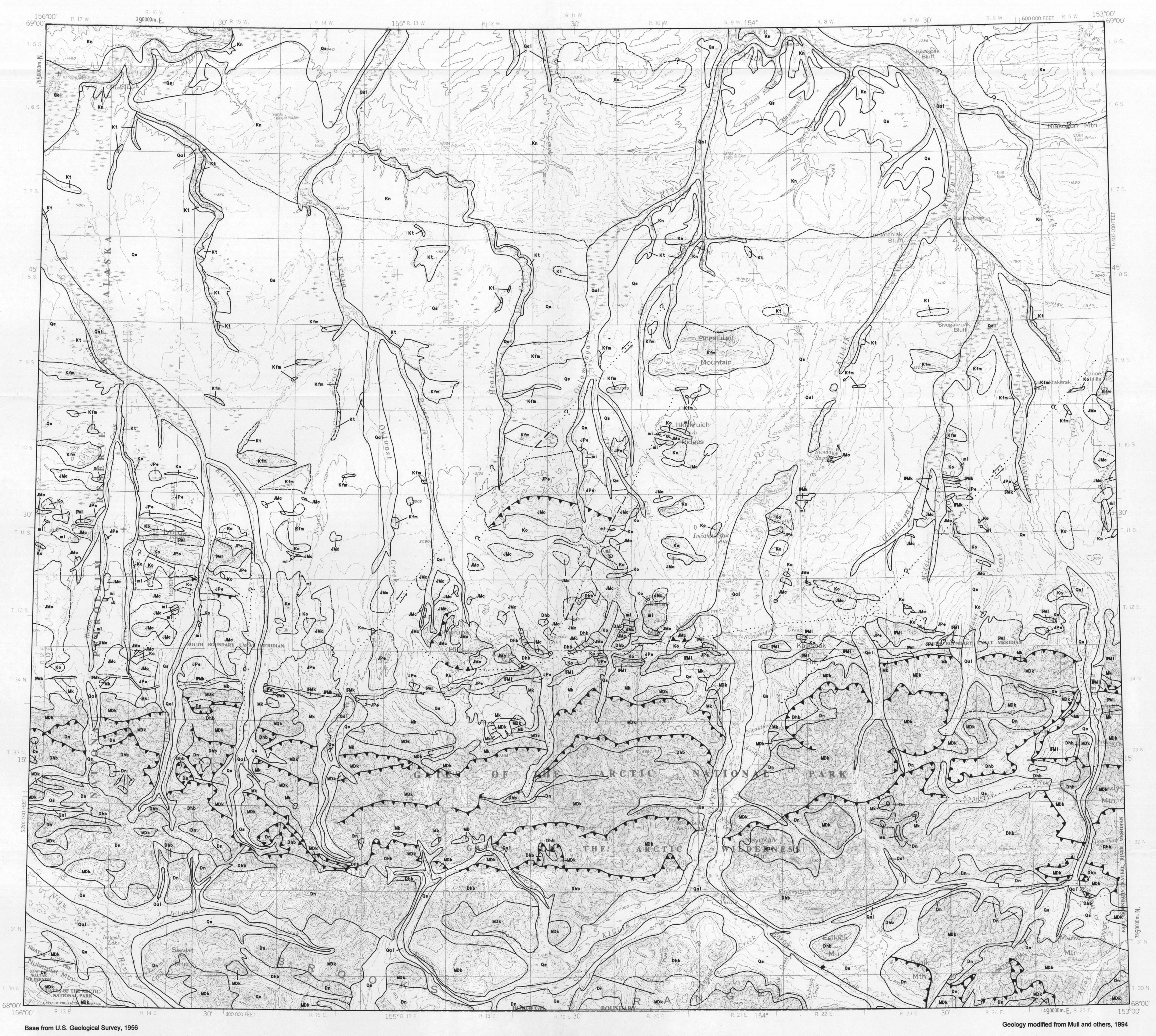
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-2225-D
SHEET 1 OF 2



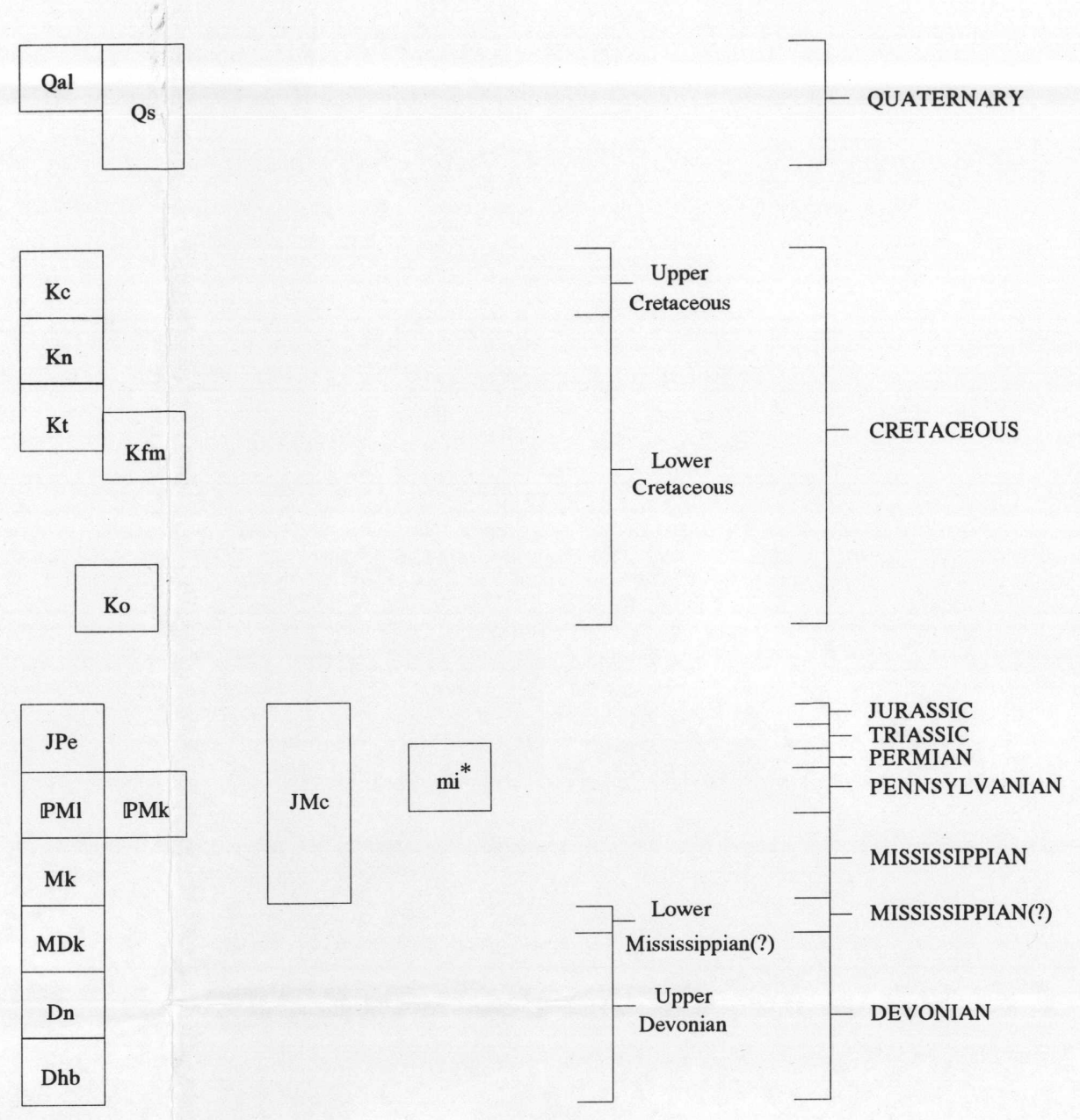
Base from U.S. Geological Survey, 1956

Geology modified from Mull and others, 1994

MAP A. GENERALIZED GEOLOGY

SCALE 1:250 000
5 0 5 10 15 MILES
5 0 5 10 15 KILOMETERS
CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

CORRELATION OF MAP UNITS



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

DESCRIPTION OF MAP UNITS

Qal	**Active alluvial deposits (Quaternary)**--Flood-plain deposits, lightly vegetated in some cases; includes sand dunes in Killik and Okokmilaga River valleys
Qs	**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 deposits
Kc	**Colville Group (Upper Cretaceous)**--Poorly exposed interbedded marine sandstone and shale
Kn	**Nanushuk Group (Upper and Lower Cretaceous)**--Dominantly gray to greenish gray sandstone and conglomeratic sandstone, interbedded with dark gray shale and coal
Kt	**Torok Formation (Lower Cretaceous)**--Dark-gray to black clay shale and interbedded silty shale; lower part interfingers with Fortress Mountain Formation
Kfm	**Fortress Mountain Formation (Lower Cretaceous)**--Dominantly greenish gray graywacke interbedded with dark-gray mudstone and shale; interfingers with Torok Formation
Ko	**Okpikruak Formation (Lower Cretaceous)**--Dominantly greenish gray graywacke with interbedded mudstone and shale
JPe	**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
mi	**Mafic igneous rocks (Triassic? to Pennsylvanian)**--Dark green, fine to coarse grained basalt and diabase dikes and sills
JMc	**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
PMl	**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:
PMk	**Kuna Formation (Lower or Middle Pennsylvanian to Upper Mississippian)**--Interbedded black chert, sooty limestone, and shale
Mk	**Kayak Shale (Mississippian)**--Dark gray to black fissile shale with yellowish brown-weathering thin fossiliferous limestone beds near top; lower part contains thin interbeds of gray sandstone; gradational downward into Kanayut Conglomerate
MDk	**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
Dn	**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
Dhb	**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 concealed
⇄	**Fault**--Showing relative horizontal movement. Dashed where approximately located; dotted where concealed; queried where uncertain

EXPLANATION
MAP C

◕	Ni (150 ppm)
◑	Ni (100 ppm)
◕	Cr (1,000 to 10,000 ppm)
◔	Cr (500 to 1,000 ppm)
◕	As (5,000 ppm)
◔	Co (150 to 200 ppm)
◔	Co (70 to 150 ppm)
☆	Sulfide mineral occurrence
◌	Area boundary delineated by nonmagnetic heavy-mineral-concentrate samples containing anomalous concentrations of one or more elements
•	Nonmagnetic heavy-mineral-concentrate sample site

SCALE 1:250 000
5 0 5 10 15 MILES
5 0 5 10 15 KILOMETERS
CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

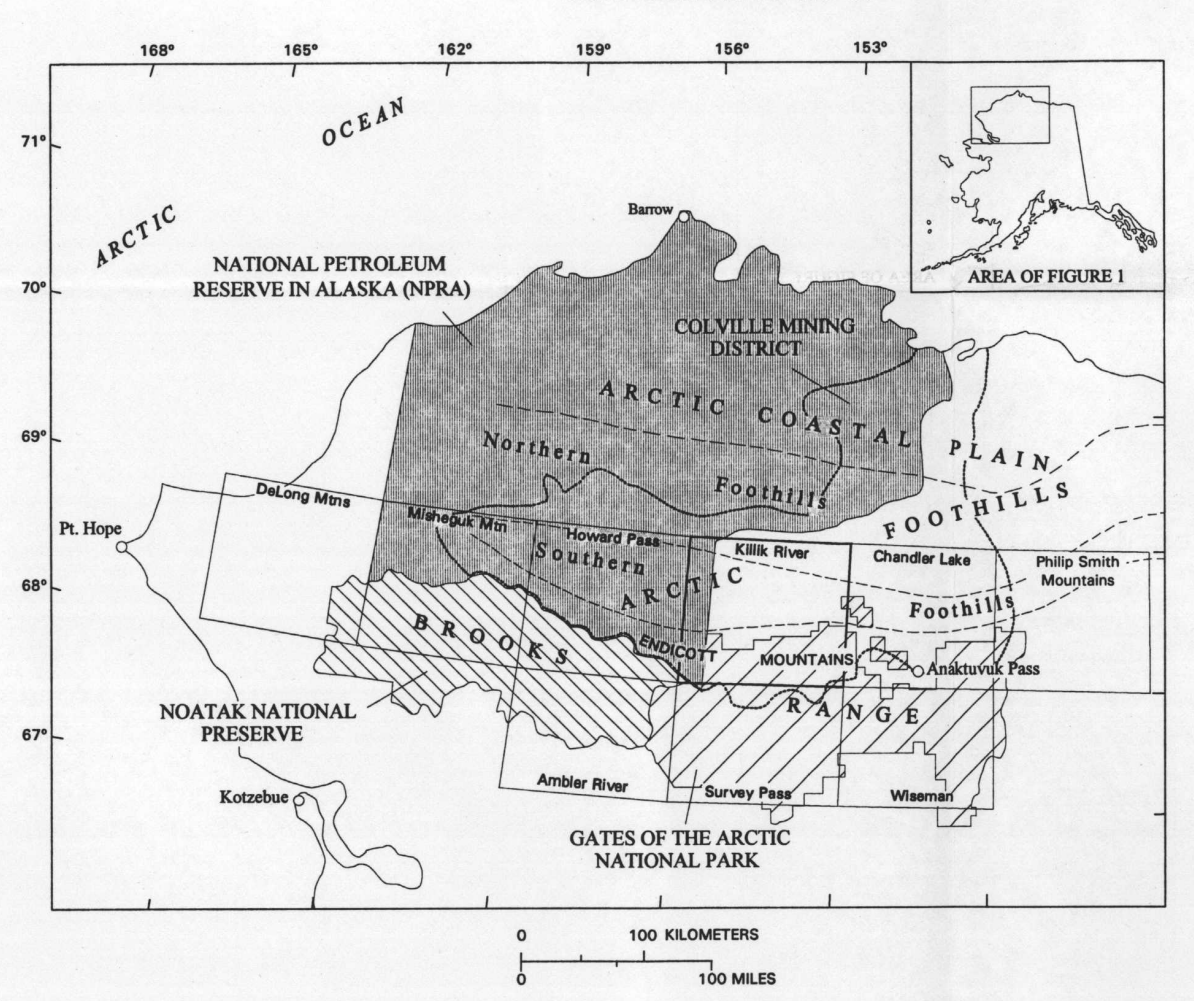


Figure 1. Location of the Killik River quadrangle, Brooks Range, Alaska.

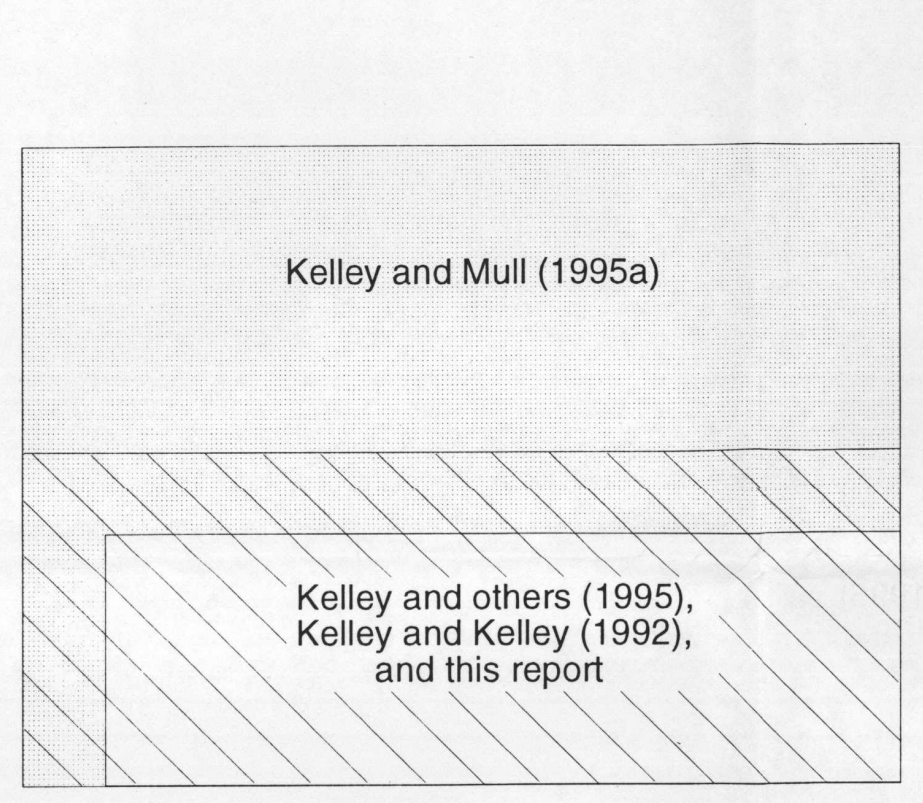
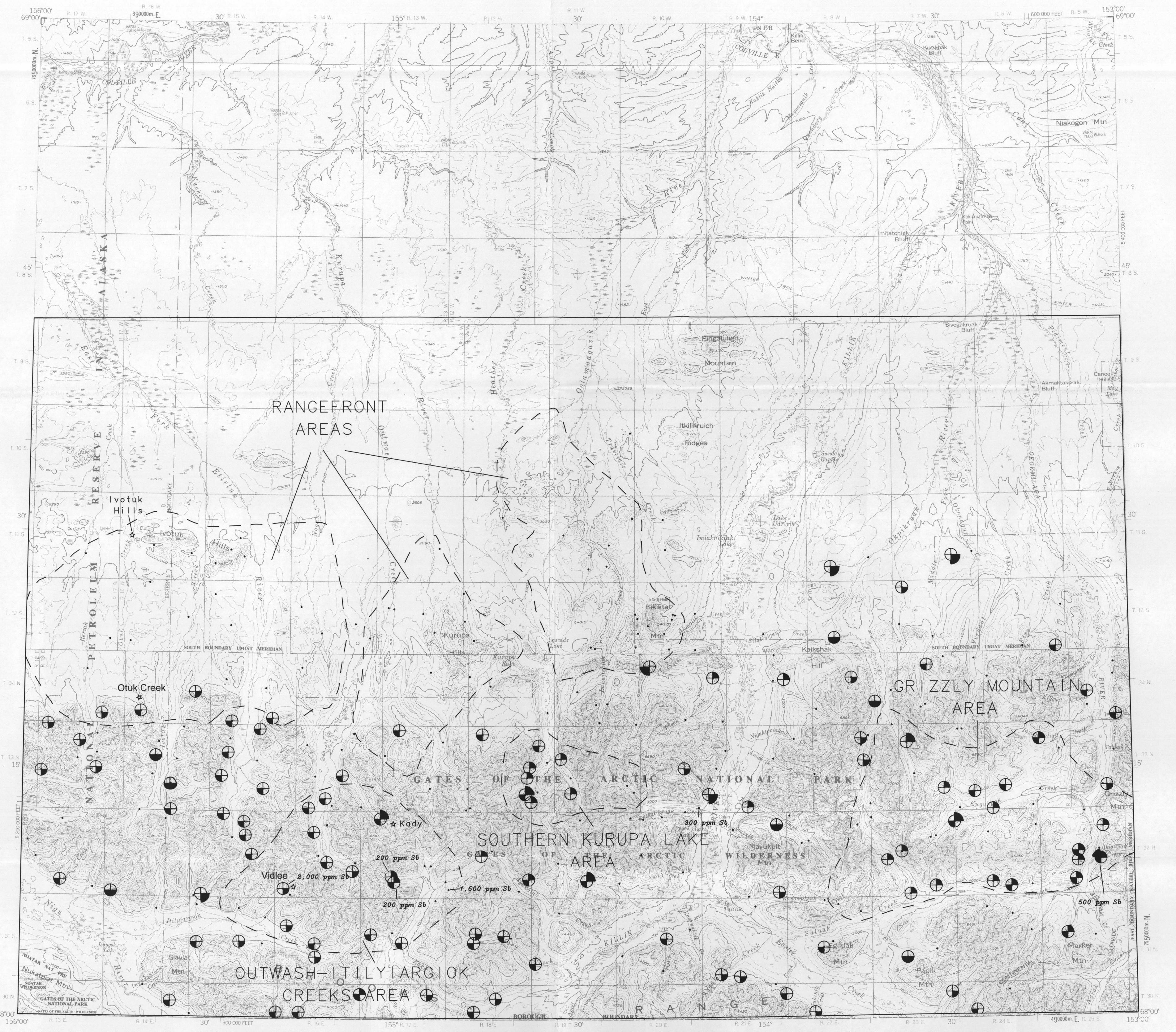
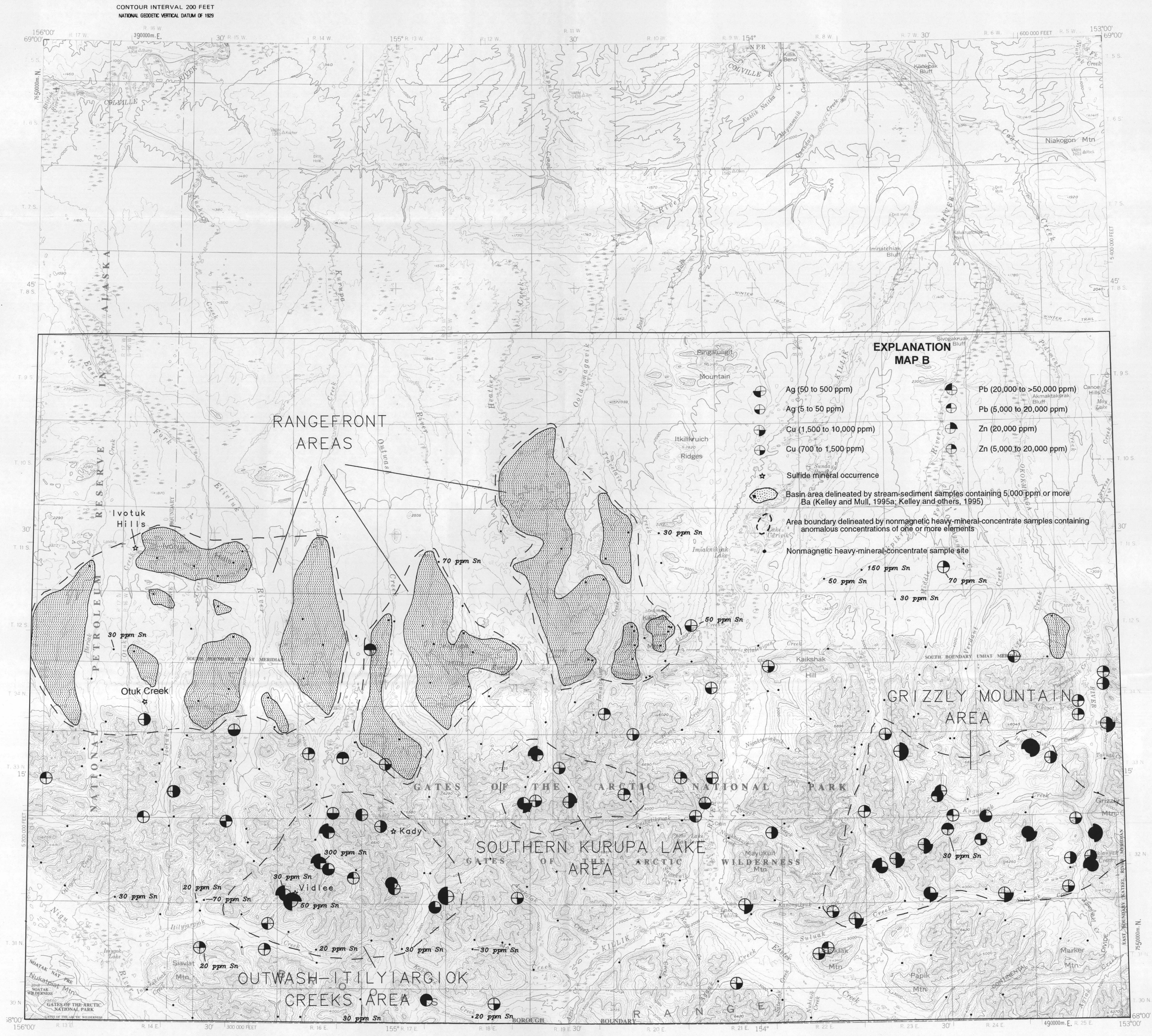


Figure 2. Killik River quadrangle showing areas covered by geochemical reports. Stippled area, Kelley and Mull (1995a); ruled area, Kelley and others (1995), Kelley and Kelley (1992), and this report.



MAP C. DISTRIBUTION OF NONMAGNETIC HEAVY-MINERAL-CONCENTRATE SAMPLES CONTAINING ANOMALOUS CONCENTRATIONS OF As, Co, Cr, Ni, AND Sb



MAP B. DISTRIBUTION OF NONMAGNETIC HEAVY-MINERAL-CONCENTRATE SAMPLES CONTAINING ANOMALOUS CONCENTRATIONS OF Ag, Cu, Pb, Sn, AND Zn

STUDIES RELATED TO AMRAP

The U.S. Geological Survey (USGS) 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. This report presents an interpretation of geochemical data from nonmagnetic heavy-mineral-concentrate samples collected from the southern part of the Killik River quadrangle, Alaska.

INTRODUCTION

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 the geochemistry and mineralogy of nonmagnetic heavy-mineral-concentrate samples collected from the southern part of the quadrangle. The area covered is shown on figure 2. Other reports include the geochemistry of USGS stream-sediment samples collected from the southern part of the quadrangle (Kelley and others, 1995), and geochemistry of minus-100 mesh stream- and lake-sediment samples collected during the NURE survey from the northern and western parts of the Killik River quadrangle (Kelley and Mull, 1995a). 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 (1995b).

In this report, selected element concentrations and the distribution of sulfide minerals, barite, and scheelite in the concentrate samples are presented on geochemical and mineralogical maps. As an aid to the interpretation of the regional geochemical data, we used factor analysis to identify the dominant geochemical associations in the heavy-mineral-concentrate samples. By expressing the overall data in terms of the principal geochemical associations, it is possible to distinguish minor variations in element concentrations related to lithology from those related to mineralization.

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 culminated 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 others, 1994).

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

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 quadrangle.

North of the range front is a belt of complexly deformed rocks composed of at least four 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.

METHODS

A total of 309 heavy-mineral-concentrate samples were collected from the southern part of the quadrangle and analyzed for this study. A few additional widely distributed samples collected in the northern part of the quadrangle are not discussed in this report, but are included in the report on minus-100-mesh NURE sediment data (Kelley and Mull, 1995a).

Sample sites were selected on first- and second-order drainages as shown on 1:63,360-scale topographic maps, or on 1:250,000-scale topographic maps in areas where the larger scale maps were nonexistent. Several grab samples were collected along 25 ft of active alluvium and composited into a single sample. Each bulk sample was passed through a 2.0-mm (10-mesh) screen to remove coarse material. The sediment passing through the screen was panned using a standard 14-in. gold pan to remove most of the quartz, feldspar, organic material, and clays. In the laboratory, the panned concentrate was air-dried and the strongly magnetic minerals were removed with a hand magnet and discarded. Any material of low specific gravity (such as quartz and feldspar) was then removed using a heavy-liquid (bromoform, 2.8 specific gravity) separation technique. The resulting heavy-mineral fraction was then separated into nonmagnetic and magnetic fractions using an isodynamic magnetic separator with 15° forward-slope and 10° side-slope settings at 1.0 ampere. The nonmagnetic fraction obtained was split into two fractions: one split was used for mineralogical analysis and the other for geochemical analysis.

The mineralogy of each concentrate sample was determined using a binocular microscope, identifying the minerals by their physical and optical properties. Occasionally, x-ray diffraction techniques were used on single grains to identify the minerals that were difficult to determine optically or to verify the analyses made by the visual examination. The split that was not used for mineralogical analysis was analyzed for 31 elements using a direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). The semiquantitative spectrographic results are reported as one of six steps (1, 0.7, 0.5, 0.3, 0.2, 0.15 and multiples of these numbers); the values are the approximate midpoints of the concentration ranges. The lower and upper limits of detection for concentrate samples are shown on table 1. The precision of the analytical method is approximately plus or minus one reporting interval at the 83-percent confidence level and plus or minus two reporting intervals at the 96-percent confidence level (Motooka and Grimes, 1976). A complete listing of the heavy-mineral-concentrate geochemical data from the Killik River quadrangle is given in Barton and others (1982) and Sutley and others (1984).

STATISTICAL SUMMARY

A univariate statistical summary of the nonmagnetic heavy-mineral concentrate data is included in table 2. Elements that were analyzed but not detected in any of the samples include gold, bismuth, and thorium; therefore, they are not included in table 2. Qualified values are those that were 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 0.30 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 the relatively uncensored elements, using the spectrographic intervals as class widths (fig. 3). The histograms conveniently show the general distribution and ranges of the data. The boundary between the background concentration and geochemical anomaly (threshold value) of a given element was chosen by evaluation of the histograms and spatial distribution of the data. For most elements, this threshold value corresponds approximately to the 90th percentile or greater (table 2). For highly censored elements such as As, Sb, and Sn, threshold values were chosen to be the lower limit of detection (table 2). The ten elements represented on the geochemical maps (maps B and C) are Ag, As, Co, Cr, Cu, Ni, Pb, Sb, Sn, and Zn. Concentrations of barium exceed 10,000 ppm in 60 percent of the samples and were not plotted. However, corresponding stream-sediment samples with barium concentrations of 5,000 ppm or more (Kelley and others, 1995; Kelley and Mull, 1995a) were plotted to show the relation to the distribution of high values of silver, copper, lead, and zinc in the concentrates (map B). In addition to plotting the geochemical data, we plotted the distribution of pyrite, chalcopyrite, galena, sphalerite, barite and scheelite (maps D and E).

GEOCHEMICAL AND MINERALOGICAL DATA

This report presents the results of geochemical analyses of nonmagnetic heavy-mineral-concentrate samples collected from the southern part of the Killik River quadrangle. Results of minus-30-mesh stream-sediment samples are reported in Kelley and others (1995), and a discussion comparing the results of the two sample media are given in Kelley and Kelley (1992).

It is apparent from the geochemical and mineralogical data from nonmagnetic heavy-mineral-concentrate samples that the high concentrations of copper, lead, and zinc are directly related to the host sulfide minerals chalcopyrite, galena, and sphalerite, respectively; cobalt, chromium, and nickel are probably contained in pyrite (maps B through E). Although small amounts of silver may also be contained in pyrite, a high positive correlation between silver and lead indicates that it is probably contained in galena.

Three areas in the southern part of the Killik River quadrangle are delineated by samples that contain anomalous concentrations of Ag, Co, Cr, Cu, Ni, Pb, and(or) Zn: (1) the Grizzly Mountain area including the tributaries of Kugukpak and Sulugiak Creeks (Tps. 32 through 33 N., Rs. 24 through 25 E.), (2) south of Kurupa Lake (T. 32 N., R. 19 E.), and (3) the headwaters of Outwash and Itilyiargiok Creeks (Tps. 32 through 33 N., Rs. 16 through 17 E.). Additional areas defined by concentrates containing scheelite and abundant barite with or without pyrite, and sediment samples with greater than or equal to 5,000 ppm Ba are located along the rangefront from Kikiktat Mountain to Ivotuk Hills; these areas are referred to as the rangefront areas on maps B through E.

As an aid to the interpretation of the regional geochemical data from the southern Killik River quadrangle, R-mode factor analysis with varimax rotation was used on the log-transformed heavy-mineral-concentrate data to define the dominant geochemical associations. This type of factor analysis groups the elements that tend to behave similarly into multielement associations, or factors (Davis, 1973, p. 500). In this way, a large number of variables is reduced to only a few variables that best characterize the original data. The factors produced from R-mode factor analysis reflect geological and geochemical processes.

Although highly censored elements such as silver and zinc are typically excluded from factor analysis, we included these elements because strong positive correlations between lead and zinc, and lead and silver exist in the unqualified data (for example, samples that contain high concentrations of silver also contain high concentrations of lead). Furthermore, results of factor analysis that included silver and zinc were similar to the results yielded from factor analysis excluding these two elements.

We selected a five-factor model (table 3) based on factor-variance diagrams. This five-factor model, explaining 67 percent of the variance within the original data set, is the most meaningful solution for the reconnaissance geochemical data. Factor loadings represent the contribution of each element onto each factor. Factor scores measure the "effect" of a factor on each individual sample. By expressing the data in terms of these five factors, it is possible to distinguish between the trace-element variability related to lithology and that related to mineralization.

Factors 1 and 4 (table 3) account for about 33 percent of the total data variability and represent lithogeochemical associations. Elements that load strongly onto factor 1 include Ca, Ti, B, La, V, Y, and Zr. Most heavy-mineral-concentrate samples containing high scores for this factor contain varying amounts of rutile, zircon, apatite, and sphene. These samples were collected from drainages underlain primarily by the Noatak Sandstone and the Kanayut Conglomerate.

Concentrates derived from local mafic igneous rocks in the vicinity of Kikiktat Mountain contain high factor 4 (Cr-Mg-Mn-Sc-V) scores. Other widely distributed samples containing high scores that are not spatially related to any mafic rocks may represent secondary manganese oxides (present as localized coatings on float rocks).

High factor 2 (Ca-Ba-Sr) scores are due to abundant barite in the concentrate samples. Samples with anomalously high scores for factor 2 are spatially related to exposures of carbonate rocks of the Lisburne Group and shale and siltstone of the Etivluk Group, particularly the Siksikpuk Formation.

Factors 3 and 5 represent mineralization suites (map F). The Ag-Pb-Zn association (factor 3) indicates the presence of galena and sphalerite; samples that have high factor 3 scores contain highly anomalous concentrations of silver, lead, and zinc (with or without copper). The Co-Cu-Fe-Ni-Zn association that characterizes factor 5 defines areas that contain the greatest concentration of pyrite (with or without chalcopyrite and sphalerite); anomalous factor 5 scores are found in samples containing anomalous concentrations of cobalt, chromium, and nickel. As with the single-element distributions, the distribution of samples containing high scores for the mineralization factors broadly define the three geochemically anomalous areas: Grizzly Mountain, the area south of Kurupa Lake, and the headwaters of Outwash and Itilyiargiok Creeks (map F).

GRIZZLY MOUNTAIN AREA

Nonmagnetic heavy-mineral-concentrate samples collected from tributaries south of Grizzly Mountain and the tributaries of Kugukpak and Sulugiak Creeks (Tps. 32 through 33 N., Rs. 24 through 25 E.) contain high concentrations of Ag (5-30 ppm), Co (70-200 ppm), Cu (700-10,000 ppm), Ni (100 ppm), Pb (5,000 to more than 50,000 ppm), and Zn (5,000-20,000 ppm) (maps B and C); these samples also contain pyrite, chalcopyrite, galena, and sphalerite (maps D and E). The abundant pyrite and chalcopyrite result in high factor 5 scores; abundant galena and sphalerite result in high factor 3 scores (map F).

In addition to the sulfide minerals and consequent anomalous concentrations of Ag, Co, Cu, Ni, Pb, and Zn, the sample collected from a small creek located south of Iklauyak Creek contains 5,000 ppm As and 500 ppm Sb (map C). Realgar was found in this sample as well as in one collected from Iklauyak Creek.

The predominant lithologies in the area are the Hunt Fork Shale and the Kanayut Conglomerate. Geochemical data for rock samples collected from the Grizzly Mountain area are listed in table 4. Most of the samples were collected from float in the stream drainages; the majority are quartz veins hosted by the Hunt Fork Shale, but three are samples of the Kanayut Conglomerate containing disseminated pyrite which, in most cases, is highly oxidized. Three of the quartz vein samples contain 130-200 ppm Zn as well as 10 percent Fe; pyrite was found in two of the vein samples and sphalerite was noted in one vein sample. Most of the sulfide-bearing veins occur as thin (1-2 cm) discontinuous veins that probably formed during compaction and diagenesis of the Hunt Fork Shale (Duttweiler, 1987). Three samples of disseminated pyrite in conglomerate and sandstone of the Kanayut Conglomerate were also collected and analyzed. Except for minor enrichments of Ag (1.0-1.9 ppm), these samples contain background concentrations of most elements (table 4).

SOUTHERN KURUPA LAKE AREA

Nonmagnetic heavy-mineral-concentrate samples collected from tributaries southeast of Kurupa Lake (T. 34 N., R. 18 E.) contain anomalous concentrations of Ag (more than 5 ppm), Cu (more than 700 ppm), Pb (more than 20,000 ppm), and Zn (more than 5,000 ppm). Cobalt concentrations of 70-200 ppm are also common in these samples (maps B and C). The sulfide mineralogy is dominated by chalcopyrite and galena, with one sample containing a trace amount of sphalerite. Sulfide-rich samples collected from this area also contain high scores for either factor 3 or 5, or both (map F).

The predominant rock unit in the area is the Kanayut Conglomerate. Iron-oxide staining, probably the result of oxidized disseminated pyrite, was found on many float rocks. Geochemical analysis of the oxidized material yielded low metal contents, with the exception of one sample containing 100 ppm Cr (sample AKD624B; table 4). A quartz vein sample collected from float in this same area contains 200 ppm As and 200 ppm Cu with low concentrations of other metals (sample AKD624A; table 4).

OUTWASH-ITILYIARGIOK CREEKS AREA

Many nonmagnetic heavy-mineral-concentrate samples collected in the western part of the quadrangle at the headwaters of Outwash and Itilyiargiok Creeks (Tps. 32 through 33 N., Rs. 16 through 17 E.) contain anomalous concentrations of Ag (as much as 500 ppm in one sample), Cu (700-1,500 ppm), Pb (5,000 to more than 50,000 ppm), and Zn (5,000-20,000 ppm). Galena and sphalerite are the predominant sulfide minerals in the concentrate samples (map D). Cobalt contents range from 100 ppm to 200 ppm and Ni concentrations of 100 ppm are common (map C). In addition, anomalous concentrations of antimony were found in 4 samples collected from this area: one sample collected from a first-order tributary of Itilyiargiok Creek contains 2,000 ppm Sb, while three samples to the east (T. 32 N., R. 17 E. and R. 18 E.) contain 200-1,500 ppm Sb (map C). There were no Sb-bearing minerals found in the concentrates. The dominant Ag-Cu-Pb-Sb-Zn association is also accompanied by Sn (map B). The values range from 20 ppm to 300 ppm. The sample containing 300 ppm Sn was collected from a first-order tributary of Outwash Creek (T. 32 N., R. 16 E.).

Further field investigation of the geochemical anomalies in this area revealed the locations of two highly mineralized vein systems (Duttweiler, 1987). The northernmost vein system, informally named the Kady occurrence, is located at the headwaters of a tributary of Outwash Creek; the other vein system, the Vidlee occurrence, is located at a tributary to Itilyiargiok Creek.

At the Kady occurrence, disseminated, massive, and quartz-vein-hosted sulfides are present in Upper Devonian sandstone and conglomerate of the Kanayut Conglomerate. The predominant sulfide minerals are sphalerite and pyrite, although galena and chalcopyrite are also present. Sulfide-bearing quartz veins and vein breccias crop out at several localities along the 3.5-km length of the east-west flowing stream (T. 32 N., R. 17 E.). The veins, which strike north to slightly northwest, range in width from 2 cm stockwork veinlets to massive veins nearly 2.5 m wide. In addition, boulders and small cobbles of massive and brecciated sulfides are found at the surface in frost boils and colluvium.

In addition to the Kady occurrence, numerous mineralized veins occurrences were found either as float or outcrop in tributaries of Outwash Creek to the northeast and southwest of the Kady occurrence (Meyer and Kurtak, 1992).

Mineralized rocks at the Vidlee occurrence are primarily sulfide-bearing veins and breccias hosted in shale and shaly siltstone of the Upper Devonian Hunt Fork(?) Shale. Galena, pyrite, and sphalerite are the predominant minerals. The mineralized outcrop is exposed at stream level over a distance of about 25 m. It cannot be traced either horizontally or vertically from this exposure due to tundra cover. Individual veins range from 1.5 cm to as much as 1.5 m in width, and strike nearly due north. Much of the mineralized material consists of breccias with shale and sandstone clasts rimmed with quartz and containing sulfides in the interstices.

The results of geochemical analyses of rock samples collected from these areas are listed in table 4. Mineralized rocks from the Kady area contain as much as 150 ppm Ag, 500-1,000 ppm As, 780-1,900 ppm Cd, 1,500 to more than 20,000 ppm Cu, 500-700 ppm Pb, and as much as 21 percent (210,000 ppm) Zn. Mineralized rocks collected from the Vidlee occurrence contain highly anomalous concentrations of Ag (150-300 ppm), As (as much as 6,400 ppm), Au (0.05-0.75 ppm), Cd (2,500-2,800 ppm), Cu (1,500-10,000 ppm), Pb (1,000 to more than 20,000 ppm), Sb (as much as 2,000 ppm), and Zn (14-25 percent). In addition to the anomalous concentrations of these elements, a few rocks contain high concentrations of cobalt and nickel, which reflects the abundance of pyrite in the veins, and several contain 200-300 ppm Sn (not shown on table 4).

RANGEFRONT AREAS

Nonmagnetic heavy-mineral-concentrate samples collected along the rangefront contain abundant barite (map D), and highly anomalous concentrations of barium (more than 10,000 ppm Ba is ubiquitous in nonmagnetic heavy-mineral-concentrate samples collected along the rangefront). Scheelite was found in several of the barium-rich concentrate samples (map D), although tungsten was not detected. Many samples contain greater than 20 percent pyrite (map E) and a few contain a trace amount (a few grains) of sphalerite and (or) galena (map D).

The source of the barite in the concentrates is most likely barite nodules, lenses, and veins in the Siksikpuk Formation of the Etivluk Group (Siok, 1985) that crops out along the rangefront from Otuk Creek to Kikiktat Mountain. The source of the scheelite is not known. Pyrite is present in two formations belonging to 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). Shale and chert of the Kayak Shale (Mk) and Kuna Formation (PMk) are also exposed along the rangefront and are additional possible sources of barite and base-metal sulfide minerals in the concentrate samples.

Based on the geochemical and mineralogical anomalies in nonmagnetic heavy-mineral-concentrate samples, detailed geochemical studies along the rangefront focused on three areas: (1) Ivotuk Hills and Otuk Creek in the western part of the quadrangle, (2) Kurupa Hills, and (3) Kikiktat Mountain.

The Ivotuk Hills consist primarily of carbonate rocks of the Lisburne Group and rocks of the Etivluk Group (units PMl and JPe; map A). In this area, the carbonate rocks and chert contain mostly background concentrations of most elements except barium, which is anomalously high in chert. However, one chert sample (the Otuk Formation of the Etivluk Group) contains 200 ppm Co, 500 ppm Cu, more than 5,000 ppm Mn, and 100 ppm Ni (sample AKD627D; table 4). Two black shale samples (samples AKD106 and AKD631A; table 4) 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 may indicate the presence of sulfide minerals. The only sulfides observed in the field were massive pyrite concretions found in float in a stream draining the west side of Ivotuk Hills; one of these pyrite concretions contains red-brown sphalerite in the core. The pyrite concretion without visible sphalerite contains 200 ppm As, greater than 20 percent Fe, and 500 ppm Zn (sample AKD627C; table 4).

At the headwaters of Otuk Creek, sulfide-bearing concretions hosted by the Lower Mississippian Kayak Shale were found to be abundant in one outcrop. The concretions range in size from 7.6 cm to 20 cm in diameter. They contain abundant calcite, and minor amounts of sulfide minerals, including red-brown sphalerite, galena, chalcopyrite, and pyrite. Geochemical analyses of the concretions are listed in table 4 (samples AKD625B, and AKD625C). In addition to anomalous concentrations of Fe (20 percent), the samples contain elevated concentrations of Ag (0.8-2.3 ppm), Ba (more 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 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 the source of anomalous concentrations of base metals in concentrate samples collected elsewhere along the rangefront.

Sooty black shale of the Kuna Formation hosts the Red Dog stratiform Ag-Ba-Pb-Zn 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 Otuk Creek and the Kurupa Hills. Although no sulfide minerals were found, one chert sample of the Kuna Formation from Otuk Creek (sample AKD625F; table 4) contains 200 ppm Zn, 700 ppm Ba, and 3 ppm Ag, which are high relative to other chert samples from the Killik River quadrangle (table 4).

In the Kurupa Hills area (T. 12 S., Rs. 17 E. and 18 E.), abundant barite and minor pyrite were found in concentrate samples. Chip samples were collected through the Mississippian to Triassic chert and shale sequence. However, the samples contain only average concentrations of most elements (table 4).

At Kikiktat Mountain (T. 12 S., R. 20 E.), concentrate samples contain abundant barite and minor pyrite. Chert and mafic igneous rocks at Kikiktat Mountain contain local disseminated pyrite and chalcopyrite. Background trace element concentrations in 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 generally contain 500-3,000 ppm Ba, 10-30 ppm Cu, 10-20 ppm Cr, 10 ppm Co, and 0.5-1 ppm Ag (table 4). 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.

CONCLUSIONS

Nonmagnetic heavy-mineral-concentrate samples collected from the Killik River quadrangle exhibit a dominant geochemical association of Ag-Pb-Zn (with or without Cu). The Grizzly Mountain area in the eastern part of the quadrangle is characterized by anomalous concentrations of these elements as well as As, Co, Cr, Ni, and Sb. Galena, sphalerite, pyrite, and chalcopyrite were found in most of the concentrates collected from this area; realgar was found in two samples collected south of Grizzly Mountain. Thin (1-2 cm) quartz-carbonate veins containing minor pyrite, sphalerite, or galena were found during follow-up geochemical studies. The veins, which are hosted primarily by the Hunt Fork Shale, appear to have formed during low-grade metamorphism. Although these veins are the only source of sulfides identified, the large area delineated by highly anomalous element concentrations in the concentrate samples indicates that a more extensive mineralized source exists (Kelley and Kelley, 1992).

Similar to the Grizzly Mountain area, numerous nonmagnetic heavy-mineral-concentrate samples collected from the headwaters and tributaries of Outwash and Itilyiargiok Creeks in the western part of the quadrangle contain anomalous concentrations of Ag, Co, Cu, Ni, Pb, and Zn (with or without Sb and Sn). Two mineralized vein systems, informally named the Kady and Vidlee occurrences, were discovered as a result of follow-up geochemical studies in this area. Both are hosted by Upper Devonian clastic rocks; in addition to Ag, Cu, Pb, and Zn, mineralized rocks contain anomalous concentrations of As, Au, Sb, and minor Sn.

Heavy-mineral-concentrate samples collected along the rangefront contain abundant barite and minor pyrite, as well as scattered occurrences of sphalerite. Rocks of the Etivluk Group, particularly the Siksikpuk Formation, are probably the source of much of the barite and pyrite. In the Ivotuk Hills area, high concentrations of silver and zinc in shale indicate that sphalerite and other sulfide minerals may also be present. Other possible sources of barite and sulfide minerals in concentrate samples collected from the headwaters of Otuk Creek and east along the rangefront to the Kurupa Hills are the Kayak Shale and Kuna Formation. Sulfide-bearing concretions were found in the Kayak Shale at one locality along Otuk Creek; although no sulfide minerals were observed in the Kuna Formation, silver and zinc concentrations in one chert sample from Otuk Creek are high relative to others. Finally, igneous rocks containing pyrite and minor chalcopyrite and shale and chert containing barite and pyrite were found at Kikiktat Mountain; these are the most likely source rocks for abundant pyrite and barite in concentrate samples collected from this area.

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GEOCHEMISTRY AND MINERALOGY OF HEAVY-MINERAL CONCENTRATES FROM THE KILLIK RIVER 1° × 3° QUADRANGLE, ALASKA

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