabee 10068	4.5	1.7	2.1	.42	370	L	89	630	2.2	L	13	120	46	26	L	L	71	24	21	L	100	180	34	160	240	27	8.0	.92	2.1	.10	L	19	14.1	4.14	Kfm
Seabee 10883	4.9	1.2	.56	.49	340	L	99	720	2.6	L	16	120	49	37	L	L	70	28	33	L	110	230	34	120	250	27	8.9	.99	2.5	.08	L	23	13.9	4.07	
Seabee 12014	5.6	1.0	.42	.46	270	L	130	740	3.2	L	40	110	58	31	15	L	98	50	19	L	140	200	31	100	240	23	8.5	.87	2.9	.09	L	21	16.02	4.65	
Oumalik 8100	4.9	1.1	.69	.51	430	L	100	480	2.5	L	15	99	39	36	L	L	48	22	18	L	130	170	34	76	260	28	8.6	1.5	2.2	.12	L	20	13.7	3.21	
Oumalik 8287	5.2	1.1	.72	.52	370	L	110	500	2.7	L	16	110	39	36	L	L	59	28	20	L	140	220	33	84	230	28	9.0	1.3	2.6	.11	L	22	15.9	4.36	
Oumalik 8498	5.3	1.2	.67	.50	500	L	100	510	2.7	L	15	110	42	33	L	L	50	26	19	L	140	190	31	89	230	28	8.9	1.5	2.5	.12	L	20	15.4	3.30	
Oumalik 8695	5.2	1.1	.66	.48	460	L	100	510	2.5	L	14	100	40	30	L	L	50	21	19	L	140	170	32	84	250	28	8.5	1.3	2.3	.12	L	18	13.0	3.51	
Oumalik 8930	5.1	1.1	.82	.48	520	L	110	520	2.8	L	15	100	39	36	L	L	50	21	19	L	140	180	34	83	260	28	8.5	1.4	2.4	.12	L	19	14.1	3.27	
Oumalik 9546	4.7	1.4	1.2	.54	400	L	130	650	3.2	L	17	110	50	37	L	L	59	26	20	L	150	210	37	70	270	26	9.2	1.3	2.7	.09	L	21	16.3	4.82	

Table 1-A. Analyses of core samples from the Torok Formation.

	Fe %	Mg %	Ca %	Ti %	Mn ppm	Ag ppm	B ppm	Ba ppm	Be ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	La ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Sc ppm	Sn ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm	Si %	Al %	Na %	K %	P %	Ce ppm	Ga ppm	Th ppm	U ppm
G	10		10					5000														1000				40				.45				
L					200	1	10		1	2				20	10	25		10	10	10				50		10		.15		.02	100	10		
Oumalik 9832	4.8	1.1	.63	.61	330	L	150	680	3.3	L	17	130	48	41	L	L	54	21	20	L	140	240	35	75	260	26	9.2	1.3	3.1	.09	L	25	18.2	4.03
Oumalik 10018	4.5	1.1	.79	.50	400	L	120	580	3.2	L	13	100	38	38	L	L	42	22	17	L	140	180	36	79	270	29	8.4	1.6	2.6	.10	L	18	15.7	3.71
Oumalik 10240	5.0	1.1	.74	.57	410	L	160	730	4.1	22	19	120	48	52	L	L	65	33	22	L	200	370	41	110	300	26	9.5	1.5	3.2	.10	100	24	22.4	5.80
Oumalik 10453	3.3	1.2	1.5	.41	380	L	100	570	2.5	L	13	85	43	31	L	L	39	20	14	L	140	140	34	91	270	29	7.4	1.5	1.9	.08	L	13	13.9	4.15
Oumalik 10680	4.8	.66	.59	.54	520	1.2	190	770	4.7	10	22	180	140	46	L	L	89	25	21	L	220	900	39	560	300	27	9.2	1.2	3.5	.11	L	25	23.4	11.3
Inigok 4214	4.0	1.2	.47	.51	300	L	100	470	2.4	L	15	110	45	33	L	L	48	18	18	L	120	180	30	92	270	28	8.1	1.1	2.3	.10	L	17	15.24	3.85
Inigok 7060	4.7	1.4	.69	.54	330	L	120	650	2.9	L	17	120	51	34	L	L	56	27	19	L	120	230	31	92	230	27	9.0	.97	2.8	.11	L	23	16.14	4.14
Inigok 8843	4.1	1.0	.44	.48	230	2.6	150	840	3.1	70	13	160	250	38	47	L	120	20	24	L	13	G	36	1900	250	25	8.5	.79	2.9	.11	L	23	20.82	23.16
Ikpikpuk 7133	5.1	1.1	.60	.51	440	L	130	660	2.8	L	16	110	52	39	L	L	52	27	21	L	140	200	36	78	250	26	8.8	1.4	2.7	.11	L	19	16.5	3.77
So. Meade 3018	5.5	1.3	.81	.52	550	L	97	500	3.0	L	16	120	39	42	L	L	56	27	22	L	130	210	34	78	260	28	9.3	1.4	2.8	.11	L	22	16.3	3.42
So. Meade 4010	4.9	1.4	.92	.46	510	L	86	430	2.5	L	15	97	42	27	L	L	50	19	17	L	140	150	29	88	230	28	8.0	1.1	2.0	.12	L	17	13.76	3.67
So. Meade 4954	5.2	1.2	.57	.52	520	L	100	490	2.9	L	17	110	42	32	L	L	52	23	18	L	150	170	31	95	240	29	8.8	1.2	2.5	.12	L	19	14.62	3.38
So. Meade 5994	3.4	1.1	1.2	.38	360	L	63	380	1.9	L	11	79	29	20	L	L	38	L	12	L	130	96	24	86	280	30	6.4	1.2	1.5	.09	L	L	10.61	3.17
Peard 4284	4.8	1.3	.81	.47	440	L	97	470	2.8	L	16	100	46	30	L	L	51	21	17	L	140	160	32	100	240	27	8.6	1.1	2.3	.14	L	20	16.32	4.00
Peard 5411	4.7	1.5	1.3	.46	600	L	92	480	3.1	L	15	96	43	28	L	L	46	23	16	L	160	140	31	100	250	28	8.4	1.3	2.2	.12	L	19	14.26	3.80
Peard 5911	4.7	1.2	.72	.53	490	L	120	560	2.8	L	18	110	47	32	L	L	51	25	18	L	150	170	32	94	240	28	9.4	1.3	2.5	.14	L	21	14.52	3.77
Peard 6122	4.7	1.1	.68	.47	570	L	120	550	2.5	L	16	98	38	29	L	L	50	23	16	L	160	140	27	94	250	29	8.2	1.4	2.4	.10	L	19	14.78	3.55
Tunalik 6504	5.4	1.1	.56	.50	750	L	90	580	3.2	L	17	110	43	41	L	L	50	26	20	L	150	180	35	73	250	25	9.4	1.2	2.8	.10	L	21	17.0	3.73
Tunalik 7879	4.3	.92	.73	.44	480	L	76	400	2.1	L	16	93	36	22	L	L	48	34	15	L	150	150	29	96	220	28	7.6	1.2	2.0	.12	L	14	13.80	3.38
Tunalik 8782	4.4	.92	.80	.41	470	L	73	410	2.1	L	18	89	35	23	L	L	49	36	13	L	150	140	28	88	210	30	7.5	1.4	2.0	.12	L	16	12.58	3.28
Dalton 4686	4.2	.96	.77	.42	410	L	70	460	2.1	L	14	88	39	23	L	L	49	20	14	L	96	120	29	84	260	29	6.9	1.3	1.7	.09	L	13	14.1	3.26
Dalton 5623	4.5	1.0	.54	.48	300	L	90	530	2.5	L	14	100	41	32	L	L	48	19	18	L	110	170	33	79	240	28	8.3	1.3	2.2	.10	L	16	14.5	3.44
Dalton 6586	5.2	1.3	.66	.51	360	L	100	540	2.7	L	15	110	44	36	L	L	53	21	21	L	120	210	34	75	260	28	9.0	1.3	2.7	.10	L	18	13.8	3.60
Drew Pt. 5532.5	4.8	1.1	.89	.48	470	L	100	550	2.5	L	13	95	40	33	L	L	46	23	18	L	110	160	35	75	260	28	8.4	1.3	2.0	.12	L	18	17.2	3.37
Drew Pt. 5910	4.5	1.4	1.6	.44	370	L	95	500	2.2	L	14	95	40	28	L	L	50	24	18	L	120	160	31	100	220	26	8.0	1.2	2.0	.11	L	17	16.3	3.55
W. Dease 1909.5	4.6	1.1	.79	.75	510	L	82	450	2.4	L	14	89	36	30	L	L	44	20	16	L	120	140	33	72	260	28	7.8	1.4	1.8	.10	L	15	14.3	3.22

Torok Fm.

Table 2. Analyses of core samples from the "pebble shale".

	Fe %	Mg %	Ca %	Ti %	Mn ppm	Ag ppm	B ppm	Ba ppm	Be ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	La ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Sc ppm	Sn ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm	Si %	Al %	Na %	K %	P %	Ce ppm	Ga ppm	Th ppm	U ppm
G	10		10					5000														1000				40				.45				
L					200	1	10		1	2				20	10	25		10	10	10				50		10		.15		.02	100	10		
Walakpa 1 1840	4.7	1.1	.36	.54	270	L	230	560	3.2	L	13	140	53	43	L	L	54	25	21	L	190	300	30	100	260	29	8.8	.95	3.0	.10	L	25	15.66	4.20
Wakakpa 1 1982	6.1	1.3	.53	.55	340	L	240	560	3.4	L	15	150	63	41	L	L	62	32	23	L	200	330	30	110	260	28	9.5	1.1	3.1	.10	L	28	14.78	3.96
Barrow 2 1951	3.5	.86	.26	.47	L	L	160	550	2.3	L	11	98	36	35	L	L	42	21	15	L	130	180	29	98	290	32	7.7	.89	2.2	.07	L	19	13.22	4.27
Barrow 2 2014	4.3	.98	.40	.49	250	L	160	560	2.3	L	13	110	35	31	L	L	43	23	16	L	130	190	30	100	270	28	7.8	.99	2.3	.11	L	19	13.16	3.53
Barrow 2 2052	5.2	1.1	.34	.51	310	L	190	580	2.6	L	15	120	42	36	L	L	66	22	19	L	130	240	27	110	280	28	7.9	.87	2.6	.08	L	20	12.26	3.35
Barrow 2 2214	4.3	1.1	.32	.55	260	L	220	740	2.8	L	15	120	51	38	L	L	52	21	20	L	150	250	27	110	290	31	8.3	.77	2.8	.07	L	23	15.38	4.35
Barrow 2 2321	2.3	.55	.09	.39	L	1.4	230	680	2.5	L	14	93	30	33	L	L	44	18	13	L	96	170	20	76	250	33	6.9	.37	1.9	.04	L	18	13.82	4.44
Barrow 18 1374.5	5.5	1.4	.65	.51	340	L	200	650	3.2	L	19	100	52	41	L	L	60	24	21	L	150	230	34	150	190	26	9.5	1.4	2.4	.12	L	19	X	X
Barrow 18 1388.5	5.7	1.3	.63	.54	320	L	210	610	3.0	L	21	93	49	39	L	L	64	25	21	L	140	220	36	130	180	26	9.9	1.3	2.4	.12	L	19	X	X
Barrow 19 1359	8.7	.88	.61	.39	210	L	180	480	2.9	4.1	42	96	99	39	37	L	130	26	24	L	130	550	40	180	260	22	7.7	1.1	2.2	.14	L	16	21.3	20.2
Tunalik 10671	4.3	1.2	.89	.51	290	1.9	200	660	3.1	L	13	170	80	56	L	L	64	32	22	L	210	560	38	130	270	25	8.9	.78	2.9	.12	120	25	17.00	8.56
Tunalik 10701	G	.98	.76	.39	380	L	H	700	2.8	L	19	92	71	54	L	L	100	26	19	L	210	350	29	H	240	22	7.7	.50	2.9	.07	H	20	16.76	3.30
Kugrua 7198	8.0	.98	.55	.29	370	L	260	520	3.3	L	19	87	36	34	L	L	46	14	21	L	140	210	33	88	250	23	6.2	.42	2.1	.08	L	13	14.9	4.26
Peard 6411	5.5	.86	.38	.46	260	L	240	570	3.0	L	16	97	44	48	L	L	56	25	18	L	160	240	30	100	260	25	9.0	.50	2.5	.06	L	22	16.24	3.87
Ikpikpuk 7372	4.1	.98	.33	.54	260	1.2	230	700	3.0	L	12	130	58	47	L	L	52	21	19	L	190	330	26	110	240	28	9.3	.62	2.9	.07	110	26	18.48	6.14
N.Kalikpuk 7032	3.8	1.0	.34	.46	230	2.6	190	840	3.5	L	14	220	110	32	20	L	85	20	24	L	160	590	37	180	240	26	9.4	.67	2.4	.09	L	26	19.6	8.87
N.Kalik 7037.2	G	.22	.21	.05	510	H	H	1300	1.9	L	16	20	33	21	H	H	18	16	L	H	100	80	32	H	44	6.7	4.8	.46	.53	.04	H	H	X	X
N.Kalik 7062.5	7.5	1.2	.57	.48	270	L	220	900	3.2	L	14	97	61	60	L	L	52	30	17	L	190	210	43	170	210	25	9.7	.46	2.2	.08	120	21	X	X
N.Kalik 7139	3.8	.65	.75	.38	290	L	160	580	2.2	L	13	98	25	21	L	L	39	11	11	L	110	110	26	88	400	32	6.4	.35	1.6	.07	L	14	13.5	3.58
Oumalik 11000	3.5	.65	.58	.40	360	L	150	460	1.8	L	11	80	15	31	L	L	36	16	11	L	190	100	21	59	300	34	6.0	.46	1.9	.06	L	10	10.52	2.93
W. Dease 2945	4.0	.98	.32	.51	220	L	160	510	4.1	L	10	120	46	48	L	L	45	20	17	L	170	230	30	80	340	31	7.7	.69	2.5	.10	L	21	14.98	4.10
W. Dease 2976	4.0	.89	.36	.46	250	L	170	500	2.5	L	8.8	90	41	39	L	L	35	20	15	L	170	190	27	81	330	29	7.0	.60	2.5	.08	L	17	14.16	4.68
Simpson 1 5467	4.8	1.1	.65	.45	240	L	150	540	2.4	3.6	18	120	75	34	28	L	100	26	20	L	200	410	27	300	240	27	7.8	.71	2.5	.07	L	20	15.76	9.17

pebble shale unit

GRZ

Table 3. Analyses of core samples from the Okpikruak Formation and the Cretaceous and Jurassic parts of the Kingak Shale.

	Fe %	Mg %	Ca %	Ti %	Mn ppm	Ag ppm	B ppm	Ba ppm	Be ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	La ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Sc ppm	Sn ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm	Si %	Al %	Na %	K %	P %	Ce ppm	Ga ppm	Th ppm	U ppm	
G	10		10					5000														1000				40				.45					
L					200	1	10		1	2				20	10	25		10	10	10				50		10		.15		.02	100	10			
Lisburne 1554	4.2	1.6	.59	.46	500	L	66	510	1.7	L	16	130	100	20	L	L	53	16	15	L	120	150	23	150	240	31	6.6	1.6	1.7	.07	L	11	10.15	2.82	Okpik-ruak Fm.
Lisburne 2991.5	6.5	2.5	.37	.54	630	L	98	780	2.0	L	20	110	87	21	L	L	60	15	23	L	140	240	27	120	220	27	7.8	1.5	2.6	.10	L	20	10.92	3.34	
Lisburne 5341	3.7	2.8	4.3	.32	1000	L	90	710	2.3	L	12	73	25	35	L	L	33	23	14	L	220	83	28	120	260	26	7.6	1.2	2.2	.10	L	15	15.18	3.15	
Lisburne 6219	5.6	1.5	.29	.40	1200	L	76	1000	1.8	L	16	85	65	L	L	L	61	25	16	L	110	160	25	110	240	28	7.1	1.1	1.9	.07	L	17	11.46	2.64	
Seabee 13220	3.1	.48	.18	.48	320	L	160	540	1.9	L	11	88	20	43	L	L	33	16	11	L	160	110	28	69	390	33	6.9	.59	1.8	.06	L	15	12.08	3.07	Kingak Sh. (Cret.)
Seabee 14596	5.3	1.0	.68	.44	530	L	180	390	2.5	L	13	96	28	41	L	L	42	19	16	L	190	150	27	77	300	27	7.5	.42	2.1	.09	L	18	14.02	3.17	
Inigok 9348	2.8	.72	.43	.46	330	L	160	450	2.6	L	14	120	22	49	L	L	33	10	14	L	180	130	27	83	330	30	7.4	.46	2.0	.08	120	19	17.0	3.34	
Inigok 9451	3.3	.61	.33	.41	390	L	160	380	2.5	L	18	100	26	46	L	L	40	16	13	L	140	120	28	75	390	31	6.7	.43	1.9	.07	130	17	14.1	3.19	
Tunalik 11685	2.4	.54	.29	.46	250	1.5	190	430	2.3	L	11	92	22	39	L	L	35	L	11	L	160	160	20	60	310	32	6.7	.44	2.4	.06	L	15	13.86	2.88	
Tunalik 12573	2.9	.50	.31	.44	240	L	170	330	2.0	L	8.9	84	17	37	L	L	28	L	10	L	140	110	25	52	360	36	6.1	.46	1.8	.06	L	12	11.11	2.99	
Tunalik 12593	2.8	.48	.28	.60	210	L	190	780	1.9	L	11	110	20	44	L	L	35	21	11	L	150	140	32	67	490	35	7.2	.45	1.8	.06	L	14	15.88	3.93	
Topagoruk 7052	4.4	1.0	.36	.51	260	L	210	530	2.7	L	16	110	33	44	L	L	56	18	16	L	190	180	25	93	250	27	9.0	.46	2.9	.10	L	24	16.62	3.73	
Ikpikpuk 7499	3.7	.71	.50	.45	440	L	150	440	2.2	L	8.6	86	20	48	L	L	25	L	13	L	200	150	25	86	420	28	6.6	.40	2.0	.07	110	15	14.26	3.31	
Inigok 11005	3.2	1.0	.99	.49	260	L	160	520	2.6	L	13	120	24	34	L	L	42	L	15	L	130	170	30	120	290	30	7.3	.42	2.0	.11	L	18	13.7	3.34	Kingak Shale (Jurassic)
Inigok 11704	3.9	.89	1.2	.48	230	L	170	960	2.8	L	22	120	37	39	L	L	62	37	16	L	150	160	33	110	310	29	7.8	.43	1.9	.15	L	18	12.4	3.80	
N. Kalik 7186	2.1	.64	.85	.38	L	L	140	560	1.9	L	8.9	95	17	23	L	L	30	12	10	L	100	95	27	75	390	35	5.8	.34	1.4	.07	L	11	11.1	3.73	
N. Kalik 7226	2.4	.77	.68	.48	L	L	190	800	3.0	L	14	110	25	28	L	L	43	12	15	L	140	140	26	97	290	29	8.4	.40	2.0	.10	L	19	13.2	3.63	
N. Kalik 7394	2.9	.78	.98	.46	210	L	170	710	2.7	L	12	120	25	28	L	L	40	17	13	L	140	140	29	88	300	32	8.0	.42	1.8	.11	L	17	13.4	3.41	
Topagoruk 8105	6.0	.98	.64	.47	240	L	270	460	3.6	L	23	140	26	32	L	L	60	18	16	L	140	110	33	120	300	29	8.8	.41	2.8	.12	L	20	15.1	3.45	
Topagoruk 8630	2.4	.59	.54	.38	L	L	150	550	2.3	L	7.5	130	21	26	L	L	33	L	12	L	140	120	34	75	350	34	5.6	.36	1.6	.09	L	11	12.7	3.82	
S. Meade 8497	2.4	.74	.78	.39	L	L	130	450	4.5	L	6.5	150	14	21	L	L	25	L	11	L	120	110	36	89	390	36	5.6	.40	1.7	.11	L	13	11.8	3.67	
Walakpa 1 2112	3.6	1.1	.66	.43	240	1.0	250	460	2.5	L	10	84	35	37	L	L	40	19	14	L	170	140	29	95	340	32	7.0	.69	2.6	.07	L	16	12.96	3.06	
Walakpa 1 2935	2.8	.81	.30	.47	200	L	240	450	3.0	L	14	140	24	35	L	L	41	13	15	L	150	150	28	99	270	30	7.9	.47	2.1	.06	L	19	17.5	3.47	
Barrow 12 2170	3.0	.67	.37	.51	L	L	280	1100	3.1	L	17	150	38	37	L	L	61	20	17	L	110	230	27	110	290	30	8.3	.42	2.1	.06	L	21	16.3	4.05	
Barrow 12 2197	2.7	.67	.50	.50	L	L	280	1200	3.3	L	14	160	33	37	L	L	49	18	18	L	120	250	28	110	290	31	8.1	.41	2.0	.06	L	20	13.9	3.86	
W. Dease 3796	2.0	.79	.48	.48	L	L	230	700	2.9	L	83	140	39	33	L	L	79	50	15	L	150	170	28	94	290	29	7.6	.33	2.2	.07	L	17	16.3	4.01	
Simpson 1 5679	2.0	.62	.60	.35	L	L	160	380	1.7	L	8.9	97	15	24	L	L	30	L	L	L	100	71	25	68	430	32	5.1	.31	1.8	.06	L	L	12.9	3.54	
Simpson 1 5866	2.7	.79	.47	.44	L	L	170	470	2.6	L	11	120	22	29	L	L	36	10	13	L	140	110	32	86	360	36	6.8	.40	2.0	.07	L	16	13.7	3.58	
Simpson 1 6070	2.7	.60	.30	.47	L	L	180	550	2.7	L	8.9	140	27	28	L	L	36	L	14	L	140	150	32	83	320	31	6.8	.34	1.9	.06	L	14	13.9	4.02	
Drew Pt. 6906	2.7	.81	.62	.53	270	L	230	890	2.8	L	16	140	39	42	L	L	45	17	18	L	180	190	32	79	300	28	9.2	.38	2.1	.07	L	23	18.3	3.27	
Drew Pt. 6919	2.8	.92	.47	.54	270	L	240	920	3.3	L	17	150	44	45	14	L	52	23	19	L	210	200	33	110	260	27	9.6	.45	2.6	.08	L	27	18.7	4.17	
Drew Pt. 6937.5	2.6	.87	.41	.57	260	L	290	980	3.2	L	19	160	53	52	L	L	69	49	17	L	220	220	30	78	260	26	9.8	.43	3.0	.08	L	29	25.8	5.39	
Drew Pt. 6952	3.5	.74	.25	.62	L	L	250	880	2.4	L	13	150	37	34	L	L	46	21	19	L	210	190	32	68	290	26	9.9	.46	2.8	.07	L	27	17.4	3.87	

Table 4. Analyses of core samples from the Shublik, Sag River and Otuk Formations, and the Sadlerochit Group.

	Fe %	Mg %	Ca %	Ti %	Mn ppm	Ag ppm	B ppm	Ba ppm	Be ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	La ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Sc ppm	Sn ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm	Si %	Al %	Na %	K %	P %	Ce ppm	Ga ppm	P_2O_5 %	Th ppm	U ppm	
G	10		10					5000														1000				40				.45						
L					200	1	10		1	2				20	10	25		10	10	10				50		10		.15		.02	100	10				
Lisburne 11164	3.3	1.5	G	.18	220	H	55	3000	1.6	L	12	600	260	H	H	H	170	H	23	L	360	390	49	H	230	21	4.1	.62	1.5	.06	L	L	.15	5.61	10.38	Shublik, Sag River and Otuk Fms.
Inigok 12273	5.6	1.1	4.7	.37	240	L	230	1300	2.6	L	19	140	79	35	52	L	210	21	18	12	280	410	17	95	250	27	7.3	.42	3.2	.02	L	20	.03	13.48	5.54	
S. Meade 8862	2.0	.64	.97	.29	L	L	96	510	4.7	L	7.2	160	13	34	L	L	25	L	L	L	160	110	22	69	360	L	3.4	.51	1.2	.15	L	L	.31	8.79	3.70	
S. Meade 9055	2.7	.80	1.8	.48	L	L	150	650	2.0	L	9.9	170	34	37	L	L	48	14	14	L	180	210	17	100	330	33	5.9	.62	2.3	.02	L	13	.04	12.96	4.78	
Ikpikpuk 10280	3.2	1.5	G	.32	L	H	150	470	2.3	L	11	180	86	H	H	H	260	H	16	L	340	670	20	H	240	25	6.4	.60	2.0	.05	L	14	.15	11.70	8.40	
Ikpikpuk 10299	1.1	.86	G	.26	L	H	60	270	2.3	L	7.3	130	14	H	L	H	27	L	11	L	360	73	46	H	490	31	3.2	.53	.98	G	H	L	1.42	12.56	9.62	ls.
Drew Pt. 7097	2.9	.73	5.8	.44	L	L	170	830	1.6	L	9.7	130	32	37	L	L	52	14	15	L	370	180	30	120	340	26	6.9	.46	1.8	.09	L	11	.19	12.32	4.38	
Drew Pt. 7360.5	2.7	.66	2.0	.45	L	L	150	530	1.6	L	9.4	140	30	27	L	L	42	15	13	L	200	130	28	120	280	32	6.4	.50	1.4	.02	L	L	.06	11.64	3.57	
Drew Pt. 7559	2.6	.69	1.1	.57	L	L	270	520	3.0	L	9.6	240	54	46	L	L	81	19	16	L	150	190	39	140	420	28	8.5	.40	2.0	.29	L	16	.57	19.54	6.16	
Drew Pt. 7572	2.5	.71	G	.13	L	L	54	480	1.2	L	7.0	51	8.1	H	L	H	40	H	11	L	790	55	43	H	430	28	2.3	L	.55	G	120	L	9.97	8.13	5.03	ls.
Drew Pt. 7572.5	3.5	.66	1.1	.47	L	L	220	440	2.5	L	10	130	31	41	L	L	48	21	15	L	160	160	33	120	300	30	7.0	.39	2.3	.24	L	16	.66	15.68	4.60	
E.Simpson 1 6865	4.8	1.1	.41	.60	270	L	300	710	4.9	L	11	150	45	37	L	L	41	41	19	L	180	180	36	96	290	28	9.4	.47	3.5	.08	L	27		18.8	4.49	limestone
Simpson 1 6240	L	1.1	.64	.30	230	L	H	190	3.5	L	18	450	15	L	L	H	56	39	15	L	60	470	27	H	430	30	4.2	.27	1.2	.02	L	L	.05	16.94	2.64	
Simpson 1 6310	2.5	.41	8.1	.31	L	L	100	360	L	L	7.5	88	15	27	L	L	25	11	L	L	370	86	28	88	350	30	4.0	.27	.97	.04	L	L	.10	8.16	3.58	
Simpson 1 6350	2.7	.54	3.5	.42	L	L	170	500	1.3	L	8.9	120	30	29	L	L	43	19	12	L	240	160	29	110	350	31	6.3	.35	1.7	L	L	L	.04	12.0	4.47	
W. Dease 3923	5.0	.82	.23	.51	L	L	290	880	3.5	L	9.1	130	46	44	L	L	31	29	17	L	140	290	29	88	320	24	8.5	.36	2.7	.04	L	20	.05	23.18	5.90	
W. Dease 3984	4.9	.86	.30	.54	L	L	220	730	2.1	L	11	120	48	37	L	L	38	23	17	L	150	210	30	95	390	31	7.5	.30	2.6	.05	L	16	.08	17.88	5.29	
W. Dease 3997.5	4.5	.61	.80	.42	L	L	140	550	1.9	L	9.2	110	28	28	L	L	47	18	12	L	110	160	30	99	480	34	5.0	.32	1.4	L	L	L	.03	12.60	4.39	
Inigok 13508	3.7	.99	.16	.54	300	L	130	980	3.4	L	18	160	47	38	L	L	61	L	21	L	180	230	28	100	240	30	9.4	.52	3.0	.09	L	27		16.4	4.28	Sadlerochit Gp (Trias)
Tunalik 14855	3.5	.87	1.5	.40	L	L	160	610	2.4	L	9.8	160	35	44	L	L	61	23	13	L	150	190	15	120	380	33	5.4	.68	2.3	.14	L	12	.30	14.94	8.05	
Tunalik 15408	2.4	.75	.56	.45	L	L	130	560	2.5	L	9.1	120	23	32	L	L	34	L	14	L	140	110	33	68	340	33	6.4	.68	2.0	.12	L	14		15.1	3.78	
Tunalik 15425	3.3	.97	.65	.55	240	L	150	690	3.4	L	14	140	30	37	L	L	52	L	18	L	170	140	34	78	280	31	8.5	.71	2.7	.14	L	22		16.4	4.02	
Tunalik 16244	3.2	1.0	.44	.51	270	L	150	750	3.4	L	17	140	32	33	L	L	53	13	18	L	160	160	29	89	250	30	8.3	.61	2.7	.09	L	23		18.5	3.92	
Peard 8995	4.9	1.0	.41	.55	290	L	200	630	3.8	L	17	140	38	34	L	L	61	15	20	L	270	200	33	72	330	29	8.8	.60	3.0	.15	L	20		18.6	4.30	
Kugrua 10486	6.4	1.4	.44	.67	1600	L	210	1000	4.2	L	25	190	53	40	L	L	70	25	25	L	220	280	28	94	320	23	11	.53	3.8	.10	L	32		23.4	4.83	
Drew Pt. 7613	1.4	.38	.36	.49	L	1.7	160	930	3.4	L	5.4	110	94	37	L	L	34	13	14	L	220	160	39	72	340	34	6.6	.20	2.0	.16	L	18		19.0	4.27	
Dalton 8081	3.4	.80	.26	.52	L	1.1	150	660	2.6	5.0	13	150	62	29	21	L	68	20	19	L	150	410	31	360	280	26	8.3	.49	2.2	.07	L	23		18.4	8.95	

Table 5. Analyses of core samples from the Etivluk, Lisburne, and Endicott Groups and the Kuna Formation and of cuttings samples from the Etivluk and Lisburne Groups.

Sample	Fe %	Mg %	Ca %	Ti %	Mn ppm	Ag ppm	B ppm	Ba ppm	Be ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	La ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Sc ppm	Sn ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm	Si %	Al %	Na %	K %	P %	Ce ppm	Ga ppm	P_2O_5 %	Th ppm	U ppm	
G	10		10					5000														1000				40				.45						
L					200	1	10		1	2				20	10	25		10	10	10				50		10		.15		.02	100	10				
Lisburne 13605.5	3.3	1.0	.30	.33	L	L	110	G	2.2	L	8.0	130	72	32	L	L	40	18	16	L	200	140	23	140	190	32	6.6	.30	2.9	.02	L	12	.05	10.79	1.95	Etvlk. Gp.
Lisburne 15329	3.2	.95	.63	.46	430	L	130	770	2.5	L	15	130	26	38	L	L	61	16	20	L	110	180	26	160	210	25	8.3	.39	2.6	.06	L	15	.16	16.74	3.28	Kuna Fm.
Lisburne 7320-30	4.3	1.0	1.9	.27	2000	L	100	G	2.3	L	14	88	74	24	L	L	63	22	17	L	250	160	31	210	190	35	5.8	.59	2.1	.07	L	11	.21	7.30	3.35	Etivluk Gp. cuttings
Lisburne 7360-70	3.7	.96	1.2	.27	1100	L	99	G	2.2	L	14	76	60	26	L	L	64	32	17	L	220	130	27	130	210	38	5.4	.53	2.2	.04	L	11	.12	8.65	2.28	
Lisburne 7380-90	4.1	1.1	1.6	.31	1200	L	110	4600	2.4	L	16	83	57	25	L	L	69	26	17	L	200	150	29	150	240	37	5.8	.71	2.6	.05	L	12	.17	9.92	3.17	
Lisburne 7390-7400	3.8	1.3	6.5	.28	2400	L	96	G	2.1	L	15	8.7	64	31	L	L	60	26	17	L	280	130	40	200	230	35	5.7	.63	2.3	.20	L	12	.62	9.13	6.04	
Lisburne 9610-20	2.2	.64	.74	.18	1700	L	80	G	1.8	L	15	50	60	L	L	L	62	26	13	L	190	71	22	130	150	39	4.0	.28	1.5	.04	L	L	.10	6.04	1.83	
Lisburne 9650-60	5.9	1.1	1.1	.33	G	L	160	G	3.0	L	51	85	140	43	L	L	230	H	22	L	260	150	36	260	300	33	6.8	.55	2.7	.06	L	15	.16	12.02	2.71	
Lisburne 11490-500	2.3	.74	1.2	.19	340	L	64	G	1.8	L	15	58	46	17	L	L	46	27	11	L	190	77	22	110	150	G	4.0	.29	1.6	.03	L	L	.06	5.73	1.69	
Lisburne 9660-70	3.8	1.7	4.5	.23	2500	L	98	G	1.9	L	31	87	69	38	L	L	83	190	14	L	260	100	52	630	240	31	4.6	.38	1.2	G	L	L	1.14	10.32	13.18	mixed cuttings
Lisburne 11540-60	1.9	2.6	7.1	.19	1100	L	56	4200	1.3	L	19	66	59	33	L	L	50	89	10	L	190	93	33	620	200	34	3.7	.26	1.4	.11	L	L	.29	6.92	5.10	
Lisburne 7400-10	2.8	1.3	G	.22	1600	L	54	4200	1.4	L	13	72	41	H	L	H	49	H	14	L	210	120	30	H	190	31	4.2	.47	1.8	.08	H	L	.31	7.80	4.94	Lisburne Gp. cuttings
Lisburne 7420-30	1.6	1.3	G	.10	640	L	L	3100	L	L	9.7	59	25	H	L	H	37	H	L	L	180	69	42	H	140	21	2.1	.30	.73	.40	L	L	1.07	5.11	8.95	
Lisburne 7450-60	1.8	2.6	G	.13	1000	L	12	3500	L	L	12	49	25	H	L	H	37	H	L	L	140	70	31	H	130	25	2.9	.33	.75	.16	L	L	.44	4.54	4.57	
Lisburne 7500-10	1.3	4.0	G	.07	660	L	L	1600	L	L	9.6	38	18	H	L	H	30	H	L	L	95	62	22	H	95	19	1.6	.28	.44	.05	H	L	.18	2.88	3.26	
Lisburne 9670-80	2.1	1.7	G	.07	1400	L	L	4500	L	L	22	37	35	H	H	L	59	H	L	L	200	53	50	H	120	16	1.7	.18	.49	.30	H	L	.72	6.76	15.45	
Lisburne 9700-10	1.1	4.2	G	.05	1700	L	L	3200	L	L	13	31	24	H	L	H	55	H	L	L	140	49	25	H	91	19	1.3	L	.29	.05	H	L	.15	3.53	7.72	
Lisburne 9770-80	2.0	1.1	G	.11	3400	L	39	G	L	L	19	38	79	H	H	H	74	H	13	L	230	63	35	H	150	16	2.9	.25	.86	.08	H	L	.24	6.24	3.51	
Lisburne 16319.5	.58	9.0	G	.03	390	H	L	150	L	L	6.6	29	6.4	H	L	H	35	H	L	L	210	32	18	H	59	L	.79	L	.59	L	H	L	.08	1.29	3.15	Lisburne limestone
Lisburne 16861	2.2	.92	G	.12	L	L	44	180	L	L	7.8	87	25	H	L	H	73	H	L	L	240	84	19	H	81	31	3.4	.15	1.3	.04	L	L	.13	4.52	6.17	
Lisburne 16984	.87	3.1	G	.09	L	H	L	140	L	L	5.8	68	19	H	L	H	56	L	L	L	520	58	13	H	71	24	2.4	L	.85	.02	L	L	.08	3.33	5.95	
Inigok 14032	2.9	1.5	3.7	.42	220	L	120	540	1.9	L	13	93	24	37	L	L	43	18	15	L	190	130	24	130	240	30	6.6	.63	2.4	.04	L	10	.09	11.03	3.74	
Inigok 15199	2.1	1.7	3.2	.39	L	L	140	700	1.8	L	12	99	24	28	L	25	71	16	13	L	580	140	16	110	220	30	6.4	.29	2.2	L	L	10	.05	11.98	5.35	
Inigok 20092	.40	.31	.07	.68	L	1.5	130	1400	3.9	L	13	180	47	76	L	L	52	L	20	L	130	290	37	L	470	27	9.5	.28	2.9	.06	180	45		32.8	9.95	Endicott Gp.
E. Simp 2 7202	.85	.36	.07	.60	L	L	130	580	2.2	L	9.2	150	35	51	L	L	38	L	17	L	120	170	22	90	220	30	9.5	.31	1.7	.05	100	26		18.4	5.08	
E. Simp 2 7212	.76	.35	.07	.61	L	1.7	150	1600	2.5	L	9.2	180	74	56	L	L	46	23	22	L	170	320	31	180	260	26	10	.38	1.6	.06	110	33		22.3	9.72	
E. Simp 2 7268	.73	.38	.06	.74	L	1.5	150	1400	3.9	L	12	210	42	68	L	L	45	13	20	L	160	260	36	120	360	31	9.7	.24	2.2	.06	180	32		21.5	8.56	
E. Simp 2 7297	.68	.37	.07	.60	L	1.4	150	2100	3.4	L	5.6	160	40	52	L	L	33	13	17	L	150	300	28	96	270	31	9.1	.33	1.9	.05	110	23		21.0	5.54	

Element and world wide average concentration in shale		Cu 42 (med.)	Pb 25 (med.)	Zn 100 (med.)	Co 19	Ni 68	Sc 12?	Ga 20	Be 3	V 130	Cr 90	B 100	La 39	Y 35	P 0.07	Th 12	U 3.7 (med.)	Ba 550	Sr 300	Zr 160
Stratigraphic Unit	Number of samples	in ppm													in %	in ppm				
Colville Gp.	6	45 +7%	24 (4%)	77 (23%)	12 (37%)	44 (35%)	17 +42%	21 +5%	2.7 (10%)	125 (4%)	85 (6%)	55 (45%)	32 (18%)	32 (9%)	.09 +29%	15.6 +30%	4.5 +22%	650 +18%	140 (53%)	260 +63%
Nanushuk Gp.	8	45 +7%	23 (8%)	97 (3%)	18 (5%)	63 (7%)	22 +83%	22 +10%	2.6 (13%)	185 +42%	125 +39%	72 (28%)	34 (13%)	34 (3%)	.09 +29%	13.8 +15%	3.8 +3%	660 +20%	110 (63%)	255 +59%
Torok and Ftrss. Mtn. Fms.	38	42 0%	24 (4%)	89 (11%)	15 (21%)	50 (26%)	19 +58%	19 +5%	2.7 (10%)	175 +35%	105 +17%	110 +10%	33 (15%)	33 (6%)	.10 +43%	14.7 +23%	3.7 0%	525 (5%)	140 (53%)	250 +56%
Pebble shale	23	49 +17%	22 (12%)	110 +10%	14 (26%)	52 (24%)	19 +58%	23 +15%	2.9 (3%)	230 +77%	98 +9%	200 +100%	39 0%	30 (14%)	.08 +14%	15 +25%	4.3 +16%	580 +5%	160 (47%)	260 +63%
Okpikruak Fm.	4	76 +81%	20 (20%)	120 +20%	16 (16%)	58 (15%)	16 +33%	16 (20%)	1.9 (37%)	155 +19%	98 +9%	83 (17%)	21 (46%)	26 (26%)	.09 +29%	11.2 (7%)	3 (19%)	745 +35%	130 (57%)	240 +50%
Cretaceous Kingak shale	9	22 (48%)	16 (36%)	75 (25%)	11 (42%)	35 (49%)	13 +8%	15 (25%)	2.5 (17%)	140 +8%	96 +7%	170 +70%	44 +13%	27 (23%)	.07 0%	14.1 +18%	3.2 (14%)	440 (20%)	110 (63%)	360 +125%
Jurassic Kingak shale	20	27 (36%)	17 (32%)	92 (8%)	13 (32%)	43 (37%)	15 +25%	18 (10%)	2.8 (7%)	150 +15%	140 +56%	210 +110%	34 (13%)	30 (14%)	.07 0%	13.8 +15%	3.7 0%	630 +15%	140 (53%)	300 +88%
Shublik, Otuk and Sag River Fms.	18	32 (24%)	19 (24%)	99 (1%)	9.7 (49%)	45 (34%)	15 +25%	L(10) (50%)	2.2 (27%)	180 +39%	135 +50%	150 +50%	33 (15%)	30 (14%)	.05 (29%)	12.6 +5%	4.7 +27%	525 (5%)	190 (37%)	345 +116%
Sadlerochit Gp.	9	38 (10%)	13 (48%)	89 (11%)	13 (32%)	61 (10%)	18 +60%	20 0%	3.4 +13%	190 +46%	140 +56%	150 +50%	37 (5%)	31 (11%)	.12 +71%	18.4 +53%	4.3 +16%	690 +25%	170 (43%)	320 +100%
Lisburne Gp.	5	24 (43%)	16 (36%)	120 +20%	7.8 (59%)	56 (18%)	L(10) (17%)	L(10) (50%)	L(1) (67%)	84 (35%)	77 (14%)	44 (56%)	33 (15%)	18 (49%)	.02 (71%)	4.5 (63%)	5.4 +46%	180 (67%)	240 (20%)	80 (50%)
Endicott Gp.	5	42 0%	13 (48%)	96 (4%)	9.2 (52%)	45 (34%)	20 +67%	32 +60%	3.4 +13%	290 +123%	180 +100%	150 +50%	56 +44%	31 (11%)	.06 (14%)	21 +75%	8.6 +132%	1400 +155%	150 (50%)	270 +69%
All units	145	39 (7%)	21 (16%)	94 (6%)	14 (26%)	50 (26%)	17 +42%	19 (5%)	2.6 (13%)	170 +31%	110 +22%	150 +50%	35 (10%)	31 (11%)	.09 +29%	14.6 +22%	3.8 +3%	570 +4%	150 (50%)	260 +63%

Table 6. Median concentrations of 19 trace elements in each stratigraphic unit and their deviation from the average (or median) concentration in shales expressed as percent of that average concentration. Average for Ga is from Weeks (1973); average for Sc in North American shale is from Norman and Haskin (1968); compare with 13 ppm listed by Turekian (1977). All others are from Rose, Hawkes, and Webb (1979).

Element and median concentration in ppm in the group of 145 samples		Cu 39	Zn 94	Ag L(1)	Cd L(2)	Co 14	Mo L(10)	Ni 50	Sn L(10)	Ga 19	V 170	Cr 110	La 35	Ce L(100)	Th 14.6	U 3.8	Ba 570	Sr 150	Zr 260
	Sample																		
Torok	Oumalik 1 10680	Cu 140	Zn 560	Ag 1.2	Cd 10						V 900					U 11.3			
Fm.	Inigok 1 8843	Cu 250	Zn 1900	Ag 2.6	Cd 70		Mo 47	Ni 120			V G(1000)					U 23.16			
Pebble shale (GRZ)	Barrow 19 1359		Zn 180		Cd 4.1	Co 42	Mo 37	Ni 130			V 550					U 20.2			
Pebble shale	N. Kalikpik 7032	Cu 110	Zn 180	Ag 2.6			Mo 20				V 590	Cr 220							
	Simpson 1 5467		Zn 300		Cd 3.6		Mo 28				V 410								
Otuk Fm.	Lisburne 1 11164	Cu 260						Ni 170				Cr 600				U 10.38	Ba 3000	Sr 360	
Shublik Fm.	Inigok 1 12273						Mo 52	Ni 210	Sn 12		V 410								
Sadleroch. Gp.	Dalton 1 8081		Zn 360	Ag 1.1	Cd 5.0		Mo 21				V 410								
Endicott Gp.	Inigok 1 20092			Ag 1.5						Ga 45			La 76	Ce 180	Th 32.8		Ba 1400		Zr 470
	E. Simpson 2 7268			Ag 1.5								Cr 210	La 68	Ce 180					
Number of anomalies in all 145 samples		5	7	14	6	3	8	5	1	1	10	5	3	2	2	4	4	8	4

Table 7. Concentration in p p m of the anomalous elements in the ten samples that contain most of the trace element anomalies. Anomalies are chosen at the 94th to 99th percentile, except that all values above the lower limit of determination are considered anomalous for Ag, Cd, Mo, and Sn. Note that these samples contain all of the U, Ga, Ce, and Sn anomalies and all but one each of the Cu, Zn, Cd, Ni, La, and Th anomalies.

Brookian Sequence	Colville Gp.	Cu,Co,Cd					P				
	Nanushuk Gp.	Cu,Co,Cd					P				
	Torok & Ftrss. Mtn. Fms.	Cu,Co,Cd					P				
	Okpikruak Fm.	Cu,Zn,Co,Cd					P				
?	Pebble shale	Cu,Zn,Co,Cd	V	V/Ni	B	RE	P		U		
	Cretaceous Kingak Sh.			V/Ni		RE					Zr
Ellesmerian Sequence	Jurassic Kingak Sh.				B						Zr
	Shublik, Sag River and Otuk Fms.			V/Ni			P	Th	U		Zr
	Sadlerochit Gp.		V			RE	P	Th	U		Zr
	Lisburne Gp.										
	Endicott Gp.		V	V/Ni		RE		Th	U	Ba	

Table 8. Stratigraphic units correlated with 14 of the trace elements on the basis of high median concentrations or abundant anomalous concentrations. Correlation of the other trace elements is uncertain. RE is La, Ce, and Y. V/Ni represents highest values for this ratio.