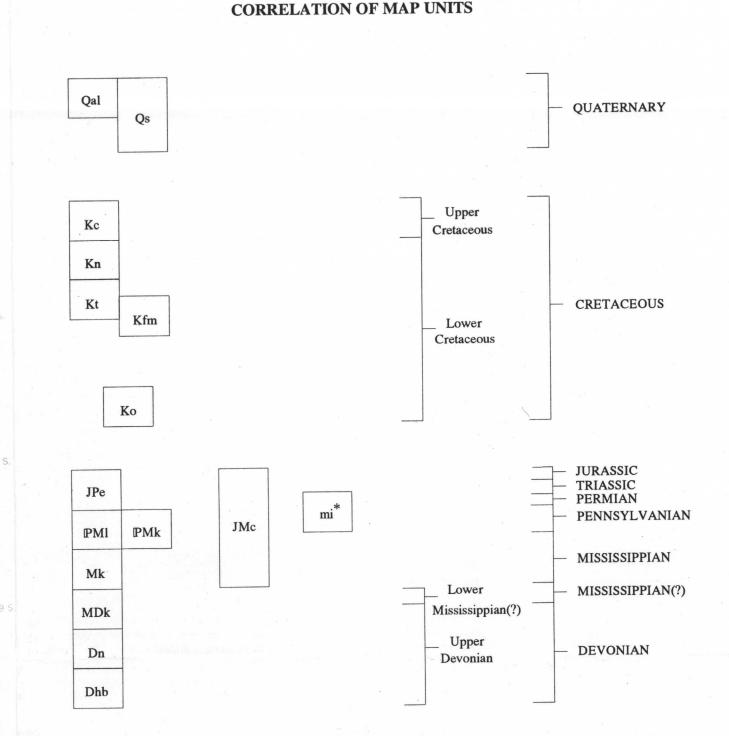
SHEET 1 OF 2

CONTOUR INTERVAL 200 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929 GATES OF THE ARCTIC

MAP B. DISTRIBUTION OF SEDIMENT SAMPLES CONTAINING ANOMALOUS CONCENTRATIONS OF Ag, Ba, Cd, Cu, Pb, AND Zn



(\* See description of map units for specific unit age assignments)

## DESCRIPTION OF MAP UNITS

Active alluvial deposits (Quaternary)--Flood plain deposits, lightly vegetated in some cases; includes sand dunes in Killik and Okokmilaga River valleys Surficial deposits, UNDIVIDED (Quaternary)--Colluvium, older vegetated alluvial deposits, morainal deposits, terrace deposits, lacustrine material, alluvial fans, and other surficial materials not otherwise differentiated; contains some undifferentiated Tertiary terrace

Colville Group (Upper Cretaceous)--Poorly exposed interbedded marine sandstone and shale sandstone and conglomeratic sandstone, interbedded with dark gray shale and coal

Torok Formation (Lower Cretaceous) -- Dark gray to black clay shale and interbedded silty shale; lower part interfingers with Fortress Mountain Formation Fortress Mountain Formation (Lower Cretaceous)--Dominantly greenish gray graywacke interbedded with dark gray mudstone and shale; interfingers with Torok Formation Okpikruak Formation (Lower Cretaceous)--Dominantly greenish gray graywacke with

nterbedded mudstone and shale

Etivluk Group, undivided (Jurassic to Permian)--Black chert, limestone, shale, and orange weathering siltstone, maroon mottled mudstone, and poorly exposed gray shale; consists of the Siksikpuk Formation and Otuk Formation; as mapped, locally includes distinctive overlying Lower Cretaceous coquinoid marker bed Mafic igneous rocks (Triassic? to Pennsylvanian) -- Dark green, fine to coarse grained basalt

Chert, shale, and limestone (Jurassic to Mississippian)--Gray and black pyritic chert, greenish gray chert, silicified shale and mudstone, and limestone; consists of the Imnaitchiak Chert, the Akmalik Chert and other unnamed units of Lisburne Group, and local quartzose sandstone and Kayak Shale at base Lisburne Group, undivided (Pennsylvanian and Mississippian)--Massive, light-gray weathering limestone and dolomite, in places with abundant black chert nodules, lenses,

and beds; as mapped, in many areas includes Kayak Shale at base. Locally, divided into: Kuna Formation (Lower or Middle Pennsylvanian to Upper Mississippian)--Interbedded black chert, sooty limestone, and shale Kayak Shale (Mississippian)--Dark gray to black fissile shale with yellowish brownweathering thin fossiliferous limestone beds near top; lower part contains thin interbeds of gray sandstone; gradational downward into Kanayut Conglomerate Kanayut Conglomerate (Lower Mississippian(?) and Upper Devonian)--Thick section of

gray to brown weathering quartzitic sandstone, quartz- and chert-pebble conglomerate, and shale; dominantly delta plain deposit Noatak Sandstone, Hunt Fork Shale, and Kanayut Conglomerate (part), undivided (Upper Devonian)--Dominantly fine to medium grained sandstone and quartzite with thick interbedded dark gray to brown shale; minor red to brown shale, siltstone, sandstone, and conglomerate; dominantly marine Hunt Fork Shale and Beaucoup Formation, undivided (Upper Devonian)--Dark gray and

olive gray shale, with interbedded quartz-chert wacke, quartzite, sandstone and minor conglomerate in upper part, dominantly phyllitic shale in lower part Contact--Dashed where approximately located; queried where uncertain Thrust fault--Sawteeth on upper plate, dashed where approximately located; dotted where

Fault--Showing relative horizontal movement. Dashed where approximately located; dotted where concealed; queried where uncertain

Minus-100-mesh sediment samples						
	Ba (15,000 to 64,350 ppm)	•	Cu (100 to 114 ppm)			
$\oplus$	Ba (5,000 to 15,000 ppm)		Cu (75 to 100 ppm)			
	Cd (5 to 22 ppm)		Zn (350 to 524 ppm)			
	Pb (30 to 72 ppm)	•	Zn (250 to 350 ppm)			
(-)	Area houndary delineated by sediment san	noles containing anoma	alous concentrations			

**EXPLANATION** 

Area boundary delineated by sediment samples containing anomalous concentrations of one or more elements Minus-100-mesh sediment sample site

## Minus-80-mesh sediment samples

•	Ag + Ba + Cu + Zn (Ag=0.5-3 ppm; Ba>5,000; Cu=100-150 ppm; Zn=300-500 ppm)	
•	Ba + Cu + Pb + Zn (Ba>5,000; Cu=100-150 ppm; Pb=50-70 ppm;Zn=300-500 ppm)	
*	Ba + Cu + Pb (Ba>5,000; Cu=100-150 ppm; Pb=50-70 ppm)	
	Cu + 7n	

(Cu=100-150 ppm; Zn=300-500 ppm)

(Ba>5,000; Cu=100-150 ppm)

CONTOUR INTERVAL 200 FEET NATIONAL GEODETIC VERTICAL DATUM OF 1929

STUDIES RELATED TO AMRAP The U.S. Geological/Survey is required by the Alaska National Interest Lands Conservation Act (ANILCA, Public Law 96-487, 1980) to survey Federal Lands to determine their mineral resource potential. Results from the Alaska Mineral Resource Assessment Program (AMRAP) must be made available to the public and be submitted to the President and the Congress. As part of the AMRAP study of the Killik River quadrangle, a reconnaissance geochemical survey was conducted. This report presents an interpretation of the reconnaissance geochemical data. It is based on data collected during the nationwide Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) survey of the National Uranium Resource Evaluation (NURE) program (Los Alamos National Laboratory, 1982), and during the AMRAP study.

The Killik River quadrangle is located in the central part of the Brooks Range and Arctic Foothills Provinces in northern Alaska (Wahrhaftig, 1965), along the northern flank and foothills of the Endicott Mountains (fig. 1). The southern third of the quadrangle is within the Brooks Range Province, whereas the northern part of the quadrangle is within the Arctic Foothills Province, which consists of the northern and southern foothills areas. The southern part of the quadrangle is characterized by rugged mountainous terrain of the Endicott Mountains with a maximum elevation of 2,236 m (7,335 ft). North of the rangefront in the central and northern parts of the quadrangle, the terrain is predominantly flat and swampy, with some low hills. Braided and meandering rivers drain northward through the quadrangle into the eastward-flowing Colville River, which eventually empties into the Arctic Ocean. The sparse vegetation includes willows, grasses, sedges, mosses, lichens, and flowering plants. Permafrost underlies the entire area. A geochemical investigation of the Killik River quadrangle was conducted by the USGS between 1981 and 1986 as part of the AMRAP program. The purpose of the survey was to define geochemical variations within the quadrangle and locate areas favorable for mineral resources. Minus-30-mesh and minus-80-mesh stream-sediment samples, nonmagnetic heavy-mineral-concentrate samples derived from the stream sediments, and rock samples were collected as part of the AMRAP study. In addition, stream- and lake-sediment data obtained during the National Uranium Resource Evaluation (NURE) program were available and utilized as part of our study (Los Alamos National Laboratory, 1982). This report is one of several reports that graphically present selected geochemical and mineralogical data in map format. In this report, we present our interpretation of minus-100-mesh stream- and lakesediment geochemical data from the NURE program, and minus-80-mesh data from stream-sediment samples collected during the AMRAP study. The area covered is shown on figure 2. Other reports include the geochemistry of minus-30-mesh stream-sediment samples (Kelley and others, 1995a), and the geochemistry and mineralogy of nonmagnetic heavy-mineral-concentrate samples collected from the southern part of the Killik River quadrangle (Kelley and others, 1995b). A discussion comparing the results of stream-sediment and nonmagnetic heavy-mineral-concentrate samples from the southern part of the quadrangle is included in Kelley and Kelley (1992). A comprehensive summary of available geologic, geochemical, and geophysical data and an assessment of the mineral resource potential of the

entire quadrangle is included in Kelley and Mull (1995). REGIONAL GEOLOGIC SETTING The Brooks Range is an east-west-trending fold and thrust belt that extends for nearly 800 km across northern Alaska and was formed during an orogenic event that began in Late Jurassic time and sulminated during mid-Cretaceous time. The northern part of the Endicott Mountains, which constitute the central Brooks Range, consists primarily of Paleozoic sedimentary rocks in a series of thrust sheets that were stacked together during the Mesozoic orogenesis. The southern foothills, located north of the Endicott Mountains, consist of a zone of intensely deformed Paleozoic and Mesozoic sedimentary rocks that are parts of several major thrust sequences known as allochthons (Mayfield and others, 1983). These allochthons were thrust from the south during the formation of the Brooks Range. Farther north in the northern foothills is the Colville basin, a depositional foredeep that is filled with over 6,000 m of

deltaic sedimentary deposits of Cretaceous age derived from the range.

GEOLOGY OF THE KILLIK RIVER QUADRANGLE Map A shows the generalized geology of the Killik River quadrangle. The quadrangle consists mainly of Devonian to Cretaceous sedimentary rocks and minor intrusive and extrusive mafic igneous rocks. Rocks of the mountainous southern third of the quadrangle and the southern foothills are part of the Brooks Range thrust belt. The northernmost part of the quadrangle within the northern foothills is underlain by sedimentary strata deposited in the Colville basin north of the thrust belt. The rocks of the Brooks Range thrust belt have been divided into allochthons containing distinctive assemblages of rock units that have been telescoped northward by thrusting (Mayfield and others, 1987; Mull, 1982). At least five allochthons have been delineated in the quadrangle (Mull and others, 1987; Mull and

The southern third of the quadrangle consists of unmetamorphosed to weakly metamorphosed sedimentary rocks of the Endicott Mountains allochthon (structurally the lowest of the allochthons in the central Brooks Range) (Brosgé and others, 1979; Mull and others, 1994). In the Killik River quadrangle, this allochthon consists of sedimentary rocks ranging from Late Devonian to Early Cretaceous age. At the base of the allochthon is the Hunt Fork Shale of Late Devonian age, which consists of a dark-gray and olive shale member interbedded with brown-weathering calcareous siltstone and fine-grained sandstone, and an overlying gray-green wacke member consisting of gray-green wacke interbedded with shale, siltstone, and sandstone. Both members represent deposition in a marine environment (Brosgé and others, 1979). Strata of the Hunt Fork Shale are overlain by the marine Upper Devonian Noatak Sandstone, which

in the Killik River quadrangle consists of light-gray to brown, fine to coarse sandstone and quartzite interbedded with dark-gray to brown shale containing ironstone nodules (Nilsen and Moore, 1984). The Noatak Sandstone is volumetrically subordinate to the underlying Hunt Fork Shale and the overlying Kanayut Conglomerate. The Kanayut Conglomerate is a Late Devonian and Early Mississippian(?) nonmarine sequence (Nilsen and Moore, 1984). It is as much as 2,600 m thick and extends east to west for more than 800 km across the Brooks Range. Sedimentary features indicate that deposition of the Kanayut Conglomerate occurred in a deltaic environment with chert-rich source areas located to the north and northeast (Nilsen and others, 1981). In the type section east of the Killik River quadrangle, the Kanayut Conglomerate contains a coarse middle part consisting predominantly of interbedded conglomerate and sandstone, and upper and lower parts consisting predominantly of sandstone, siltstone and shale. However, the conglomerate beds become progressively thinner to the west and contain smaller clasts than those present in the type section, so that conglomerate is only a minor part of the formation in the western part of the quadrangle.

The sedimentary section of Hunt Fork Shale to Kanayut Conglomerate represents a southward- or southwestward-prograding deltaic complex; the fine-grained prodelta shale beds of the Hunt Fork Shale grade upward into the wacke member of the Hunt Fork Shale and into the marine sandstone of the Noatak Sandstone, and eventually into the coarse delta-plain deposits of the Kanayut Conglomerate (Nilsen and Moore, 1984). The Kanayut Conglomerate, therefore, forms the fluvial part of the delta that prograded to the southwest during the Late Devonian and retreated during the Late Devonian and Early Mississippian(?) (Nilsen and others, 1981).

Overlying the Kanayut Conglomerate are fossiliferous marine strata of the Lower Mississippian Kayak Shale that consist dominantly of shale, with lesser amounts of siltstone, and shaly sandstone near its base, and interbedded argillaceous and ferruginous limestone near its top (Brosgé and others, 1979). Platform carbonate rocks of the Mississippian and Pennsylvanian Lisburne Group (Patton and Tailleur, 1964; Mull and others, 1982) overlie the Kayak Shale and consist primarily of medium- to light-gray limestone and dolomite with an interval of sooty black phosphatic shale and limestone near the top. Along the mountain front in the eastern part of the quadrangle, carbonate rocks of the undivided Lisburne Group are more than 300 m thick, but the unit thins westward and apparently grades into about 50 m of black chert, sooty limestone, and shale of the Kuna Formation of the Lisburne Group in the western part of the quadrangle. The Kuna Formation formed in a euxinic basin in an epicontinental setting (Mull and others, 1982). Disconformably overlying the Lisburne Group are rocks of the Etivluk Group, which consist of the Permian Siksikpuk Formation and the Triassic and Jurassic Otuk Formation (Mull and others, 1982). The Siksikpuk and Otuk Formations are combined as unit JPe on map A. The Siksikpuk Formation consists of about 100 m of pyritic siltstone, greenish-gray to maroon mottled mudstone and siltstone, greenish-gray silicified mudstone or chert, and an upper gray shale horizon. The greenish-gray to

The overlying Otuk Formation is also about 100 m thick and consists of a basal interval of black shale that grades upward successively into black silicified limestone and then into thinly interbedded light-gray to black banded siliceous limestone and shale containing abundant pelecypod fossils (Mull and others, 1982). Locally, a thin (less than 3 m) but distinctive marker interval of Early Cretaceous coquinoid limestone overlies the Otuk Formation and marks the stratigraphic top of the Endicott Mountains allochthon. This marker interval is too thin to be differentiated in the Killik River North of the range front is a belt of complexly deformed rocks composed of at least four

maroon siltstone and mudstone characteristically contain white barite lenses and nodules (Siok, 1985).

allochthons that structurally overlie the Endicott Mountains allochthon (Mull and others, 1987). The stratigraphy of this belt differs markedly from that of the Endicott Mountains allochthon to the south, although there are common characteristics that suggest that all of the allochthons represent parts of a formerly continuous sedimentary basin. These allochthons consist primarily of relatively thin Upper Mississippian and Lower Pennsylvanian black pyritic chert and limestone of the Akmalik Chert of the Lisburne Group, and overlying greenish-gray chert and green and maroon siliceous shale of the Pennsylvanian to Jurassic Imnaitchiak Chert (Mull and others, 1987; Mull and others, 1994). Locally, these siliceous rocks and limestone are underlain by a thin interval of the Mississippian Kayak Shale and Mississippian quartzose sandstone that was deposited as a turbidite. The Imnaitchiak Chert, Akmalik Chert, and local basal units are combined as unit JMc on map A. Rocks within this unit locally overlie the Upper Devonian Hunt Fork Shale. The allochthons in the deformed foothills belt also contain the Lower Cretaceous Okpikruak Formation. This formation consists dominantly of greenish-gray graywacke with interbedded mudstone and shale, but local massive boulder conglomerate and chaotic debris-flow deposits are also present. These Lower Cretaceous rocks represent the oldest detritus derived from uplift of the Brooks Range. Mafic igneous rocks intrude some of the allochthonous siliceous rocks and limestone of the deformed belt in the Otuk and Iteriak Creek area in the western part of the quadrangle. In addition, pillow basalt and other extrusive igneous rocks are present in the Kikiktat Mountain and Itkilikruich

Ridges area in the central part of the quadrangle and at one locality near the western edge of the quadrangle. The extrusive igneous rocks are part of probably one of the structurally highest allochthons in the Brooks Range and are an erosional remnant of oceanic crust transported from the south and emplaced during the formation of the range. The complexly deformed rocks of the Endicott Mountains and overlying allochthons are regionally overlain by gently folded conglomerate and graywacke of the Lower Cretaceous Fortress Mountain Formation. These proximal coarse-grained beds were derived from the Brooks Range and interfinger laterally with more complexly folded gray to black shale of the Lower Cretaceous Torok Formation

(Detterman and others, 1963). The northernmost third of the quadrangle within the northern foothills is part of the Colville Basin and contains gently deformed clastic rocks of the Lower and Upper Cretaceous (Albian and Cenomanian) Nanushuk Group (Detterman and others, 1963; Huffman, 1989). The Nanushuk Group is a deltaic clastic wedge composed of interbedded conglomerate, sandstone, coal, and shale. It is composed of sediments derived primarily from pre-existing sedimentary rocks with a variable contribution from mafic and ultramafic rocks, as well as metamorphic rocks and volcanic detritus (Huffman, 1985). Transport directions determined from the nonmarine facies of the delta, as well as studies of sandstone percentage and modal grain-size distribution indicate that, in the Killik River quadrangle, the delta prograded generally northward from the Endicott Mountains (Huffman, 1989). This clastic wedge was folded into a series of broad, long, linear, east-west-trending synclines and more tightly folded anticlines. Poorly exposed interbedded marine sandstone and shale of the Upper Cretaceous Colville Group (Detterman and others, 1963) overlie Nanushuk Group rocks in the northeast corner of the quadrangle, and Quaternary surficial deposits cover most of the central and northern parts of the quadrangle.

A total of 554 stream-sediment and 65 lake-sediment samples were collected and analyzed by Los Alamos National Laboratories (1982) as part of the NURE program. Wherever possible, sediment samples were collected from active stream channels; in areas with poorly developed drainages, lake sediments were sampled. Sediment samples were collected at a density of approximately one sample per 10 km<sup>2</sup>. For stream-sediment samples, approximately 1 kg of sediment was composited from three localities in the active stream. For lake-sediment samples, a tethered, stainless steel bottom sampler was dropped near the center of the lake from a pontoon-equipped helicopter. The samples were dried at 100°C or less prior to sieving to minus-100 mesh (Bolivar, 1980). The minus-100-mesh stream- and lake-sediment samples were analyzed for 42 elements at the Los Alamos National Laboratory by delayed-neutron counting (DNC), neutron-activation analysis (INAA), and x-ray fluorescence (XRF). The analytical methods used and the lower limits of detection are summarized in table 1. Due to elemental interference, the detection limits for elements determined by INAA will vary between samples as a function of the composition of the sediment (Bolivar, 1980). All of the data for each geochemical variable determined by INAA were adjusted to a common lower limit of detection, which corresponds to the highest detection limit contained within the data set. The adjusted lower detection limits are

shown in table 1. As part of the AMRAP study, an additional 65 minus-80-mesh stream-sediment samples were collected from the central and northern parts of the quadrangle in order to partly overlap the area sampled during the NURE program. The samples were analyzed for 31 elements using a direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). Limits of detection for emission spectrography are listed in table 2. Gold in sediments was also determined using an atomic-absorption method with a lower detection limit of 0.05 ppm (Thompson and others, 1968). Details of sample collection, preparation, and analysis are described in Sutley and others (1984). In 1989, many of the NURE and AMRAP sediment samples were resubmitted for analyses by emission spectrography and (or) inductively coupled plasma-atomic emission spectroscopy (Church, 1981); results of these analyses were tabulated by Motooka and others (1989) but these data were not

used in the interpretation presented in this report.

STATISTICAL SUMMARY Statistical summaries of the NURE minus 100-mesh stream- and lake-sediment data and the AMRAP minus-80-mesh stream-sediment samples are given in tables 3 and 4, respectively. Although stream- and lake-sediment samples may be considered two distinct sample media, the two data sets were combined prior to statistical analysis; initial evaluation of the two as separate data populations revealed that, within each data set, most elements show similar concentration ranges, geometric means, and interelement correlation. Because they were combined, they are referred to as minus-100-mesh "sediment samples" throughout the remainder of this report.

The tables list the number of qualified values for each element. Qualified values are those not detected (N), less than the lower limit of detection (L), and more than the upper limit of detection (G). The detection ratio (DR) is the number of samples with unqualified values divided by the total number of samples analyzed. For instance, a detection ratio of 1.0 indicates that all samples contain unqualified values for a particular element; these elements are considered "uncensored". Conversely, a detection ratio of 0.10 indicates that only 10 percent of the samples contain unqualified values of a given element; these are "highly censored" elements. In addition to the range in concentrations of all elements, the geometric mean and deviation, and the 50th, 80th, and 90th percentiles were calculated for elements with detection ratios of 0.40 or greater (i.e., the relatively uncensored elements). Prior to any calculations, values qualified with "N" were set equal to 0.5 times the lower limit of detection; those qualified with "L" were set equal to 0.7 times the lower limit of detection; those with "G" were set equal to 1.5 times the upper limit of detection.

Frequency distribution diagrams, or histograms, were constructed for selected elements (figs. 3 and 4). The histograms conveniently show the general distribution and ranges of the data. The boundary between the background concentration and geochemical anomaly (threshold value) for a given element was determined by study of the histograms and spatial distribution of the data, and by comparison of the sediment data with (a) worldwide average abundances of chert, shale, and limestone obtained from the literature (table 5), and (b) rock geochemical data that we collected for background information (table 6). For most elements, this threshold value corresponds approximately to the 90th percentile or greater (tables 3 and 4). For highly censored elements such as silver and cadmium, threshold values were chosen to be the lower limit of detection. The twelve elements represented on the geochemical maps (maps B through D) are Ag, As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn.

DISCUSSION AND INTERPRETATION OF GEOCHEMICAL DATA Evaluation of correlation matrices and spatial distributions of the minus-100-mesh sediment data indicate that there are three major elemental associations that may be indicative of mineralization: (1) barium, copper, and zinc (with or without cadmium, manganese, lead, and silver), (2) arsenic, cobalt, iron, and manganese (with or without nickel), and (3) chromium and nickel. Anomalous concentrations of these elements are portrayed graphically on maps B through D. Uranium and tungsten are discussed but are not shown graphically, primarily because samples containing anomalous concentrations of these elements are isolated and widely distributed, or these elements show little correlation with other orerelated elements. Likewise, bismuth and tin were detected in a few samples, but their distribution is so randomly distributed that interpretation is not possible. Gold contents are all less than detection limits in minus-100-mesh and minus-80-mesh sediment samples (0.2 ppm and 0.05 ppm lower limits for minus-100-mesh and minus-80-mesh samples, respectively).

BARIUM, COPPER, AND ZINC (WITH OR WITHOUT CADMIUM, MANGANESE, LEAD, AND SILVER) In the minus-100-mesh sediment samples, Ba concentrations range from less than 265 to 64,350

ppm (6.4 percent), Cu from less than 10 to 114 ppm, and Zn from less than 150 to 524 ppm (table 3). Eighteen samples contain detectable Cd, ranging from 5 to 22 ppm. Although most of the minus-100mesh sediment samples contain less than 30 ppm Pb, three samples contain 30-72 ppm Pb; all three samples contain associated anomalous concentrations of cadmium and zinc. Map B shows the localities of minus-100-mesh samples containing anomalous concentrations of Ba, Cd, Cu, Pb, and Zn. Minus-80-mesh stream-sediment samples containing anomalous concentrations of Ag (0.5-3 ppm), Ba (more than 5,000 ppm), Cu (100-150), Pb (50-70 ppm) and Zn (300-500 ppm) are also shown on map B (cadmium concentrations in minus-80-mesh stream-sediment samples were all below the lower detection There are five areas in the northern part of the Killik River quadrangle that contain geochemical

anomalies delineated by sediment samples: (1) the Ivotuk Hills, (2) the tributaries of the Oolamnagavik

River, (3) the Otuk-Iteriak Creeks area, (4) the area between Ivotuk Creek and the Kurupa Hills, and (5) Kikiktat Mountain. Many of the samples collected from these five areas also contain anomalously high concentrations of Mn (0.48-1.05 percent in minus-100-mesh sediment samples and 5,000 ppm or more in minus-80-mesh stream-sediment samples; map C), an element regarded as a pathfinder element for silver-lead-zinc mineralization (Maynard, 1983; 1991a). The Ivotuk Hills and the tributaries of the Oolamnagavik River are underlain primarily by rocks of the Etivluk Group and Lisburne Group (map A). The rocks of the Siksikpuk Formation of the Etivluk Group commonly contain barite as veins, lenses, and nodules (Siok, 1985); they are the most likely source of the anomalous barium in the two areas. The source of the anomalous concentrations of cadmium, copper, manganese, and zinc is probably also shale and chert of the Etivluk Group.

Although most chert samples collected from the Ivotuk Hills contain only background concentrations of these elements, one sample (Otuk Formation of the Etivluk Group) contains 200 Co, 500 ppm Cu, more than 5,000 ppm Mn, and 100 ppm Ni (sample AKD627D; table 6). Two black shale samples (samples AKD106 and AKD631A; table 6) contain anomalous concentrations of Ag (7-20 ppm), Cd (30 to more than 100 ppm), Cr (200-1,500 ppm), Cu (150-200 ppm), Ni (150-500 ppm), and Zn (1,000-2,000 ppm), which are higher than average concentrations in shale (table 5) and may indicate the presence of sulfide minerals. The only sulfide minerals observed in the field were massive pyrite concretions found in float in a stream draining the west side of the Ivotuk Hills; one of these pyrite concretions contains redbrown sphalerite in the core. The pyrite concretion without visible sphalerite contains 200 ppm As, more than 20 percent Fe, and 500 ppm Zn (sample AKD627C; table 6). No geochemical data from rock samples are available from the Oolamnagavik River. However,

sediment samples from the Oolamnagavik River area contain anomalous concentrations of elements that are similar to the Ivotuk Hills area, indicating that shale and chert of the Etivluk and Lisburne Groups in the Oolamnagavik River area may also be enriched in metals. Rocks of the Etivluk Group and shale and chert of the Kayak Shale (Mk) and Kuna Formation (PMk) are exposed along the rangefront in the Otuk-Iteriak Creeks area, and between Ivotuk Creek and the Kurupa Hills. Any of these units could be the source of anomalous concentrations of barium and base metals in sediment samples. Sulfide-bearing concretions in the Lower Mississippian Kayak Shale are abundant in one outcrop located at the headwaters of Otuk Creek (map B). The concretions range in diameter from 7.6 to 20 cm. They contain abundant calcite, as well as minor amounts of sulfide

minerals including red-brown sphalerite, galena, chalcopyrite, and pyrite. Geochemical analyses of the concretions are listed in table 6 (samples AKD625B, AKD625C). In addition to anomalous concentrations of Fe (20 percent), the concretions contain elevated concentrations of Ag (0.8-2.3 ppm), Ba (greater than 5000 ppm), Mn (3,000 ppm), and Zn (300-1,500 ppm). Although sulfide-bearing concretions such as these were not found in the Kayak Shale elsewhere in the quadrangle, they were found in the Howard Pass quadrangle to the west (K.D. Kelley, unpub. data, 1990) and in the Chandler Lake quadrangle to the east (J.M. Kurtak, oral commun., 1994). This indicates they may be fairly

common in the Kayak Shale, and may be a source of anomalous concentrations of base metals in sediment samples collected elsewhere along the rangefront. Sooty black shale of the Kuna Formation hosts the Red Dog stratiform silver-barium-lead-zinc deposit in the western Brooks Range (Moore and others, 1986). The Kuna Formation is exposed in a few of the basins containing geochemical anomalies between Iteriak Creek and the Kurupa Hills. Although no sulfide minerals were found, one chert sample of the Kuna Formation from Otuk Creek contains 200 ppm Zn, 700 ppm Ba, and 3 ppm Ag (sample AKD625F; table 6), which are high relative to average worldwide abundances of these elements in chert (table 5), or compared to other chert samples from the Killik River quadrangle (table 6). In the Kurupa Hills area (T. 12S., Rs. 17E. and 18E.), a few samples contain anomalous

concentrations of barium and copper (with or without cadmium) (map B), and abundant barite and minor pyrite were found in nonmagnetic heavy-mineral-concentrate samples (Kelley and others, 1995b). Chip samples were collected through the Mississippian to Triassic chert and shale sequence. Except for one pyritic chert sample that contains 500 ppm Ni (sample AKD079; table 6), the samples contain elemental concentrations similar to those of average chert and shale (table 5). At Kikiktat Mountain (T. 12 S., R. 20 E.), a few minus-100-mesh sediment samples contain anomalous concentrations of copper, and minus-80-mesh stream-sediment samples contain anomalous concentrations of barium (more than 5,000 ppm). Chert and mafic igneous rocks at Kikiktat Mountain contain local disseminated pyrite and chalcopyrite. Background trace element concentrations of the mafic rocks are as follows: 3-5 percent Fe, 20-50 ppm Co, 150-500 ppm Cr, 100 ppm Cu, and 50-100 ppm Ni. Chert samples contain mostly 500-3,000 ppm Ba, 10-30 ppm Cu, 10-20 ppm Cr, 10 ppm Co, and 0.5-1 ppm Ag (table 6). Except for the local accumulation of pyrite and minor chalcopyrite in the chert and mafic igneous rocks, and barite in shale and chert which surrounds Kikiktat Mountain, the rocks of this area do not appear to be mineralized.

ARSENIC, COBALT, IRON, AND MANGANESE (WITH OR WITHOUT NICKEL) There is a close association between arsenic, cobalt, iron, and manganese in the minus-100-mesh sediment samples. The localities of sediment samples that contain anomalous concentrations of these elements are widely distributed throughout the quadrangle (map C), and many are in swampy terrain covered by alluvial and colluvial deposits. The drainages in this terrain are mostly short first-order streams that are nearly stagnant and contain abundant organic matter and iron-manganese oxides. The anomalous concentrations of arsenic, cobalt (map C), zinc and cadmium (map B) found in these widely distributed samples are probably a result of the presence of these oxides, which serve as scavengers of

Not all of the samples that contain anomalous concentrations of arsenic, cobalt, iron, and manganese are a result of scavenging by iron-manganese oxides. Along the rangefront from the Kurupa Hills (T. 12 S., Rs. 17 E. and 18 E.) to Kikiktat Mountain (T. 12 S., R. 20 E.), minus-100-mesh sediment samples containing anomalous concentrations of these elements may be indicative of abundant pyrite. Many nonmagnetic heavy-mineral-concentrate samples collected near Kikiktat Mountain and farther to the west along the rangefront contain greater than 50 percent pyrite (Kelley and others, 1995b). The corresponding minus-80-mesh stream-sediment samples contain anomalous concentrations of cobalt, iron (map C), and (or) nickel (map D). All of these elements are incorporated in pyrite (Levinson, 1974). There are many possible sources for the widespread pyrite. Pyrite is present in two formations of the Etivluk Group: the lowermost part of the Siksikpuk Formation contains large euhedral crystals and finely disseminated framboids (Siok, 1985); the Otuk Formation consists, in part, of a black pyritic shale interval (Bodnar, 1984). In addition to these units, mafic igneous rocks at Kikiktat Mountain commonly contain disseminated pyrite.

CHROMIUM AND NICKEL Chromium concentrations in minus-100-mesh sediments range from less than 43 to 2,340 ppm; nickel concentrations range from less than 15 to 241 ppm (table 3). Anomalous concentrations (500-2,340 ppm Cr; 100-241 ppm Ni) are shown on map D. Most of the minus-100-mesh and minus-80mesh sediment samples were collected from the northern part of the quadrangle where rocks of the Nanushuk Group are exposed. These sediment samples have the highest chromium and nickel concentrations in the quadrangle, even greater than samples collected from tributaries draining mafic igneous rocks such as those at Kikiktat Mountain (T. 12 S., R. 20 E).

In the northern part of the Chandler Lake quadrangle (east of the Killik River quadrangle), Kelley and Sutley (1993) report similar anomalous concentrations of chromium and nickel. X-ray diffraction and laser microprobe analysis of selected grains from nonmagnetic heavy-mineral-concentrate samples collected within the Chandler Lake quadrangle identified the source of the anomalies as a chromiumand nickel-bearing spinel, with a unit cell (Å=8.36) very close to that of chromite (Kelley and Sutley,

Rocks of the Lower and Upper Cretaceous Nanushuk Group represent a deltaic complex composed of interbedded conglomerate, sandstone, coal, and shale. Huffman (1989) suggested the delta prograded northward from the Brooks Range. The chromite is most likely a detrital mineral in sandstone and (or) conglomerate of the Nanushuk Group, or in Quaternary sand and gravel, having been reworked from the Cretaceous sedimentary rocks. The source of the chromite was probably mafic and ultramafic igneous rocks that were located in the Brooks Range to the south and eroded and deposited in the

deltaic complex. Several mafic and ultramafic igneous intrusions in the Howard Pass quadrangle (west of the Killik River quadrangle) host podiform chromite occurrences. There are also placer-chromite occurrences in valleys that drain the chromite-bearing ultramafic rocks (J.Y. Foley, personal commun., 1991). Highly anomalous concentrations of Cr (5,000 ppm or greater) were found in sediment samples collected north (50 km) of the intrusions in areas with no exposed igneous rocks (Schmidt and others, 1990, Planning document for mineral resource studies in the southern NPRA study area; unpublished USGS administrative report, 249 p). All of these sediment samples have relatively low platinum-group element (PGE) and other precious metal concentrations (J.Y. Foley, personal commun., 1991). The PGE contents in sediment samples collected from the Killik River quadrangle are not known but are probably similar to the generally low concentrations found in the sediment samples collected farther

Values for uranium in minus-100-mesh sediment samples range from 0.17 to 7.98 ppm. Nearly all of the anomalous concentrations (3.5 ppm and higher) are associated with relatively high concentrations of thorium. Most are associated with Upper Devonian clastic rocks of the Kanayut Conglomerate and (or) the Noatak Sandstone in the southwestern part of the quadrangle, or rocks of the Etivluk Group in the central part of the quadrangle. Nonmagnetic heavy-mineral-concentrate samples collected from areas of the clastic rocks contain abundant zircon, which is the source of anomalous uranium and thorium in these areas. High concentrations of uranium in samples collected from areas that contain metalliferous shale of the Etivluk Group probably reflect the presence of organic material that serves to adsorb uranium. A few other samples with relatively high uranium contents are distributed throughout the quadrangle in areas characterized by low flat terrain with poorly defined drainage basins. The high concentrations of uranium in these samples is probably due to abundant organic matter. Large areas in the northern part of the quadrangle are comprised of Lower and Upper Cretaceous

sandstone that contains interbedded shale of the Nanushuk Group. Rocks such as these may host rollfront-type uranium deposits, consisting primarily of uranium-bearing, low-thorium minerals such as uraninite. Four sediment samples collected from basins that drain Nanushuk Group rocks contain anomalous concentrations of U (3.5 to 4.8 ppm) with no associated high concentrations of thorium. These samples were collected from an area located between Aupuk and Kurupa Creeks near the northern boundary of the quadrangle. However, other pathfinder elements for roll-front uranium deposits (such as copper and vanadium; Maynard, 1991b) do not correlate with uranium in this area, indicating that these anomalies are not significant. This conclusion is consistent with studies by Huffman (1985), who measured uranium concentrations in rocks of the Nanushuk Group at several localities in the Killik River quadrangle and adjacent quadrangles; he concluded that the resource potential of uranium in roll-front-type deposits is low.

Nineteen sediment samples collected throughout the Killik River quadrangle contain detectable (15-30 ppm) concentrations of tungsten. Most of these elevated concentrations are isolated single-sample anomalies that are widely scattered throughout the quadrangle in areas that contain a wide variety of rock types. In addition, no consistent correlation between tungsten and any other element was found in these samples, indicating the variations in concentration may be due to analytical variation rather than lithologic variation or mineralizing processes. However, four samples in the Otuk-Iteriak Creeks area and farther east towards the Kurupa Hills contain 20-30 ppm W in addition to anomalous concentrations of barium, cadmium, and (or) zinc previously discussed (map B). Four nonmagnetic heavy-mineral-concentrate samples collected from the same general area contain scheelite (Kelley and others, 1995b). The source of the scheelite and anomalous tungsten concentrations are not known. Bedrock in the area consists of shale and chert of the Etivluk Group, Kayak Shale, and Kuna

CONCLUSIONS Five areas in the Killik River quadrangle are characterized by sediment samples containing anomalous concentrations of Ag, Ba, Cd, Cu, Pb, and (or) Zn. Many of these samples also contain anomalous concentrations of As, Co, Fe, Mn, and Ni. The Ivotuk Hills and the area located at the headwaters of the Oolamnagavik River primarily contain rocks of the Etivluk and Lisburne Groups, which are the probable source rocks of the anomalous elemental concentrations found in the sediment samples. Pyrite and barite are common in these rocks, and the geochemical data indicate that other sulfides, such as chalcopyrite and sphalerite, may also be present. The Otuk-Iteriak Creeks area and the Ivotuk Creek-Kurupa Hills area contain two other shale and (or) chert units that may also be metal-rich: one is the Lower Mississippian Kayak Shale and the other is the Lower Mississippian to Lower or Middle Pennsylvanian Kuna Formation that hosts the Red Dog deposit in the western Brooks Range. At the headwaters of Otuk Creek, sulfide-bearing concretions were found to be abundant in the Kayak Shale. These concretions contain anomalous concentrations of Ag, Ba, Fe, Mn, and Zn. Although sulfide minerals were not observed in chert of the Kuna Formation, it is enriched in silver and zinc. The area surrounding Kikiktat Mountain is characterized by several sediment samples that contain anomalous concentrations of copper (with or without barium). Although there are of pyrite, chalcopyrite, and barite in mafic igneous rocks and shale and chert at Kikiktat Mountain, the

high concentrations of barium and copper in sediment samples probably reflect relatively high background concentrations in rocks of this area. Sediment samples collected from the northern part of the quadrangle containing anomalous concentrations of chromium and nickel are associated with rocks of the Lower and Upper Cretaceous Nanushuk Group. These rocks represent a deltaic complex that prograded northward from the Brooks Range. The source of the anomalous chromium and nickel is probably chromite, which may be a detrital mineral contained in sandstone or conglomerate of the Nanushuk Group, or in Quaternary sand and gravel. The source of the chromite was probably mafic and ultramafic igneous rocks located to the

south that were eroded during formation of the deltaic complex. Although several sediment samples contain anomalous concentrations of uranium, most samples are related to abundant zircon in clastic rocks or to organic-rich shale. Four uranium-rich samples were collected from areas containing sandstone and conglomerate of the Nanushuk Group. These samples do not contain associated copper or vanadium, which are common pathfinder elements for sandstone-hosted roll-front-type uranium deposits. Therefore, the uranium anomalies probably do not indicate the presence of mineralized uranium-bearing rocks. Nineteen sediment samples containing detectable tungsten were collected from widely distributed localities throughout the quadrangle in areas that contain a wide variety of rock types. Most of these localities are isolated and the samples do not contain anomalous concentrations of other elements.

However, four tungsten-bearing samples collected along the rangefront between Iteriak Creek and the Kurupa Hills also contain anomalous concentrations of barium, copper, and zinc. Scheelite was found in four nonmagnetic heavy-mineral-concentrate samples collected from the same general area. The source of the scheelite and anomalous concentrations of tungsten in sediment samples is not known.

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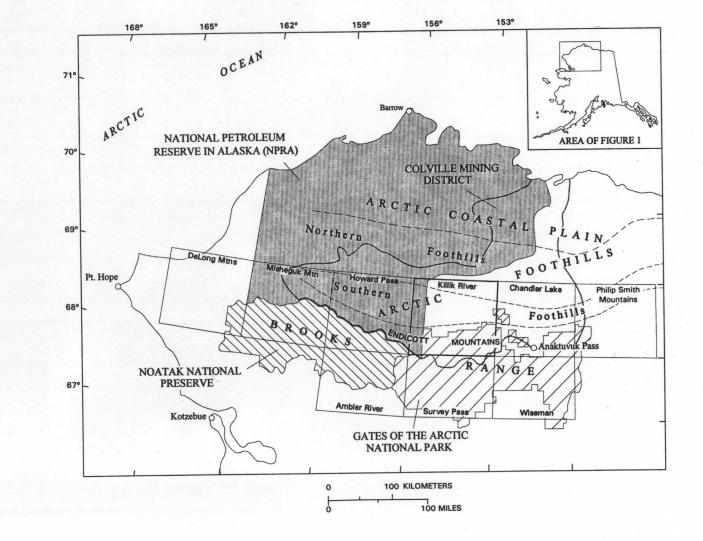


Figure 1. Location of the Killik River quadrangle, Brooks Range, Alaska

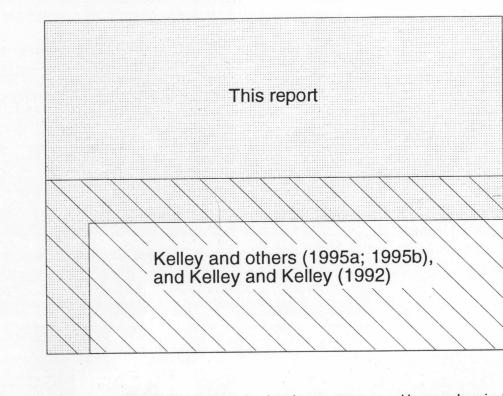


Figure 2. Killik River quadrangle showing areas covered by geochemical reports. Stippled area, this report; ruled area, Kelley and others (1995a; 1995b); and Kelley and Kelley (1992).

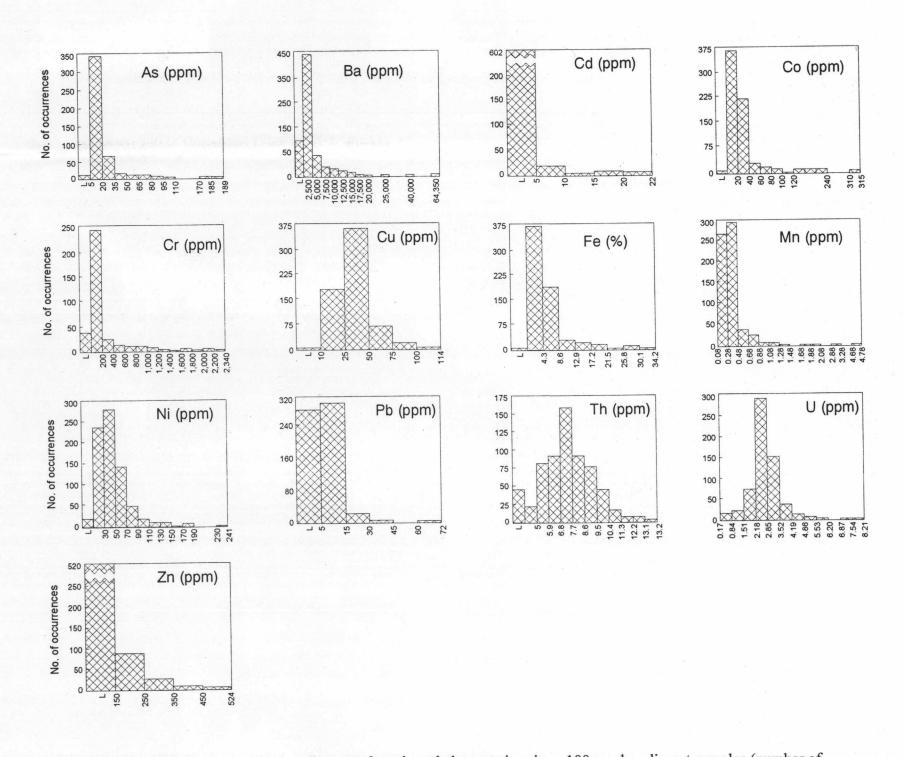


Figure 3. Frequency distribution diagrams for selected elements in minus-100-mesh sediment samples (number of samples, 602; L, less than lower detection limit).

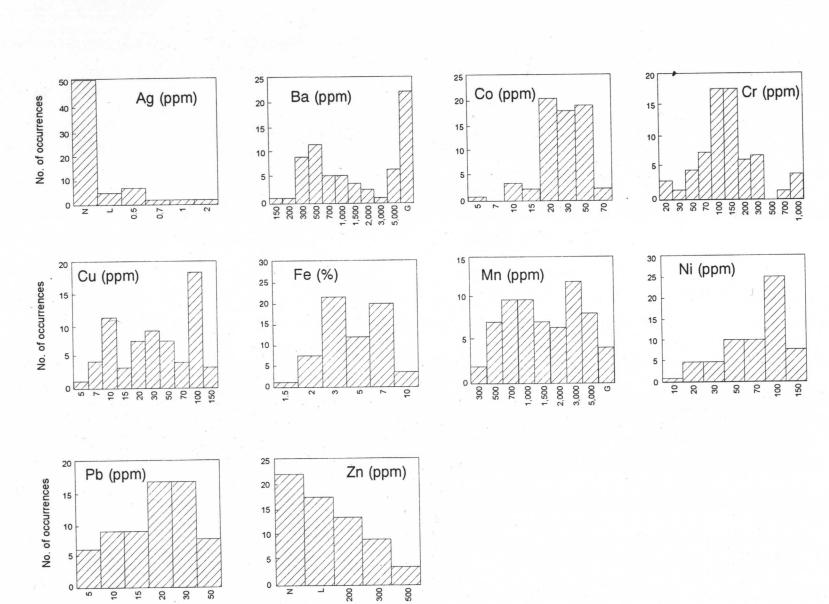


Figure 4. Frequency distribution diagrams for selected elements in minus-80-mesh sediment samples (number of samples, 65; N, not detected at lower detection limit; L, less than lower detection limit; G, greater than upper

GEOCHEMISTRY OF MINUS-100-MESH AND MINUS-80-MESH SEDIMENT SAMPLES FROM THE KILLIK RIVER  $1^{\circ} \times 3^{\circ}$  QUADRANGLE, ALASKA