The Alaska Mineral Resource Assessment Program—Background Information to Accompany Geologic and Mineral-Resource Maps of the Killik River 1°×3° Quadrangle, Northern Alaska

U.S. GEOLOGICAL SURVEY CIRCULAR 1117

Cover. View from hill west of Kikiktat Mountain looking south toward Gates of the Arctic National Park. Akmalik Creek runs through the center of the photograph. The low hills in the foreground are underlain by chert of Jurassic to Mississippian age and graywacke of the Lower Cretaceous Okpikruak Formation. Carbonate rocks of the Mississippian and Pennsylvanian Lisbourne Group form the knife-edge ridges in the center of the photograph. The mountains in the background are made up of clastic rocks of the Upper Devonian and Lower Mississippian(?) Kanayut Conglomerate. Photograph by Karen Duttweiler Kelley, June 18, 1982.

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By K.D. Kelley *and* C.G. Mull

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The Alaska Mineral Resource Assessment Program—Background Information to Accompany Geologic and Mineral-Resource Maps of the Killik River 1°×3° Quadrangle, Northern Alaska

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ABSTRACT

This report summarizes results of integrated geological, geochemical, and geophysical field and laboratory studies conducted by the U.S. Geological Survey in the Killik River 1°×3° quadrangle, Brooks Range, northern Alaska. These studies were designed to provide an assessment of the mineral resources of the quadrangle.

The geological and geochemical data were the primary sources of information used to assess the mineral-resource potential of the quadrangle. The presence of permissive host rocks and favorable geochemical signatures in stream- and lake-sediment and (or) heavy-mineral-concentrate samples were used to infer the potential for undiscovered resources of minerals in deposits of different types. The Killik River quadrangle may contain undiscovered resources of precious- and base-metals (principally lead, silver, and zinc) in veins and breccias hosted by Devonian and Mississippian clastic sedimentary rocks or in stratiform massive sulfide deposits hosted primarily by Mississippian and Pennsylvanian sedimentary rocks. Resources of barium, phosphate, and manganese may be present in Mississippian to Jurassic sedimentary rocks. Cretaceous fluvial sedimentary rocks in the northern part of the quadrangle are permissive hosts for uranium deposits, as well as for placer deposits of heavy minerals such as gold and chromite; however, geochemical data suggest that the potential for deposits of this type is low. Numerous coal beds are present in the Cretaceous rocks throughout the northern part of the quadrangle, but the limited thickness and lateral extent of most of the beds reduce their resource potential. Although the southern third of the quadrangle has no potential for petroleum resources, there is potential in the northern two-thirds.

INTRODUCTION

PURPOSE AND SCOPE

Field and laboratory studies in the Killik River 1°×3° quadrangle of northern Alaska were conducted from 1981 to 1986 as part of the Alaska Mineral Resource Assessment Program (AMRAP). The overall objective was to provide geologic, geophysical, and geochemical data for delineating areas favorable for hosting mineral deposits. The studies were also aimed at enhancing the geologic knowledge of a remote area that has received few recent earth-science investigations. A list of maps and reports that provide the primary mineral-resource data for the Killik River quadrangle is given in table 1. Other sources of information on the geology of the quadrangle are cited in the text and listed in the accompanying references.

Geological and geochemical data were the primary sources of information used to assess the mineral resource potential of the Killik River quadrangle. These data were evaluated utilizing mineral deposit models (Cox and Singer, 1986). Geophysical data from the Killik River quadrangle were of limited use, however, because only aeromagnetic data are available for the entire quadrangle (U.S. Geological Survey, 1983). Furthermore, the flight lines were flown parallel with the range crest, making leveling from line to line, and thus evaluation of the aeromagnetic data, difficult (D.L. Campbell, oral commun., 1991).

GEOGRAPHY AND ACCESS

The Killik River quadrangle is in the central part of the Brooks Range and Arctic Foothills physiographic provinces

Table 1. Geologic, geochemical, geophysical, and mineral-resource maps and reports of the Killik River 1°×3° quadrangle, northern Alaska.

Reference	Subject
Barton and others (1982)	Analytical data for stream-sediment and nonmagnetic heavy-mineral-concentrate samples collected during the Alaska Mineral Resource Assessment Program (AMRAP) survey.
Los Alamos National Laboratory (1982)	Analytical data for stream- and lake-sediment samples collected during the National Uranium Resource Evaluation (NURE) Program.
U.S. Geological Survey (1983)	Aeromagnetic survey.
Sutley and others (1984)	Analytical data for stream-sediment and nonmagnetic heavy-mineral-concentrate samples collected during the AMRAP survey.
Motooka and others (1989)	Analytical data for stream-sediment samples collected during the AMRAP and NURE surveys.
Mull and others (1994)	Geologic map of the Killik River quadrangle (1:125,000 scale).
Kelley and others (1995a)	Geochemical maps and interpretations of stream-sediment geochemical data for the southern part of the quadrangle.
Kelley and others (1995b)	Geochemical maps and interpretations of nonmagnetic heavy-mineral-concentrate geochemical data for the southern part of the quadrangle.
Kelley and Mull (1995a)	Mineral-resource assessment; generalized geologic map (1:250,000 scale), and delineation and characterization of areas having potential for undiscovered resources of metallic and nonfuel minerals.
Kelley and Mull (1995b)	Geochemical maps and interpretation of stream- and lake-sediment geochemical data for the northern part of the quadrangle.

(Wahrhaftig, 1965), along the northern flank and foothills of the Endicott Mountains (figs. 1, 2). About half of the quadrangle lies within the National Petroleum Reserve in Alaska (NPRA), and half is in Gates of the Arctic National Park. The quadrangle is also within an area designated as the Colville mining district by the U.S. Bureau of Mines (fig. 1).

Topography varies from moderately steep terrain in the Endicott Mountains in the southern part of the quadrangle to nearly flat in the northern part of the quadrangle. The highest elevation is 2,236 m (7,335 ft). Although the mountains were extensively glaciated during Tertiary and Quaternary time, glaciers are presently confined to a few north-facing cirques at elevations above 1,500 m (5,000 ft) in the highest part of the mountains. 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, flowering plants, and peat. Permafrost underlies the entire area.

There is no year-round human habitation in the study area. The nearest supply centers are at Anaktuvuk Pass (50 km to the east), Barrow (250 km to the north), Kotzebue (400 km to the southwest), and Fairbanks (about 480 km to the south). Access is limited to aircraft, boat, snowmachine, or foot travel. All-weather gravel-surfaced airstrips are available at the abandoned Lisburne No. 1 test well site at the western end of the Ivotuk Hills and at the abandoned Killik No. 1 test well site north of Kikiktat Mountain; an unimproved, marginally usable airstrip on a gravel bar is at the confluence of the Etivluk and Colville Rivers in the extreme northwest part of the quadrangle (fig. 2). Rivers navigable by raft or canoe include the Killik, Okpikruak, and Colville Rivers.

Acknowledgments.—Many colleagues participated in the earth-science investigations of the Killik River quadrangle that are summarized in this circular. We gratefully acknowledge their important contributions, many of which are cited in the accompanying list of references. In particular, we acknowledge Harlon N. Barton, Stanley E. Church, John Haggard, and Sally K. Odland, who assisted in field work related to the reconnaissance geochemical survey. Jim Domenico, Harlan Barton, Steve Sutley, and Rich O'Leary provided analytical assistance. Fossils were identified by J.T. Dutro, Jr., A.G. Harris, and K.M. Reed. We also thank D. L. Campbell for his interpretation of the geophysical data from the quadrangle. Finally, our gratitude to our helicopter pilot, Mose Car, for safely transporting us to peaks, ridges, and valleys during several years of field work.

LAND STATUS

The Killik River 1°×3° quadrangle is mostly federally administered public land. The National Petroleum Reserve in Alaska (NPRA) is under the jurisdiction of the U.S. Bureau of Land Management, whereas the Noatak National Preserve (in the extreme southwestern part of the quadrangle) and Gates of the Arctic National Park are administered by the National Park Service. Figure 2 shows the location and classification of Federal lands and State of Alaska and Native land selections within the quadrangle.

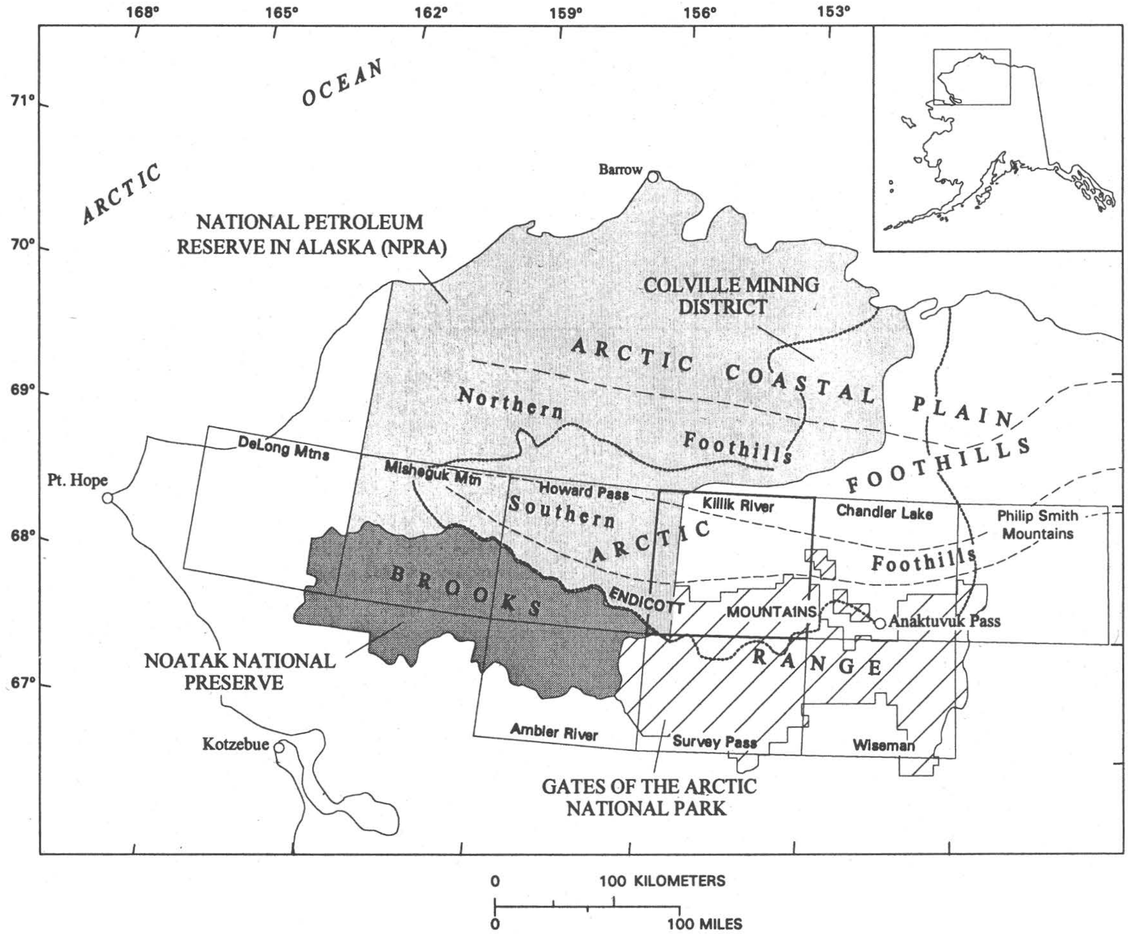


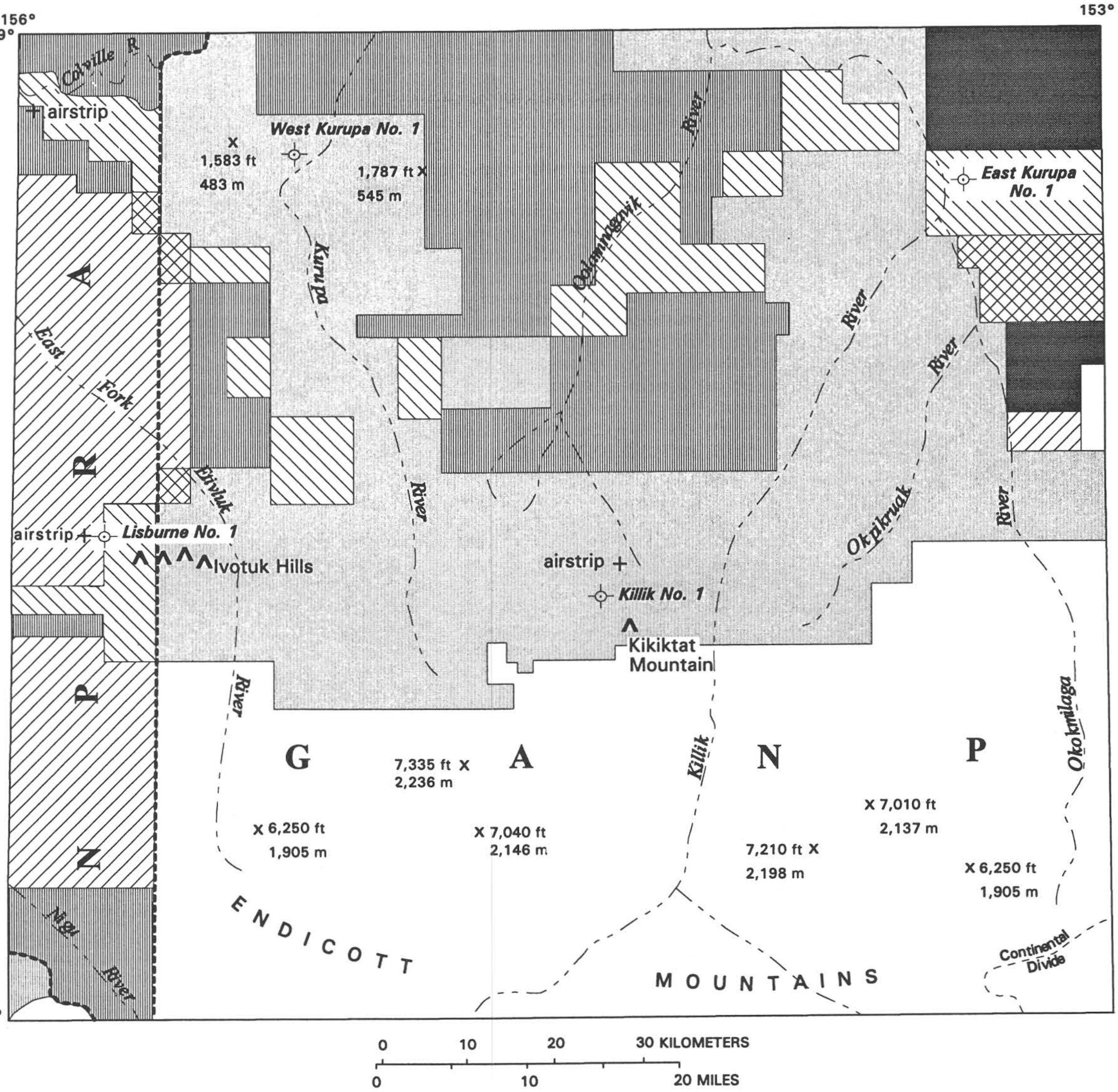
Figure 1. Map showing location of the Killik River 1°×3° quadrangle and other quadrangles in the Brooks Range, northern Alaska.

MINERAL AND ENERGY PRODUCTION AND EXPLORATION

There has been no commercial production of metallic mineral or energy resources in the Killik River 1°×3° quadrangle, and until this AMRAP study there were no known occurrences or deposits. Mineral and energy exploration and studies related to resource evaluation in the Killik River quadrangle and adjacent areas began in the early 1900's and have continued to the present. The earliest studies in the Brooks Range were conducted by geologists and geographers (Schrader, 1904; Brooks, 1909). Oil seeps and favorable geologic structures described in these reports and by early U.S. Navy expeditions led President Harding to establish the Naval Petroleum Reserve No. 4 (also called NPR-4 and later renamed NPRA) in 1923. From 1923 to 1926, the U.S. Navy commissioned the U.S. Geological Survey (USGS) to assess the potential for oil and other mineral resources in NPR-4 as well as in adjacent areas to the east, including much of the Killik River drainage area. The results of these investigations are summarized in Smith and Mertie (1930) and include the first topographic and geologic maps of the area.

Concern for long-term petroleum supplies during World War II prompted further geologic investigations of NPR-4. As a result, a geologic and topographic mapping program was conducted from 1944 to 1953 in NPR-4 and adjacent areas (Detterman and others, 1963; Chapman and others, 1964; Patton and Tailleur, 1964). During these investigations, the only minerals noted were occurrences of sedimentary phosphate at widely scattered locations along the northern front of the Brooks Range and in the adjacent foothills. Detailed studies of selected phosphate occurrences were conducted by Patton and Matzko (1959), and as part of these studies selected rock samples were collected from the Killik River quadrangle and analyzed for phosphate and uranium.

In 1976, under the Naval Petroleum Reserves Production Act, Congress renamed NPR-4 the National Petroleum



EXPLANATION

- GANP — Gates of the Arctic National Park (administered by National Park Service)
- NPRA — National Petroleum Reserve in Alaska (NPRA) (administered by U.S. Bureau of Land Management)
- Noatak National Preserve (administered by National Park Service)
- State-owned land
- Native-owned land
- Native selection
- State selection
- Native and State selection
- U.S. Bureau of Land Management land open for selection

Figure 2 (facing page). Map showing geographic and physiographic features and land status within the Killik River 1°×3° quadrangle, northern Alaska.

Reserve in Alaska (NPRA) and transferred administration of the reserve to the U.S. Department of the Interior. The USGS, as an agency in the Department of the Interior, was directed to continue exploration in the reserve to aid in assessing petroleum and other resources (Carter and others, 1977; Schindler, 1988). Extensive geophysical surveys were conducted in the NPRA and a number of exploratory wells drilled under contract by Husky Oil, but there were no significant petroleum discoveries. One of these wells, Lisburne No. 1, was drilled in the Killik River quadrangle (fig. 2). Data obtained from the Lisburne No. 1 well and from the geophysical surveys are available from the National Geophysical Data Center (Ikelman, 1986). Interpretation of much of the seismic and borehole data and results of USGS mapping and field studies in NPRA are summarized by Gryc (1988).

Three wells were drilled in the Killik River quadrangle outside NPRA. Two wells, West Kurupa No. 1 and East Kurupa No. 1, were drilled by Texaco, Inc., in 1976, and Chevron USA, Inc., drilled Killik No. 1 in 1980. Drillhole data from the Kurupa wells are available from Petroleum Information, Inc. (243 5th Ave., Anchorage, Alaska 99501, unpub. data, 1992), but no data from the Killik No. 1 well have been released.

Numerous studies have focused on uranium and coal resources in the Arctic Foothills, which includes parts of the central and northern Killik River quadrangle. Huffman (1985) evaluated the potential for uranium deposits in Cretaceous sandstone and conglomerate. Coal deposits are widespread in the Arctic Foothills and have been the subject of numerous reports (Barnes, 1967; Affolter and Stricker, 1987; Roehler, 1987; Sable and Stricker, 1987).

In 1978, much of the mountainous land in the southern part of the Killik River and adjacent quadrangles was designated by Presidential proclamation as Gates of the Arctic National Park. Since then, access has been limited, and few mineral-exploration or geologic studies have been conducted other than by governmental agencies such as the Alaska Division of Geological and Geophysical Surveys and the USGS.

During the late 1970's and 1980's, the USGS conducted multidisciplinary mineral-resource assessments of several quadrangles adjacent to the Killik River quadrangle. Churkin and others (1978) conducted a mineral-resource assessment of the NPRA in the area west of the Killik River quadrangle, including parts of the Howard Pass and Misheguk Mountain quadrangles. Mineral-resource assessments were also prepared for the Ambler River quadrangle on the southwest (Mayfield, Tailleur, Albert, and others, 1983), the Wiseman quadrangle on the southeast (Bliss and others, 1988), and the Chandler Lake quadrangle (Church and others, 1995) and Philip Smith Mountains quadrangle (Reiser and others, 1983; Menzie and others, 1985) on the east.

For the AMRAP investigations of the Killik River quadrangle, which began in 1981, geologic, geochemical, and geophysical field and laboratory studies were undertaken by the Alaska Division of Geological and Geophysical Survey and the USGS. Detailed geologic mapping was conducted in specific areas, and a geologic map of the Killik River quadrangle at a scale of 1:125,000 was prepared (Mull and others, 1994). This map was generalized and published at a scale of 1:250,000 (Kelley and Mull, 1995a). A map of the Quaternary deposits was published by Hamilton (1980).

Reconnaissance and detailed geochemical surveys conducted in the southern part of the Killik River quadrangle are summarized by Kelley and others (1995a, b). These surveys included collection of stream-sediment, nonmagnetic heavy-mineral-concentrate, and rock samples. In addition, lake- and stream-sediment data collected in the northern part of the quadrangle during the National Uranium Resource Evaluation Program (NURE) (Los Alamos National Laboratory, 1982) were evaluated and interpreted by Kelley and Mull (1995b).

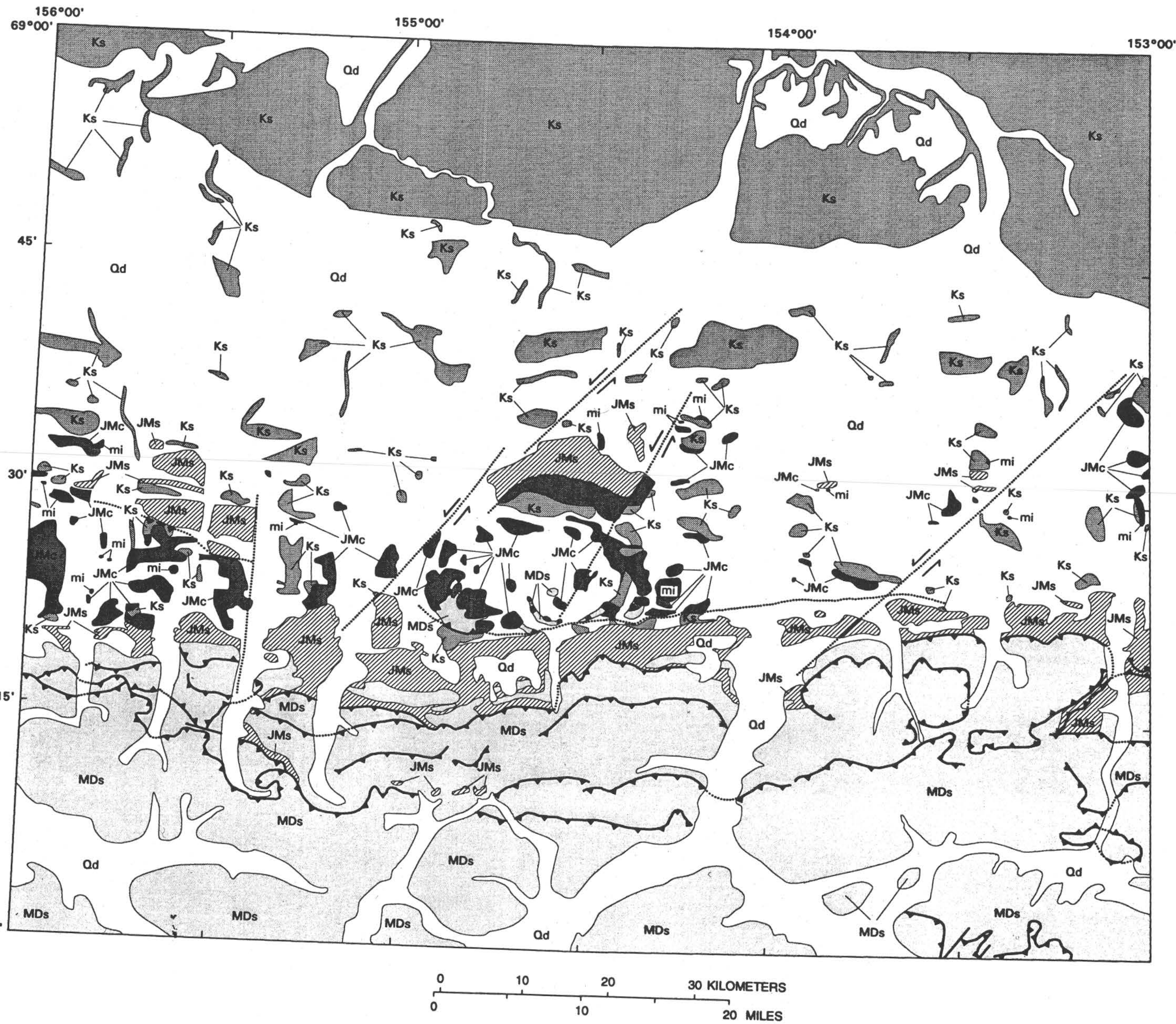
During the course of the geochemical studies in the Killik River quadrangle, four base-metal sulfide mineral occurrences were discovered. At two of these, Ivotuk Hills and Otuk Creek, the cores of iron-rich concretions contain sulfide minerals (pyrite, sphalerite, galena, or chalcopyrite). The other two, informally named the Kady and Vidlee occurrences, consist of sulfide-bearing quartz veins and breccias hosted by clastic sedimentary rocks. The dominant sulfide minerals are galena, pyrite, and sphalerite, but minor chalcopyrite is also locally present. Detailed descriptions of these four occurrences and the geochemical exploration criteria used to delineate them are summarized in Duttweiler (1987), Kelley and Kelley (1992), and Kelley and Mull (1995a).

Geophysical studies conducted during the AMRAP investigations were limited. An aeromagnetic survey was flown across the Killik River quadrangle by the USGS to provide regional data for the AMRAP study (U.S. Geological Survey, 1983), but, because the flight lines were flown parallel with the range crest, leveling from line to line, and thus evaluation of the data, is difficult (D.L. Campbell, oral commun., 1991).

All available geologic, geochemical, and geophysical data collected during the AMRAP study were compiled, and summary maps were prepared that define areas favorable for the occurrence of specific types of mineral resources (Kelley and Mull, 1995a).

GEOLOGY

The Brooks Range is an east-trending fold and thrust belt that extends for nearly 800 km across northern Alaska. It 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, mostly consists of Paleozoic sedimentary rocks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JMc
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EXPLANATION

Qd **Quaternary surficial deposits**

Ks **Sedimentary rocks (Cretaceous)**--Includes Colville Group, Nanushuk Group, Torok Formation, Fortress Mountain Formation, and Okpikruak Formation

mi **Mafic igneous rocks (Triassic(?) to Pennsylvanian)**

JMc **Sedimentary rocks (Jurassic to Mississippian)**--Includes Imnaitchiak Chert, Akmalik Chert of Lisburne Group, and local quartzose sandstone and thin Kayak Shale at base

JMs **Sedimentary rocks (Jurassic to Mississippian)**--Includes Etivluk Group, Lisburne Group, and Kayak Shale

MDs **Sedimentary rocks (Early Mississippian(?) to Late Devonian)**--Includes Kanayut Conglomerate, Noatak Sandstone, and Hunt Fork Shale

Contact

Thrust fault--Sawteeth on upper plate. Dashed where approximately located; dotted where concealed

Fault--Arrows show orientation of movement. Dashed where approximately located; dotted where concealed

Figure 3. Generalized geologic map of the Killik River 1°×3° quadrangle, northern Alaska. Modified from Mull and others (1994).

in a series of thrust sheets that were stacked together during the Mesozoic orogenesis. The southern foothills 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, Tailleur, and Ellersieck, 1983). These allochthons were thrust from the south during the formation of the Brooks Range. Farther to the north, in the northern foothills, the Colville Basin is a depositional foredeep that is filled with more than 6,000 m of deltaic sedimentary deposits of Cretaceous age derived from the range.

Figure 3 shows the generalized geology of the Killik River 1°×3° quadrangle. More detailed geologic maps and unit descriptions are given in Mull and others (1994) and Kelley and Mull (1995a). The quadrangle area consists mainly of Devonian to Cretaceous sedimentary rocks and minor mafic igneous rocks. The oldest rocks belong to the Upper Devonian Hunt Fork Shale, which consists of phyllitic shale, wacke, brown-weathering calcareous siltstone, and fine-grained sandstone. Rocks of the Hunt Fork Shale 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 (Nilsen and Moore, 1984), which in turn is overlain by the Kanayut Conglomerate. The Kanayut Conglomerate is an Upper Devonian and Lower Mississippian(?) nonmarine sequence (Nilsen and Moore, 1984; Brosgé and others, 1988). It is as thick as 2,600 m and extends from east to west for more than 900 km across the Brooks Range. Sedimentary features indicate that deposition of the Kanayut Conglomerate occurred in a deltaic environment with chert-rich source areas to the north and northeast (Nilsen and others, 1981).

The sedimentary section of Hunt Fork Shale to Kanayut Conglomerate (unit MDs, fig. 3) represents a southward- or southwestward-prograding deltaic complex; 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 (included in unit JMs, fig. 3) that consist dominantly of shale and lesser amounts of siltstone, sandstone, and limestone (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 and 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 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 (included in unit JMs, fig. 3), which consists of the Permian Siksikpuk Formation and the Triassic and Jurassic Otuk Formation (Mull and others, 1982). The Siksikpuk Formation consists of about 100 m of pyritic siltstone, mudstone, greenish-gray silicified mudstone or chert, and an upper gray shale horizon. The siltstone and mudstone characteristically contain thin white barite seams and crystal aggregates (Siok, 1985). The Otuk Formation is also about 100 m thick and consists of a basal interval of black shale that grades upward into black silicified limestone and shale containing abundant pelecypod fossils (Mull and others, 1982).

North of the range front in the central part of the quadrangle is a belt of complexly deformed rocks emplaced by long-distance thrust faulting from the south. The stratigraphy of this belt consists primarily of relatively thin Upper Mississippian and Lower Pennsylvanian black pyritic chert and limestone of the Akmalik Chert and other unnamed rocks 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). Locally, the siliceous rocks of the Lisburne Group 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 in figure 3. The deformed belt also contains the Lower Cretaceous Okpikruak Formation (included in unit Ks). This formation consists dominantly of graywacke and interbedded mudstone and shale, but local massive boulder conglomerate and chaotic debris-flow deposits are also locally present. These Lower Cretaceous rocks represent the oldest detritus derived from uplift of the Brooks Range.

Mafic igneous rocks (unit mi, fig. 3) of Pennsylvanian to Triassic(?) age intrude some of the allochthonous siliceous rocks and limestone of the deformed belt. In addition, pillow basalt and other extrusive igneous rocks are present in the central part of the quadrangle and at one location near the western edge of the quadrangle. The extrusive igneous rocks are an erosional remnant of oceanic crust transported by thrust faulting from the south and emplaced during the formation of the range (Mull and others, 1987).

The complexly deformed rocks are unconformably overlain by relatively gently folded conglomerate and graywacke of the Lower Cretaceous Fortress Mountain Formation (part of unit Ks, fig. 3). 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 is within the northern foothills and contains gently deformed clastic rocks of the Lower and Upper Cretaceous Nanushuk Group (Detterman and others, 1963; Huffman, 1989) deposited in the Colville Basin. The Nanushuk Group is a deltaic clastic wedge composed of interbedded conglomerate, sandstone, coal, and shale. It is composed of sediments derived primarily from preexisting sedimentary rocks but also variably 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 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-trending synclines and more tightly folded anticlines. Locally, poorly exposed interbedded marine sandstone and shale of the Upper Cretaceous Colville Group (Detterman and others, 1963) overlie Nanushuk rocks, and Quaternary surficial deposits cover most of the central and northern parts of the quadrangle (fig. 3).

GEOCHEMICAL INVESTIGATIONS

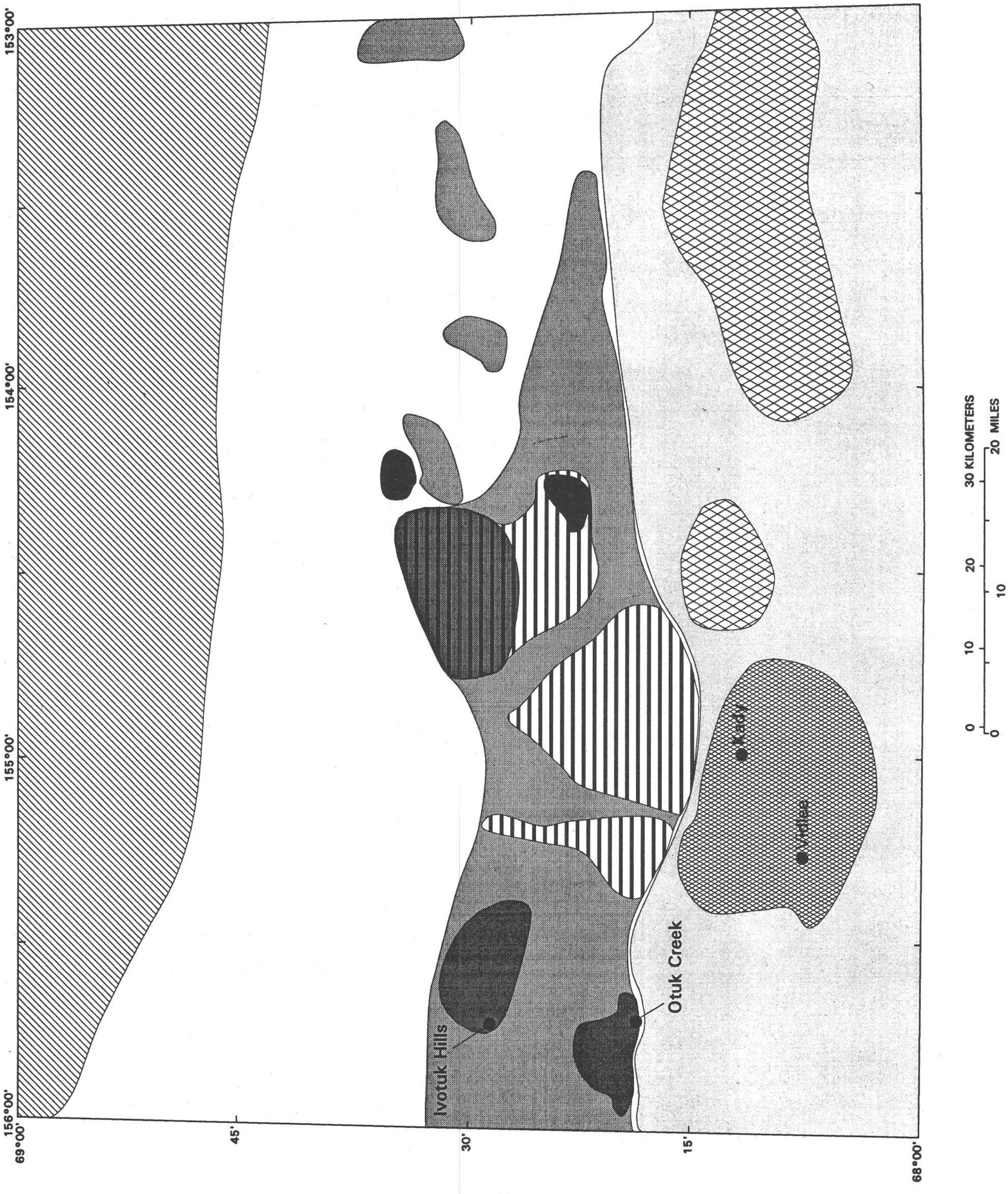
Two reconnaissance geochemical surveys have been conducted in the Killik River 1°×3° quadrangle. The northern part of the quadrangle (the area north of the Gates of the Arctic National Park) was sampled in 1981 during the NURE program. A total of 65 lake-sediment samples and 554 stream-sediment samples were collected as part of this survey (Los Alamos National Laboratory, 1982). All samples were analyzed for 42 elements by neutron activation analysis, X-ray fluorescence, and delayed neutron counting. The data were evaluated and interpreted by Kelley and Mull (1995b).

As part of the AMRAP study, the U.S. Geological Survey also conducted a reconnaissance geochemical survey of the Killik River quadrangle from 1981 through 1986. 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. The primary emphasis during this survey was on the southern and central parts of the quadrangle. Samples were collected at a density of approximately 1 sample per 5 km^2 (2 mi^2) in the mountainous southern third of the quadrangle and 1 sample per 13 km^2 (5 mi^2) in the foothills north of the range front. Except for 65 stream-sediment and concentrate samples that were collected in the northern part of the quadrangle for comparison with samples collected during the earlier NURE program, the northern part of the quadrangle was not resampled during the AMRAP study.

All samples collected during the AMRAP study were analyzed by semiquantitative emission spectrography (Grimes and Marranzino, 1968), and selected elements in the stream-sediment samples were determined by atomic absorption spectrophotometry (Thompson and others, 1968; Viets and others, 1984) and inductively coupled plasma-atomic emission spectroscopy (Church, 1981). In addition, the nonmagnetic heavy-mineral-concentrate samples were examined microscopically to determine the type and approximate percentage of heavy minerals in each sample. The geochemical data were tabulated by Barton and others (1982), Sutley and others (1984), and Motooka and others (1989); evaluation and interpretation of the data were made by Kelley and others (1995a, b). These interpretive reports include the results of R-mode factor analysis to define dominant geochemical associations within stream-sediment and nonmagnetic heavy-mineral-concentrate data sets and detailed descriptions of geochemical anomalies.

Three distinct signatures or element associations were identified in the geochemical and mineralogical data that likely relate to metallic mineral occurrences. (1) Nonmagnetic heavy-mineral-concentrate and (or) stream-sediment samples contain anomalous concentrations of silver, lead, and zinc (with or without gold and copper); the concentrate samples commonly contain galena, pyrite, and sphalerite (with or without chalcopyrite). (2) Lake- and stream-sediment samples contain anomalous concentrations of silver, barium, manganese, and zinc (with or without arsenic, cadmium, and lead), and concentrate samples contain anomalous concentrations of barium (with abundant barite). (3) Lake- and stream-sediment samples contain anomalous concentrations of chromium (with or without nickel).

The stream-sediment and concentrate samples characterized by anomalous concentrations of silver, gold, copper, lead, or zinc (geochemical signature 1) were collected primarily from the southern third of the quadrangle, which consists of Devonian and Mississippian clastic sedimentary rocks (unit MDs, fig. 3). The geochemically anomalous samples are generally concentrated in three areas. The first area is in the southwestern part of the quadrangle in the vicinity of the Kady and Vidlee sulfide mineral occurrences (fig. 4). Numerous stream-sediment samples collected from this area contain 0.7–1.0 ppm Ag, 70–100 ppm Cu, 50–300 ppm Pb, and 200–1,500 ppm Zn; two of these sediment samples also contain anomalous concentrations of gold (0.05–0.1 ppm). In addition, nonmagnetic heavy-mineral-concentrate samples contain 5–500 ppm Ag, 700–10,000 ppm Cu, 5,000 to more than 30,000 ppm Pb, and 5,000–20,000 ppm Zn; trace amounts to 1 percent galena and sphalerite and 50 percent or more pyrite are present in these samples (Kelley and others, 1995a, b). Detailed studies in this area led to the discovery of the Kady and Vidlee sulfide occurrences, which are sulfide-bearing quartz veins and breccias hosted by sandstone, siltstone, or conglomerate. The dominant sulfide minerals are galena, pyrite, and sphalerite, but minor chalcopyrite is also present. In addition to silver, lead, and zinc, mineralized rocks contain anomalous concentrations of gold and copper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Ivotuk Hills
Otuk Creek
Kady
0 10 20 30 KILOMETERS
0 10 20 MILES

EXPLANATION

SEDIMENTARY EXHALATIVE MASSIVE SULFIDE DEPOSITS (SILVER, LEAD, AND ZINC, WITH OR WITHOUT BARIUM)

Low resource potential (certainty level C*); permissive host rocks; no significant geochemical anomalies in stream- or lake-sediment samples

Moderate resource potential (certainty level C*); permissive host rocks; many stream- and lake-sediment samples contain anomalous concentrations of silver, arsenic, barium, manganese, lead, or zinc; nonmagnetic heavy-mineral-concentrate samples contain anomalous concentrations of Ba; area contains occurrences of iron-rich sulfide-bearing concretions

VEIN BRECCIAS (SILVER, LEAD, AND ZINC, WITH OR WITHOUT GOLD AND COPPER)

Moderate resource potential (certainty level B*); permissive host rocks; few scattered nonmagnetic heavy-mineral-concentrate and (or) stream-sediment samples contain anomalous concentrations of silver, copper, lead, or zinc; few concentrate samples contain galena, pyrite, or sphalerite

High resource potential (certainty level C*); permissive host rocks; many nonmagnetic heavy-mineral-concentrate and a few stream-sediment samples contain highly anomalous concentrations of silver, copper, lead, or zinc; concentrate samples contain variable amounts of galena, pyrite, and sphalerite (with or without chalcopyrite)

High resource potential (certainty level D*); permissive host rocks; numerous nonmagnetic heavy-mineral-concentrate and (or) stream-sediment samples contain highly anomalous concentrations of silver, copper, lead, or zinc (with or without gold); concentrate samples contain abundant galena, pyrite, and sphalerite; area contains two sulfide-bearing quartz-vein breccia occurrences

SEDIMENTARY BARITE DEPOSITS (BARIUM)

Low resource potential (certainty level C*); permissive host rocks; no significant geochemical anomalies in stream- or lake-sediment samples

Moderate resource potential (certainty level B*); permissive host rocks; many stream-and lake-sediment and nonmagnetic heavy-mineral-concentrate samples contain highly anomalous concentrations of Ba (and abundant barite)

CYPRUS-TYPE MASSIVE SULFIDE DEPOSITS (COPPER AND ZINC)

Low resource potential (certainty level C*); permissive host rocks; no significant geochemical anomalies

PLACER DEPOSITS (CHROMIUM AND GOLD), ROLL-FRONT URANIUM DEPOSITS (URANIUM,VANADIUM, AND COPPER), AND COAL DEPOSITS

Low resource potential (certainty level B*); permissive host rocks; widespread distribution of stream- and lake-sediment samples containing anomalous concentrations of chromium and nickel; no significant gold anomalies; no significant uranium anomalies; coal is present but individual beds are mostly less than 1 m thick and are interbedded with shale, sandstone, or siltstone

*Certainty levels

B Available information only suggests the level of mineral resource potential

C Available information gives a good indication of the level of mineral resource potential

D Available information clearly defines the level of mineral resource potential

Figure 4. Map showing boundaries of areas with potential for mineral resources, Killik River 1°×3° quadrangle, northern Alaska. Solid circles indicate sulfide mineral occurrences. Modified from Kelley and Mull (1995a).

(Duttweiler, 1987; Kelley and Kelley, 1992; Meyer and Kurtak, 1992; Kelley and Mull, 1995a).

Two other areas in the south-central and southeastern part of the quadrangle were delineated by geochemically anomalous samples. These areas are defined primarily by nonmagnetic heavy-mineral-concentrate samples containing anomalous concentrations of silver, copper, lead, and zinc and corresponding variable amounts of sulfide minerals; the stream-sediment samples contain mostly background concentrations of metals. The source of the sulfides was not conclusively demonstrated, but it is probably in thin (1–2 cm wide) quartz-calcite veins, which are ubiquitous in the weakly metamorphosed Hunt Fork Shale in this area. These veins contain a few scattered occurrences of galena, pyrite, or sphalerite (Duttweiler, 1987).

North of the range front, in the central part of the quadrangle, the belt of complexly deformed rocks consists primarily of Mississippian to Jurassic sedimentary rocks (units JMs and JMc, fig. 3). Three areas within this belt are defined by lake- and stream-sediment samples containing anomalous concentrations of silver (0.5–3 ppm), arsenic (35–189 ppm), barium (5,000–15,000 ppm and a few containing as much as 6 percent Ba), manganese (0.48–1 percent), lead (50–72 ppm), and (or) zinc (250–524 ppm) (geochemical signature 2). Although the concentrate samples generally do not contain anomalous concentrations of base metals, they do contain highly anomalous concentrations of barium (more than 5,000 ppm Ba), due to the presence of more than 50 percent barite.

Within this central belt of rocks, two occurrences of iron-rich sulfide-bearing concretions were identified. At the Otuk Creek occurrence (fig. 4), abundant concretions in the Kayak Shale are 7–20 cm in diameter and contain calcite as well as trace amounts of sulfide minerals including sphalerite, galena, chalcopyrite, and pyrite (Kelley and others, 1995a, b; Kelley and Mull, 1995b). The Ivotuk Hills occurrence consists of coarse pyrite nodules, some of which contain minor sphalerite in the cores, that are in float on the west side of the Ivotuk Hills. A black shale sample collected from the top of the Lisburne Group in the Ivotuk Hills yielded as much as 20 ppm Ag, 30 ppm As, 100 ppm Cd, and 2,000 ppm Zn. Although sulfide minerals were not identified in this sample, the geochemical values are interpreted to indicate the presence of sphalerite and perhaps other sulfide minerals (Kelley and others, 1995b; Kelley and Mull, 1995b).

Within this central belt of rocks additional areas are characterized by sediment and concentrate samples containing anomalous concentrations of barium without associated base metals. Many of these sediment samples contain more than 10,000 ppm Ba, and concentrate samples contain 50–70 percent barite.

The third geochemical signature is defined by lake- and stream-sediment samples containing anomalous concentrations of chromium (1,400–2,340 ppm) and nickel (150–241 ppm). The spatial distribution of these anomalous samples correlates with the distribution of Cretaceous rocks of the Nanushuk Group (included in unit Ks, fig. 3) in the northernmost part of the quadrangle. Chromite was identified by X-ray diffraction studies to be the source mineral for the geochemical anomalies in the sediment samples (Kelley and Mull, 1995b). The Nanushuk Group is a deltaic clastic wedge composed of sediments derived primarily from preexisting sedimentary rocks and variably from mafic and ultramafic rocks (Huffman, 1989). The chromite is either a detrital mineral in the Nanushuk Group or a detrital mineral in Quaternary deposits that were reworked from the Cretaceous sedimentary deposits (Kelley and Mull, 1995a, b). Although the geochemical data suggest that chromite is widespread in areas that contain Nanushuk Group rocks, gold and other heavy-metal concentrations are generally near background levels (Kelley and Mull, 1995b).

POTENTIAL MINERAL RESOURCES

The assessment of mineral resources in the Killik River 1°×3° quadrangle is based primarily on geologic and geochemical data collected during the NURE and AMRAP studies. The emphasis in the assessment was on metallic minerals and selected nonmetallic minerals (barite and phosphate). Numerous reports on coal, hydrocarbons, and uranium within the Arctic Foothills of the Brooks Range were prepared as part of the NPRA studies, which include some of the Killik River quadrangle. These studies were briefly summarized and utilized in the assessment of energy resources (Kelley and Mull, 1995a).

Criteria for determining resource potential and certainty of assessment were described by Goudarzi (1984). Mineral resources include known deposits or occurrences, which may not be economically or technologically recoverable at present, and unknown deposits that are inferred to exist. The degree of resource potential assigned to areas is based on geological and geochemical evidence and does not take into account the extreme remoteness of the Killik River quadrangle or the availability of land for development of these resources.

The expected mineral deposits in the Killik River quadrangle are stratiform and (or) stratabound types hosted by sedimentary and mafic igneous rocks. No felsic plutonic rocks are present, and there are no aeromagnetic anomalies that would indicate the presence of buried intrusions (D.L. Campbell, oral commun., 1987). Therefore, deposit types that crosscut lithologic boundaries, such as skarns, porphyry deposits, and stockworks, are not expected.

The types of deposits that may be expected to exist within the Killik River quadrangle and which are evaluated in terms of their resource potential include (1) vein breccia deposits, (2) sedimentary-exhalative massive sulfide deposits, (3) sedimentary barite, manganese, and phosphate deposits, (4) Cyprus-type massive sulfide deposits, (5) placer deposits, and (6) roll-front uranium deposits. Coal and petroleum resource potential was also evaluated based primarily on studies conducted previous to the AMRAP investigations.

The southern third of the quadrangle is underlain by Devonian and Mississippian clastic sedimentary rocks of the Hunt Fork Shale, Noatak Sandstone, and Kanayut Conglomerate, which are considered permissive host rocks for sulfide-bearing vein breccia deposits. In addition to the known occurrences within the quadrangle (Kady and Vidlee), these rocks host a number of deposits of this type west of the Killik River quadrangle (Kelley and Mull, 1995a). The vein breccias do not belong to any well-established deposit model. They are stratabound within the Devonian and Mississippian clastic rocks. Geochemical and isotopic data suggest that they may be related genetically to stratiform sedimentary-exhalative massive sulfide deposits; more specifically, they may represent the feeder systems of minimally developed, eroded, or structurally removed stratiform bodies.

As previously discussed, stream-sediment and nonmagnetic heavy-mineral-concentrate samples collected downstream from these occurrences contain highly anomalous concentrations of silver, gold, copper, lead, or zinc. Based on the presence or absence of geochemical anomalies, three levels of potential and certainty of assessment for resources of silver, lead, and zinc (with or without gold and copper) in vein breccias were assigned for the southern part of the quadrangle (fig. 4). Most of the area was assigned a moderate potential, but three specific areas were considered to have a high potential (Kelley and Mull, 1995a).

The broad belt in the central part of the quadrangle is characterized by chert, shale, and carbonate rocks of the Kayak Shale, Lisburne Group, Etivluk Group, Imnaitchiak Chert, and Akmalic Chert (units JMc and JMs, fig. 3). In the western and central Brooks Range, chert and shale of Mississippian and Pennsylvanian age are host to several sedimentary-exhalative massive sulfide deposits and occurrences, including the world-class Red Dog deposit. Stream-sediment samples collected downstream from these occurrences and deposits are characterized by highly anomalous concentrations of silver, barium, manganese, and zinc (with or without arsenic, cadmium, lead, and antimony) (Kelley and others, 1992). Based on similar geochemical anomalies in the Killik River quadrangle, three small areas within the central belt of rocks were assigned a moderate potential for resources of lead, silver, and zinc (with or without barium) in sedimentary-exhalative massive sulfide deposits. The remaining area, which contains permissive host rocks but lacks significant geochemical anomalies, was assigned a low potential (fig. 4).

Several areas are assigned a moderate potential for sedimentary barite deposits based on the presence of permissive host rocks and anomalous concentrations of barium in geochemical samples (fig. 4). Although not shown in figure 4, areas having potential for resources of manganese and phosphate are also present within this central belt of rocks (Kelley and Mull, 1995a).

Mafic pillow basalts and associated chert, exposed in two small areas in the central part of the quadrangle, are permissive host rocks for copper and zinc resources in Cyprus-type massive sulfide deposits. The relatively small volume of the mafic rocks and the absence of copper and zinc geochemical anomalies indicate, however, that these areas have a low resource potential (fig. 4).

Nonmarine sedimentary rocks of the Cretaceous Nanushuk Group (unit Ks, fig. 3) comprise the northern part of the quadrangle. These rocks are permissive host rocks for roll-front-type uranium deposits, placers, and coal deposits. Few geochemical anomalies for uranium in this area suggests that the resource potential for uranium is low (Huffman, 1985; Kelley and Mull, 1995a). Although there are no geochemical anomalies for gold, there are significant geochemical anomalies for chromium and nickel due to abundant chromite in the sediment samples. These data indicate that chromite is widespread in areas that contain rocks of the Nanushuk Group; however, the degree of concentration of the chromite is not known from the available geochemical data, and therefore the area was assigned a low resource potential (certainty level B) for chromium and gold in placer deposits. Coal beds are abundant and widespread in rocks of the Nanushuk Group; however, individual beds are generally less than 1 m thick and are interbedded with shale, sandstone, or siltstone (Barnes, 1967; Affolter and Stricker, 1987). The limited thickness and probable limited lateral extent of most of the beds reduce their resource potential.

Although the mountainous southern third of the quadrangle is considered to have no hydrocarbon resource potential, the southern and northern foothills of the northern two-thirds of the quadrangle area have some potential; however, present data are not adequate to assign levels of resource potential. Potential source beds are present in black shale and limestone that have high organic contents, and the presence of solid degraded hydrocarbon in porous dolomite suggests that generation and migration of hydrocarbons has occurred. It is difficult, however, to evaluate the relationship between the timing of hydrocarbon generation, migration, and trapping, which must be considered to fully evaluate the level of potential (Kelley and Mull, 1995a).

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