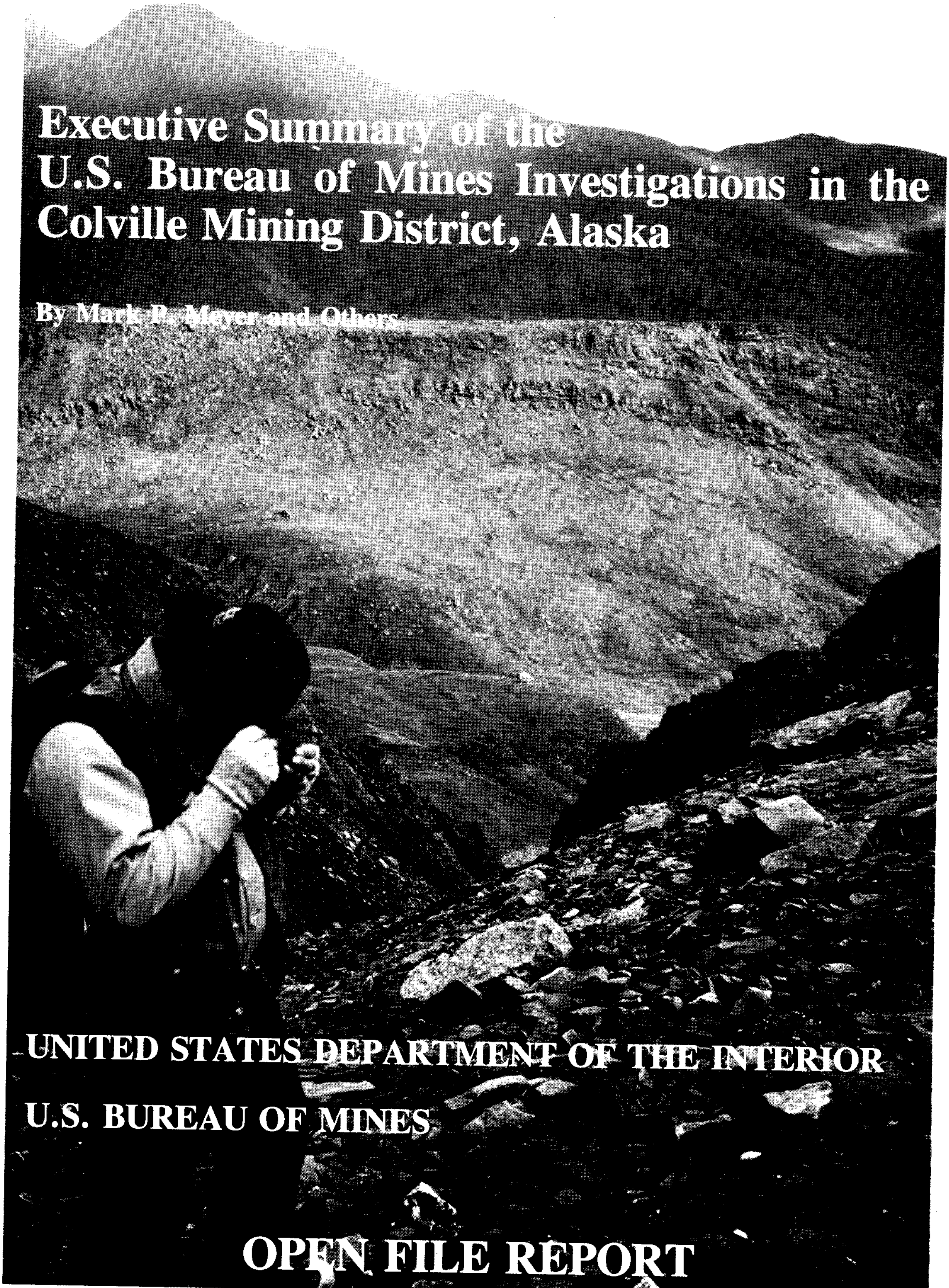
# Executive Summary of the U.S. Bureau of Mines Investigations in the Colville Mining District, Alaska

By Mark P. Meyer and Others



UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. BUREAU OF MINES

OPEN FILE REPORT

OFR 07-95

ABOVE - Lisburne Group limestone exposed at Sphinx Mountain. (Photo: Mark Meyer)

COVER - U.S. Bureau of Mines geologist examining sulfide-bearing outcrops in the Kurupa River drainage. (Photo: Mark Meyer)

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| Symbol | Definition |
|---|---|
| % | percent |
| °C | degree Celsius |
| cm | centimeter |
| g/mt | gram per metric ton |
| kcal | kilocalorie |
| kg | kilogram |
| km | kilometer |
| m | meter |
| mt | metric ton |
| mmt | million metric ton |
| ppb | part per billion |
| ppm | part per million |

# EXECUTIVE SUMMARY
# of the
# U.S. BUREAU OF MINES INVESTIGATIONS
# in the
# COLVILLE MINING DISTRICT, ALASKA

**By Mark P. Meyer[1] and others**

## INTRODUCTION

During 1991 through 1993, the U.S. Bureau of Mines (Bureau) - Alaska Field Operations Center (AFOC) in cooperation with the Bureau of Land Management (BLM) - Arctic District Office and the State of Alaska, Division of Geological and Geophysical Surveys (ADGGS), conducted exploration, geological, geochemical, geophysical, mineral resource, and mineral potential investigations in the 6.7 million hectare Colville Mining District (CMD) study area. This mining district study area, located in northern Alaska, includes the Colville River drainage basin as well as 0.35 million hectares of the southern part of the National Petroleum Reserve in Alaska (NPRA). This investigation was conducted as part of the Bureau's continuing Mineral Land Assessment (MLA) mining district program.

The Bureau's MLA mining district program is designed to provide reliable and comprehensive mineral resource information that supports mineral resource policy and land use decisions made by Congress and Federal land management agencies. Information gathered also provides the basis for decisions that would expand the domestic supply of important mineral resources. Ultimate objectives of this study are to: 1) identify mineral deposits, 2) study the application of modern beneficiation technologies on known deposits, 3) perform mining feasibility studies using hypothetical mine models, and 4) perform a probabilistic mineral resource and economic assessment of the CMD study area.

Authorization to the Secretary of the Department of the Interior is by Title X, Section 1010 of the Alaska National Interest Lands Conservation Act (ANILCA) of 1980 (PL96-487, Title 16, USC 3150) to expand the data base of oil, gas, and minerals as well as assess the mineral potential on all public lands in the State of Alaska. Also, Section 105(c) of the Naval Petroleum Reserves Act of 1976 (PL 94-258, Title 42 USC 6505) mandated that a mineral inventory of the petroleum reserve be completed. During 1977 and 1978, the U.S. Geological Survey (USGS) and the Bureau were involved in the original 105(c) mineral inventory. USGS personnel conducted

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[1]*Physical scientist, Alaska Field Operations Center, Anchorage Branch, U.S. Bureau of Mines, Anchorage, Alaska.*

preliminary regional geologic mapping and regional geochemical sampling while Bureau personnel conducted site-specific examinations and detailed sampling of identified mineral occurrences.

Ransom and Kerns *(1954)*[2] have identified and defined sixty-seven mining districts within Alaska. After consulting with State and Federal land managers, the Bureau prioritized the mining districts based on; 1) the availability of mineral data, 2) the need for additional minerals information, 3) the national need for contained commodities, and 4) the physical accessibility of the mining districts.

Investigative work by the Bureau on this mining district study took four years to complete. The first year, 1990, was spent in a intensive literature search and data compilation along with an initial field work in the central part of the study area. During 1991-93, field work was conducted over three parts of the study area: 1) the eastern area between Chandler River and Atigun Pass, 2) the central area between Rolling Pin Creek and the Chandler River, and 3) the western area between Spike Creek and Rolling Pin Creek. Site-specific investigations were conducted on mineral occurrences identified by previous work and geologic sampling. All data necessary to establish the mineral data base on which this evaluation is based was acquired during this mining district study. The final year, 1994, was devoted to the compilation of all data, completion of complementary studies from the data acquired during the field study years, and the preparation of the final reports. This final report is published as an executive summary and special publication. During the course of the study, open-file reports have been published yearly describing the field work completed and including the yearly sample analytical results *(Meyer, 1991*; *Meyer and Kurtak, 1992*; *Meyer and others, 1993*; *Meyer, 1994*). An open-file report is being published detailing the work completed on the mineralized occurrences and areas identified during this study *(Kurtak, 1994*).

During the course of the CMD investigation, Bureau field personnel located and sampled twenty-two known mineral occurrences, discovered thirty previously unreported mineral occurrences, and collected 1,593 rock, stream, and soil samples. Two types of field crews were utilized during the investigation. One crew conducted a geologic sampling program over the entire southern part of the study area. A second crew conducted site-specific investigations including geological and geochemical sampling of identified mineral occurrences.

This document discusses the pertinent recent and historical information about the CMD, summarizes the findings of Bureau work performed in the CMD to date, and can be used as a principal reference to information on mineral resources within the CMD study area.

## LOCATION

Located in northern Alaska, the study area comprises most of the west-central part of the northern slope of the Brooks Range and includes the CMD and the NPRA (fig. 1). The CMD is geographically defined by the drainage divides of the Colville and Itkillik Rivers and their tributaries. The study area

[2]*Italic names and numbers in parentheses refer to items in the list of references at the end of this report.*

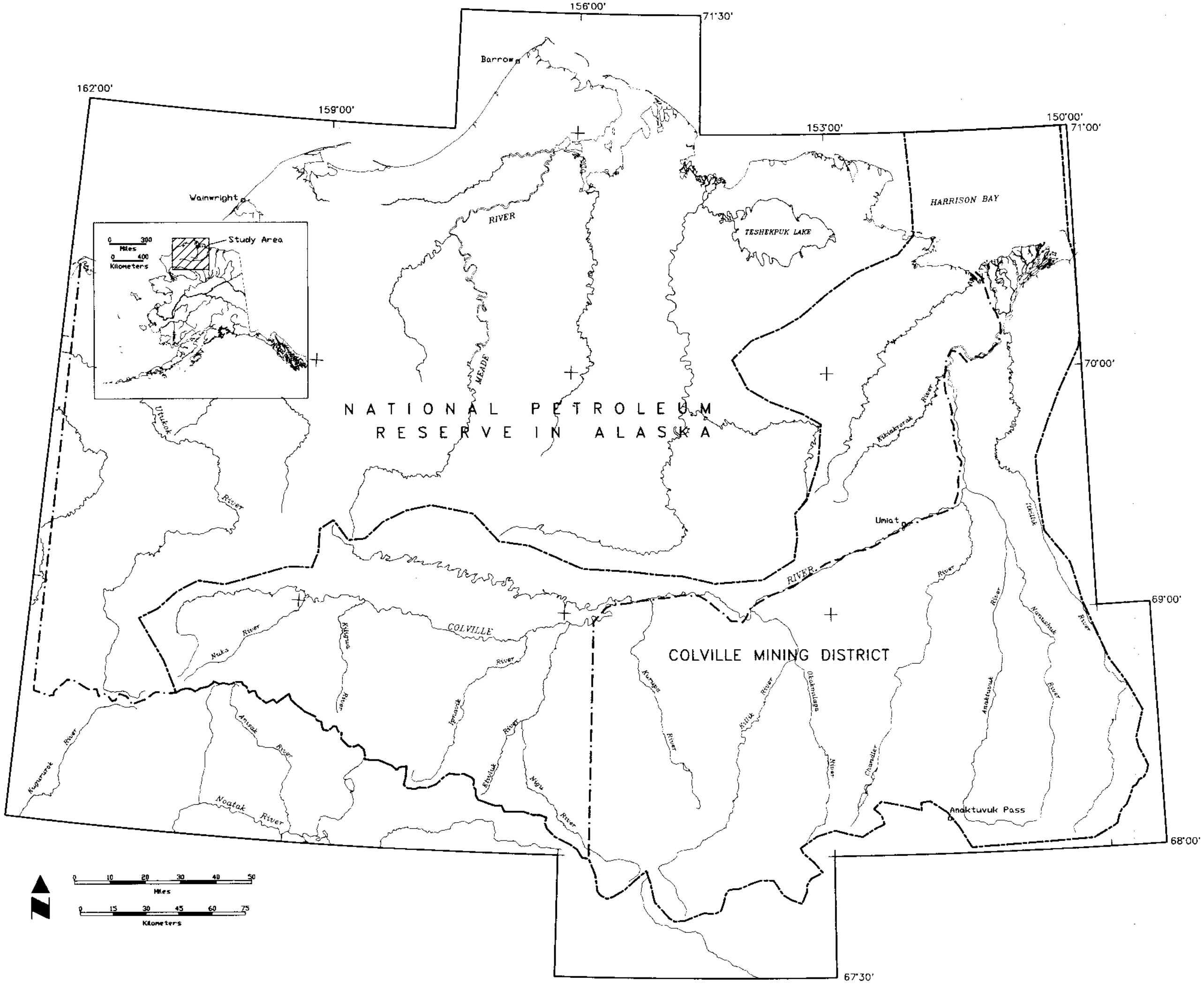


*FIGURE 1. - Location map of the Colville Mining District, Alaska.*

is bounded on the south by the crest of the Brooks Range, the west by the western boundary of the NPRA, on the east by the Itkillik River, and the Arctic Ocean to the north. The study area encompasses a vast and diverse landscape.

## LAND STATUS

Land ownership of the CMD study area includes those lands managed by the BLM, National Park Service (NPS), State of Alaska, and Native regional and village corporations (fig. 2). The BLM manages the NPRA which is open for oil and gas exploration but unavailable for mineral exploration and development. The NPS manages the Gates of the Arctic National Park, Preserve, and Wilderness, which is closed to oil, gas, and mineral exploration and development. The State of Alaska has made land selections in the area, which includes lands that are available and are not available for mineral exploration and development. Native regional and village corporations have also made similar land selections in the area. Small parcels of private inholdings are also located within the study area. Some of these private lands may be available for mineral exploration and development subject to the management policies of the land owners.

## PHYSIOGRAPHY

Wahrhaftig has identified three physiographic provinces in the CMD study area. These provinces include: 1) the Arctic Coastal Plain, 2) the Arctic Foothills, and 3) the Central and Eastern Brooks Range (*Wahrhaftig, 1965*).

The Arctic Coastal Plain physiographic province is characterized by a low lying plain rising to the south from the Arctic Ocean, eventually reaching an elevation of 180 m. This area, which is poorly drained, contains many marshes and braided meandering sluggish rivers. Numerous shallow lakes occur in the low lying areas. An occasional abrupt scarp, up to 61 m high, separates the coastal plain from the arctic foothills.

The Arctic Foothills physiographic province consisting of rolling plateaus and low linear ridges is subdivided into the northern and southern foothills. Rising in elevation from 180 to 1,100 m, the northern foothills have broad east-west trending ridges dominated by mesa-like mountains. This area contains north-flowing swift braided rivers crossing broad gravel flats that locally contain extensive sheets of aufeis (fig. 3). Morainal lakes are occasionally located along the upper valleys of the major rivers and their tributaries. The southern foothills are characterized by irregular buttes, knobs, mesas, east-west trending ridges ranging from 350 to 1,100 m, and intervening gently undulating tundra plains.

The Central and Eastern Brooks Range physiographic province is composed of rugged glaciated east-west trending ridges with elevations ranging from 900 to 2,100 m. This area is the drainage divide between the Arctic Ocean and the Yukon River system. The steep nature of the area creates swift-moving steams and rivulets often occurring as water falls and cascades. Small cirque glaciers are common in the higher parts of this division and often contain tarn lakes.

Higher elevations in the Brooks Range are devoid of trees and have sparse lichen vegetation covering the rocky slopes. At the lower elevations the vegetation grades into typical tundra species including

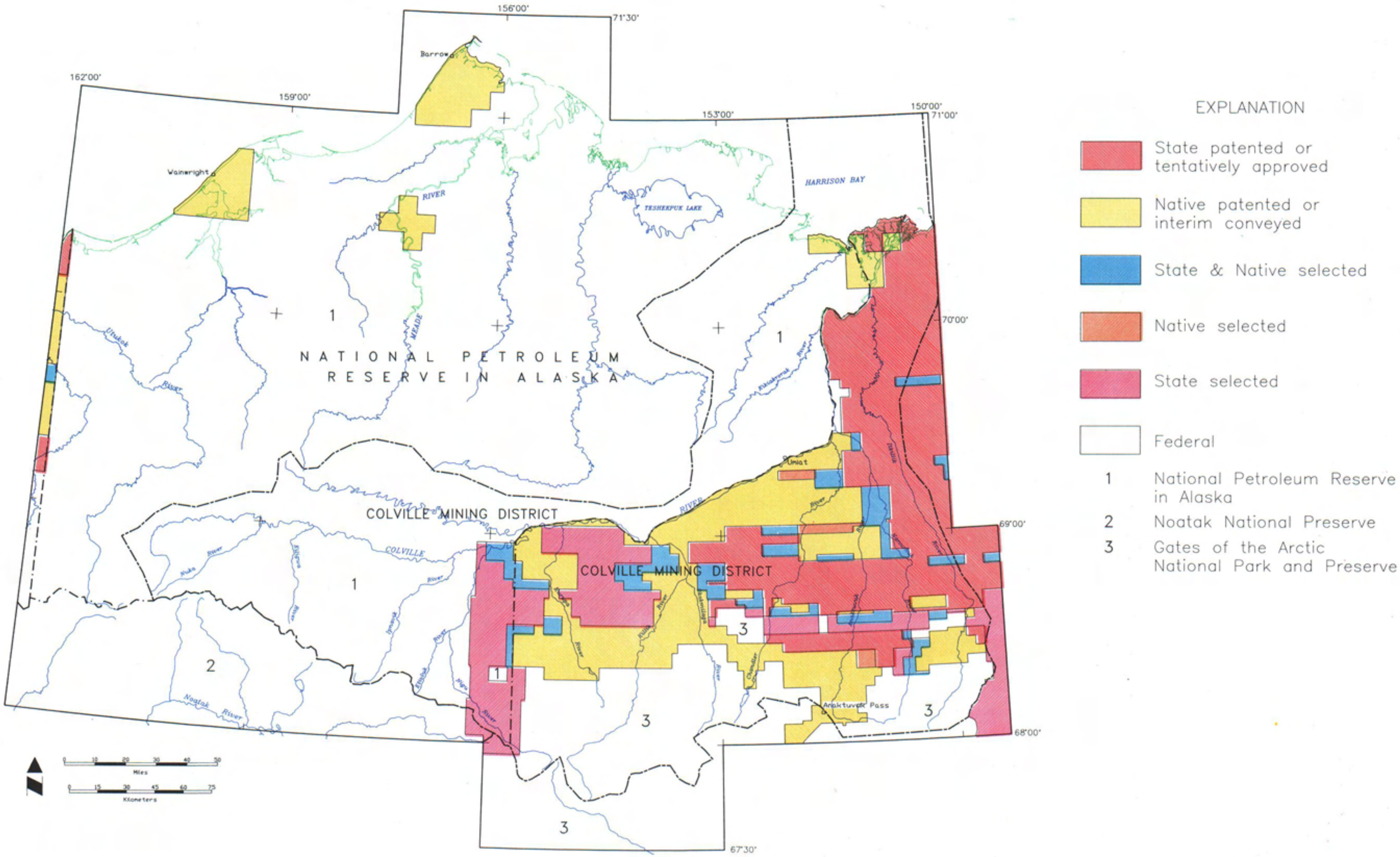


*FIGURE 2. - Land status map of the Colville Mining District, Alaska.*

bearberry, blueberry, scrub birch and willow along with stunted alder and willow, up to 2 m tall, growing along the river gravel bars. Numerous flowering plants can be found at all elevations of the study area with the different species flowering throughout the entire summer period.

*FIGURE 3. - Aufeis conditions located along the Itkillik River, eastern Colville Mining District, Alaska. (Photo: Mark Meyer)*

A wide variety of wildlife can be found throughout the study area. Grizzly bear, caribou, dall sheep, and ground squirrels are the most common animals. Other less common animals include wolverines, wolves, moose, muskox, swans, ptarmigan, and other small birds. Raptors inhabiting the area include snowy owls, eagles, and peregrine falcons.

## CLIMATE

The CMD study area lies within a zone of continuous permafrost (*Wahrhaftig, 1965*). Average summer temperatures range between -2° and 7° C and winter temperatures average between -32° and -21° C in Barrow (*Jansons and Mowatt, 1978*). Mid-day summer temperatures of 29° C have been experienced at both the Ivotuk and Eagle Creek airstrips. Strong winds blow frequently throughout the year, generally from either the southwest or northeast at Ivotuk and from the southwest or southeast at Eagle Creek. Summer afternoon rainstorms and thunderstorms arrive from the south and southwest while morning fog banks move in from the Arctic Ocean either from the northeast or the northwest.

Average annual precipitation in Anaktuvuk Pass is 25 cm with 14.5 cm falling in the form of snow. Though precipitation occurs mostly as snow, scattered localized light rain showers are common during the summer months, along with an occasional severe afternoon thunderstorm (*Jansons and Mowatt, 1978*). Occasional snow squalls and hail storms can also occur throughout the summer months in the upper foothills area.

Due to the long winter season as well as the extreme weather conditions, field work is limited to the time period from early to mid June through early August. Early spring snow conditions include all northern drainages being snow filled, numerous snow drifts, aufeis conditions, and the higher elevations snow covered. Most drainages and higher elevations, excluding glaciated areas, are snow free by the end of June. Snow (termination dust) begins collecting on the higher elevations during the first two weeks of August. Occasional snow flurries reach the lower elevations during the summer months but the snow usually melts quickly.

## ACCESS

There are no roads, highways, or railroads located within the study area. A few useable gravel airstrips within the study area are located at Anaktuvuk Pass, Ivotuk, Kikiktat Mountain, and Umiat (fig. 1).

Anaktuvuk Pass is the only village within the CMD study area while Umiat has a small year-round population. Anaktuvuk Pass is located on the southeastern boundary of the study area at the headwaters of the Anaktuvuk and John Rivers. Umiat is located in the central part of the study area on the north bank of the Colville River 120 km south of Barrow. A private airstrip, located 32 km west of the NPRA, along Eagle Creek, was used for access to the western part of the study area. Access to the villages and base camps within the study area is by aircraft from either Anchorage, Barrow, Bettles, Deadhorse, Fairbanks, or Kotzebue. Located just outside the eastern boundary of the study area, the Dalton Highway and the Galbraith Lake airstrip can be utilized for access to the eastern part of the study area.

Bureau crews conducted field work out of base camps situated at the Ivotuk airstrip (1990-1993), the Eagle Creek airstrip (1992), and the Galbraith Lake airstrip (1993).

## ACKNOWLEDGMENTS

Completion of the CMD study would not have been made possible without the effort and expert contributions of many people. AFOC - Anchorage Branch personnel included Michael D. Balen, Steven A. Fechner, Denise A. Herzog[3], Jerry L. Kouzes, Joseph M. Kurtak, and Nathan J. Rathbun who contributed with their knowledge and strong backs. Other Bureau personnel who helped contribute to the study include James R. Coldwell from the AFOC - Juneau Branch office, Juneau, Alaska; Frank S. Oliver from the Salt Lake City Research Center, Salt Lake City, Utah; and William K. O'Conner and Cathy A. Summers from the Albany Research Center, Albany, Oregon. Recognition for their resourcefulness and tenaciousness goes to the AFOC summer field assistants Nick Enos, Russ Hicks, Ed Klimasauskas, Bruce McDonald, Matt Nelson, Allan Nakanishi, and Steve Oswald. Special thanks goes to Jennifer Claxton for the fine food and cheerful disposition which helped keep the base camps running smoothly.

The author gratefully wishes to acknowledge the expertise contributed to the CMD study by ADGGS, BLM, and USGS geologists. ADGGS personnel include Laurel E. Burns, James G. Clough, C. G. (Gil) Mull, and DeAnne S. Pinney. BLM personnel include Arthur C. Banet, Jr., William Diel, Chuck Joy, and Don Keill. USGS personnel include John S. Kelley, Jeanine M. Schmidt, and Gary D. Stricker. Thanks also goes to Rainer J. Newberry,

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[3]*Presently employed by Ryan Lode Mines, Inc., Fairbanks, Alaska.*

Professor, University of Alaska, Fairbanks (UAF) and Melanie B. Werdon UAF graduate student for her work in geologic mapping and interpretation of the Drenchwater and Story Creek and Kivliktort Mountain West occurrences.

Thanks also goes to the Alaska Helicopter Inc. pilots and mechanics as well as all those people and companies, too numerous to mention, who helped in the logistical support of the three base camp facilities at Eagle Creek, Galbraith Lake, and Ivotuk.

## PREVIOUS INVESTIGATIONS

Investigations of Alaska's north slope was started by the USGS for mineral and fuel resources in the early 1900's (*Brooks, 1908*; *Brooks, 1909*; *Leffingwell, 1913*; *Schrader, 1902*). Additional investigations occurred during the 1920's (*Smith and Mertie, 1930*) but was followed by a lull in exploration during the 1930's. A renewed interest was shown during the 1940's and 1950's with an increase in oil exploration activity (*Patton, 1955*). A USGS metallic mineral resource appraisal program was initiated in 1974 and was conducted through 1982 (*Churkin and others, 1978*; *Mayfield and others, 1978*; *Nokleberg and others, 1979*; *Nokleberg and Winkler, 1982*; *Theobald and Barton, 1978*). Cobb published the first summary of metallic resources of Northern Alaska in 1975 which included the mineral occurrences identified at that time within the CMD study area (*Cobb, 1975*). An updated version of that report on the metallic resources was published by Cobb in 1981 (*Cobb and others, 1981*).

Currently the USGS, with assistance from the ADGGS, is conducting an Alaska Mineral Resource Appraisal Program (AMRAP) study of the Killik River and Howard Pass quadrangles. An administrative report written by the USGS summarizes the historical geologic, geochemical, and geophysical work that has been conducted within the Howard Pass, western Killik River, and Misheguk Mountain quadrangles (*Schmidt and others, 1991*). USGS personnel are also conducting investigations on the barite deposits located within the study area (*Kelley and others, 1993*).

Private companies and Native corporations have carried out their own exploration projects within the NPRA. Regional reconnaissance studies were conducted during the late 1950's and early 1960's, while site-specific studies were conducted at Drenchwater Creek, Story Creek, and Kivliktort Mountain during the 1980's (*Schmidt and others, 1991*). Private industry has brought a renewed interest the mineral potential of the central Brooks Range during the 1990's. Kennecott Exploration, Spokane, WA. conducted field work at the Drenchwater Creek deposit as well as reconnaissance work in the area during 1992. This interest is a result of the opening of the world-class Red Dog lead-zinc-silver mine in 1990 in the southern DeLong Mountains.

Involvement in the NPRA by the Bureau began in 1923 when the Bureau Director was given authorization to define the National Petroleum Reserve Number 4. The Director then added the administration of the area to the duties of the Supervising Mining Engineer in Alaska.

Appraisal of the mineral resources of the southern part of the NPRA by the Bureau in conjunction with the USGS was conducted during 1977 and 1978. During the field investigations, the USGS conducted regional geological mapping to determine the geological setting of the NPRA, and mapped zones of mineral potential. Regional geochemical surveys were conducted by the USGS (*Theobald and Barton, 1978*; *Theobald and others, 1978*). Bureau personnel used the analytical results and preliminary interpretation in selecting areas of anomalous concentrations of specific elements for further detailed sampling and investigations. Eighty drainages with anomalous metal values were identified from the USGS geochemical surveys.

Bureau field work consisted of traversing those drainages containing the geochemical anomalies in search of the source rock. Stream sediments and select rock samples were collected from the drainages to further define and identify zones of mineralization. Due to time constraints, only 25 of the drainages with lead-zinc anomalies were examined during the two years of field work (*Jansons, 1982*; *Jansons and Baggs, 1980*; *Jansons and Mowatt, 1978*; *Jansons and Mowatt, 1976*; *Jansons and Parke, 1981*). Bureau geologists identified and sampled additional sulfide mineralization in widely scattered areas along the geochemical trends which track the region's east-west geological structure. Barium, chromium, fluorite, phosphorus, rare-earth elements (e.g. lanthanum), scandium, and yttrium, and vanadium were also noted within the NPRA (*Jansons, 1982*; *Jansons and Baggs, 1980*; *Jansons and Mowatt, 1978*; *Jansons and Mowatt, 1976*; *Jansons and Parke, 1981*).

## REGIONAL GEOLOGY[4]

The southern part of the CMD study area is located within a fold and thrust belt that extends across northern Alaska and includes the northern part of the western Brooks Range and the Arctic Foothills. This belt consists of Upper Devonian to Cretaceous clastic and carbonate rocks that were deposited in a variety of environments ranging from nonmarine deltaic settings to marine prodelta and shallow marine carbonate bank settings (fig. 4). During the Brooks Range orogeny, which predominantly occurred during the Cretaceous, the rocks were deformed by thrust faulting which has resulted in the recognition of a series of telescoped allochthons composed of distinctive stratigraphic sequences. Imbricate and generally south-dipping thrust faults and associated north-vergent folds have shortened and juxtaposed the sedimentary rocks, obscuring their original depositional relationships. Various late Tertiary and Quaternary glacial and alluvial sediments overlie the rocks in some areas (*Schmidt and others, 1991*).

In the central Brooks Range, most of the Endicott Mountains, which form the southern part of the study area, are composed of the Endicott Mountains allochthon. This allochthon consists dominantly of rocks of the Upper Devonian to Lower Mississippian Endicott Group (Hunt Fork Shale, Noatak Sandstone, Kanayut Conglomerate, and the Kayak Shale) and the Mississippian to Lower Pennsylvanian Lisburne Group (fig. 5). A

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[4]*Coauthored by C. G. Mull, Geologist, State of Alaska, Division of Geological and Geophysical Surveys, Fairbanks, Alaska.*

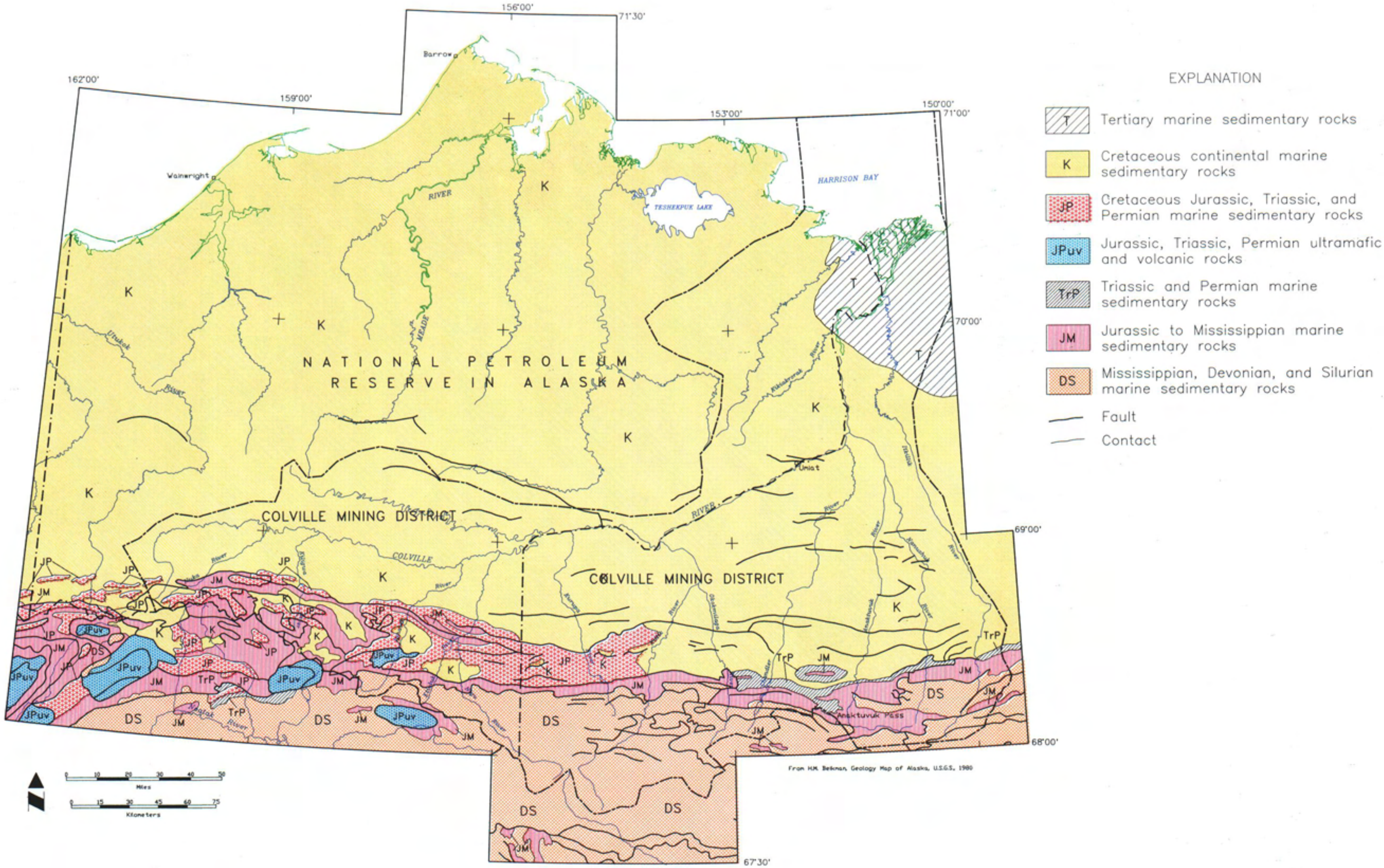


*FIGURE 4. - Generalized geologic map of the Colville Mining District, Alaska.*

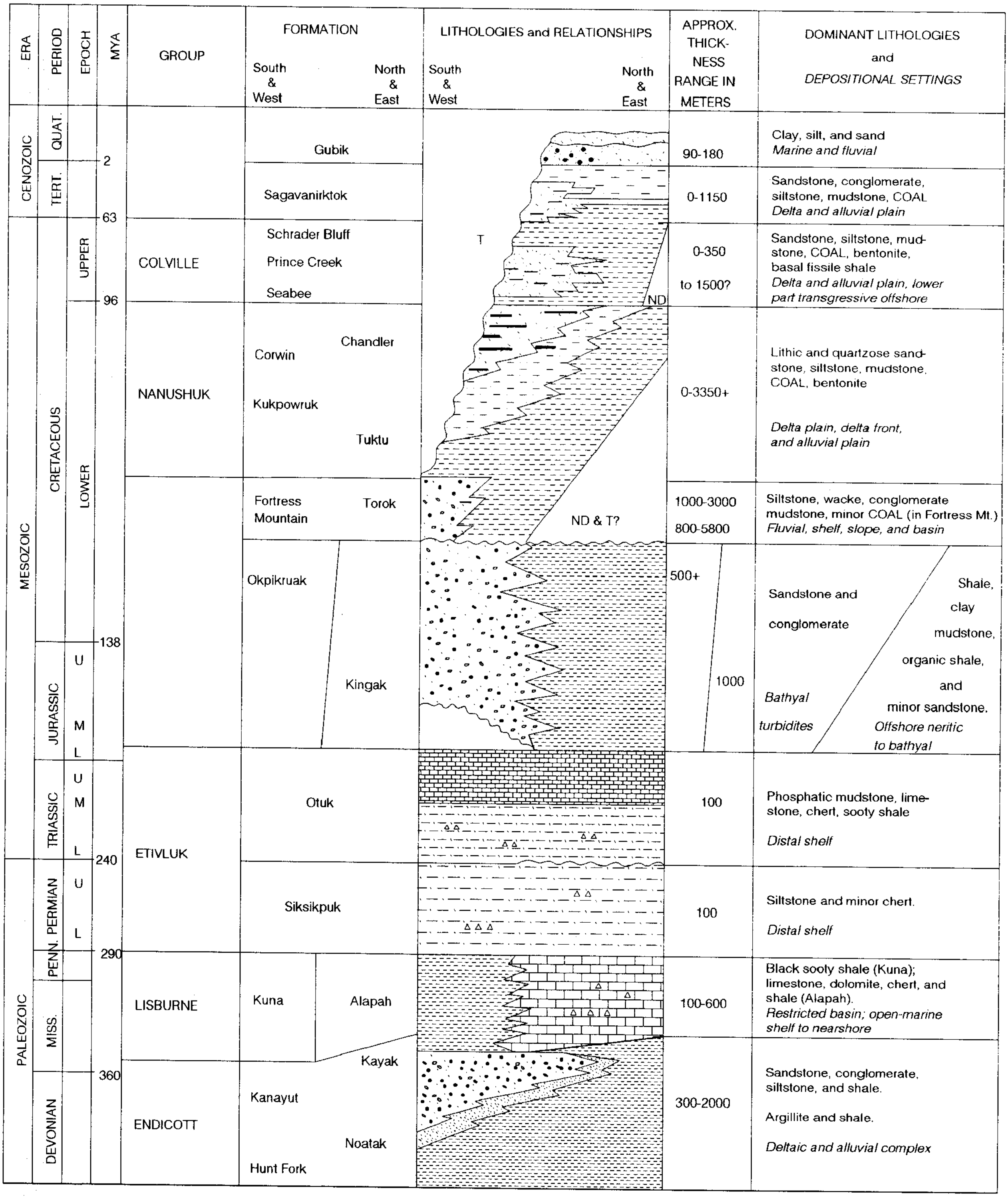


***FIGURE 5. - Generalized columnar section of Mesozoic to Paleozoic strata in the CMD: T-tectonic and erosional unconformity, ND-mostly nondepositional (modified from Sable & Stricker, 1987, with assistance from C. G. Mull).***

thin section of Permian and Triassic shaley and cherty rocks of the Etivluk Group and very thin Lower Cretaceous shale and limestone forms the top of the Endicott Mountains allochthon. Structurally higher allochthons in the area consist dominantly of Mississippian to Triassic cherty rocks of the Lisburne and Etivluk Groups and clastic rocks of the Opikruak Formation. In the foothills north of the mountains, the allochthonous rocks are unconformably overlain by mid-Cretaceous clastic rocks of the Fortress Mountain Formation and the Torok Formation, which is overlain by coal-bearing deltaic rocks of the Nanushuk Group. North of the Eastern part of the foothills belt, the Upper Cretaceous Colville Group is present overlying the Nanushuk Group (*Mull and Adams, 1989*).

Metallic mineral occurrences found within the CMD study area occur in rocks of the Endicott Mountains allochthon as either sediment-hosted stratiform massive sulfide deposits, sediment-hosted bedded barite deposits, breccia-vein deposits, or in metalliferous black shales (*Schmidt and others, 1991*). One known sediment-hosted stratiform sulfide deposit occurs within the Kuna Formation of the Lisburne Group. The breccia-vein deposits occur within the Endicott Group and metalliferous black shales occur within the Kayak Shale. Sediment-hosted bedded barite deposits occur in the Etivluk Group and within the thrust faulted boundary at the top of the Endicott Mountains allochthon (*Schmidt and others, 1991*).

## BUREAU INVESTIGATION

In 1990, the Bureau conducted an 8-day field orientation of the southcentral CMD and its known mineralization. Previously reported lead-zinc-silver and phosphate occurrences were visited between Drenchwater Creek eastward to Otuk Creek (*Meyer, 1991*). A detailed literature search and prefield logistical activities were started in 1990. A bibliography as well as property summaries were begun.

During 1991, the Bureau began the three-year field program. A total of 56 days were spent collecting 736 rock, soil, and stream sediment samples during 1991. Geological sampling, out of the Ivotuk airstrip base camp, was conducted from Rampart Creek eastward to the Okokmilaga River. Site-specific investigations were conducted from Drenchwater Creek eastward to the Outwash Creek area. Bulk sampling of Drenchwater Creek, Story Creek, and Ivotuk Hills was completed during the site-specific investigations (*Meyer and Kurtak, 1992*).

During the second year of field work, 56 days were spent working in the area from Spike Creek eastward to Ivotuk Creek. A total of 350 rock, soil, and stream sediment samples were collected. Two base camps were utilized by independent crews, one at the Eagle Creek airstrip (56 days) and the other at the Ivotuk airstrip (30 days). The Eagle Creek crew conducted a geologic sampling program of the area between Spike Creek and Bogie Creek collecting a total of 126 samples. The Ivotuk crew conducted site-specific investigations and geological and geochemical sampling in the area from Rolling Pin Creek to Ivotuk Creek collecting a total of 224 samples (*Meyer and others, 1993*).

During the third year of the study, 56 days were spent conducting the geologic sampling program in the area from Chandler River eastward to Galbraith Lake. Several site-specific studies were conducted on phosphate and zinc occurrences within the study area. A total of 487 rock, soil, and stream sediment samples were collected. Both the geologic sampling and site-specific crews worked out of the base camp located at the Galbraith Lake airstrip (*Meyer, 1994*).

Bureau open-file reports containing sample analyses and a brief description of the work accomplished have been published every year during this study and are listed in Table 1. The 1990 and 1991 analysis are listed in OFR 75-92 (*Meyer and Kurtak, 1992*), 1992 analysis in OFR 12-93 (*Meyer and others, 1993*), and the complete 1990 through 1993 analysis can be found in OFR 34-94 (*Meyer, 1994*). A detailed Bureau open-file report describing the mineralized occurrences and mineralized areas is currently being published (*Kurtak, 1994*).

*TABLE 1. - Publications by Bureau authors resulting from the CMD investigation.*

| Title | Publication | |
|---|---|---|
| | **Date** | **Type** |
| U.S. Bureau of Mines Colville Mining District/NPR-A 1990 Field Reconnaissance (*Meyer, 1991*). | 1991 | Field report |
| Results of the 1991 U.S. Bureau of Mines Colville Mining District Study (*Meyer and Kurtak, 1992*). | 1992 | OFR |
| Searching for Minerals Above the Arctic Circle (*Kurtak, 1992*). | 1992 | Minerals Today |
| Results of the 1992 U.S. Bureau of Mines Colville Mining District Study (*Meyer and others, 1993*). | 1993 | OFR |
| U.S. Bureau of Mines Mineral Investigations in the Colville Mining District (*Kurtak, 1993*). | 1993 | Outside publication |
| Lead and Zinc Mineralization at Story Creek, Colville Mining District, Alaska (*Summers and others, 1993*). | 1993 | Outside publication |
| Barite Deposits in the Howard Pass Quadrangle and Possible Relations to Barite Elsewhere in the Northwestern Brooks Range, Alaska (*Kelley and others, 1993*). | 1993 | USGS OFR |
| Analytical Results From U.S. Bureau of Mines Investigations in the Colville Mining District, Alaska (*Meyer, 1994*). | 1994 | OFR |
| Site-Specific Investigations of the Colville Mining District, Alaska (*Kurtak, 1994*). | 1994 | OFR |

*FIGURE 6. - Bureau geologist sampling mineralization in the Sharp Peak area, western Colville Mining District. (Photo: Mark Meyer)*

concentrated along the southern part of the study from Spike Creek eastward to Atigun Pass (fig. 1). Lead, zinc, copper, phosphate, manganese, and barite were the primary commodities of interest in this area.

As a result of the 1991 field season the Bureau identified a mineralized zone located between Rampart Creek and the Okokmilaga River. Occurrences containing elevated levels of lead, zinc, copper, silver, manganese, and nickel were noted at the Drenchwater - Story Creek, Kakivalak Creek, Kivliktort and Koiyaktot Mountain, and the Kurupa River - Outwash Creek

## GEOLOGIC SAMPLING

Geologic sampling in the CMD study area consisted of traversing both ridges (fig. 6) and stream drainages (fig. 7) in an attempt to verify anomalous values indicated from previous USGS geochemical sampling (*Theobald and others, 1978*), and previous field work by Bureau geologists (*Jansons, 1982*; *Jansons* and Baggs, 1980; *Jansons and Mowatt, 1978*; *Jansons and Mowatt, 1978*; *Jansons* and Mowatt, 1976; *Jansons and Parke, 1981*). Traverses were

*FIGURE 7. - Bureau geologist examining marcasite crystals along Spike Creek, western Colville Mining District. (Photo: Mark Meyer)*

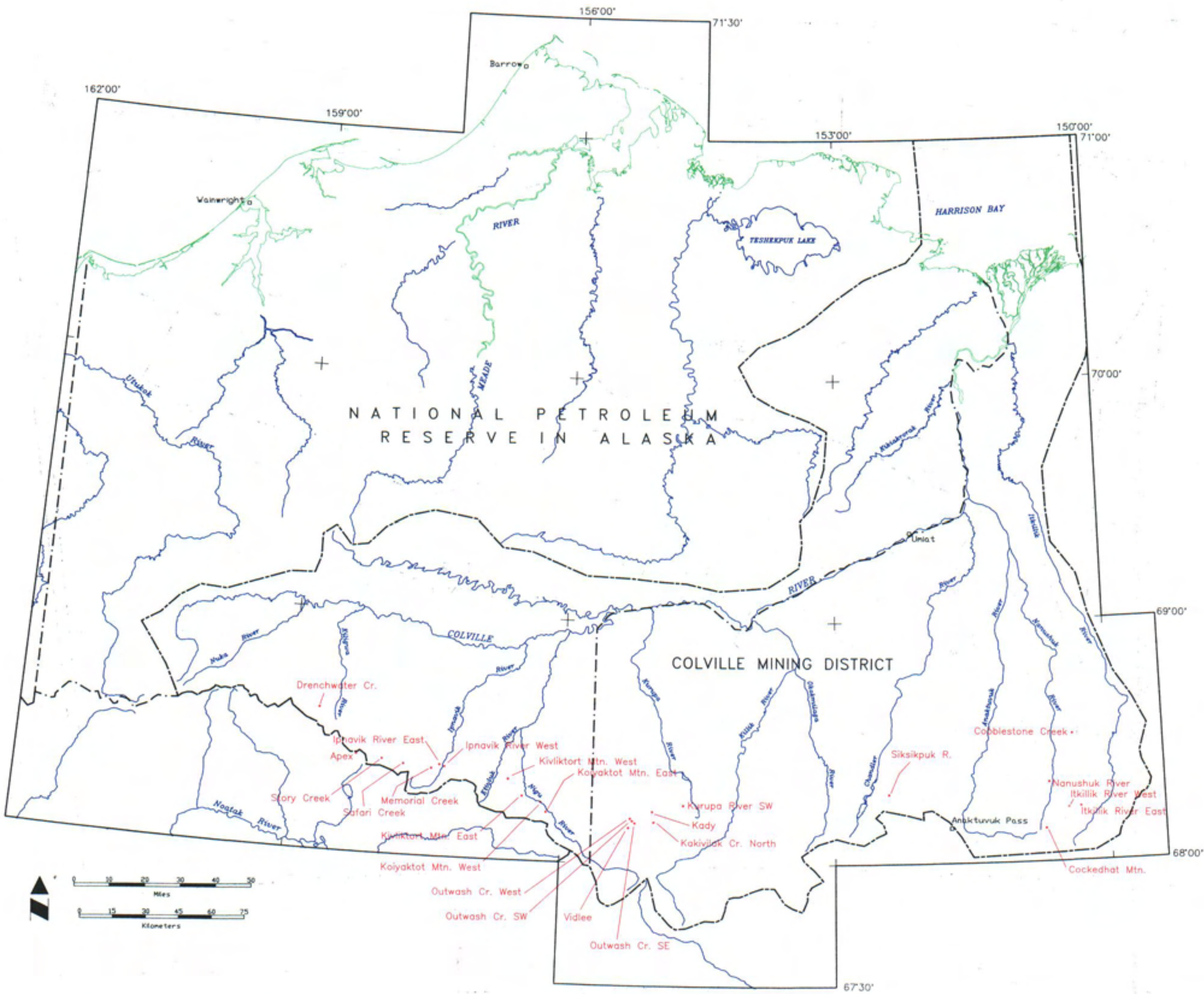


*FIGURE 8. - Sulfide and manganese occurrences and favorable area location map of the Colville Mining District, Alaska.*

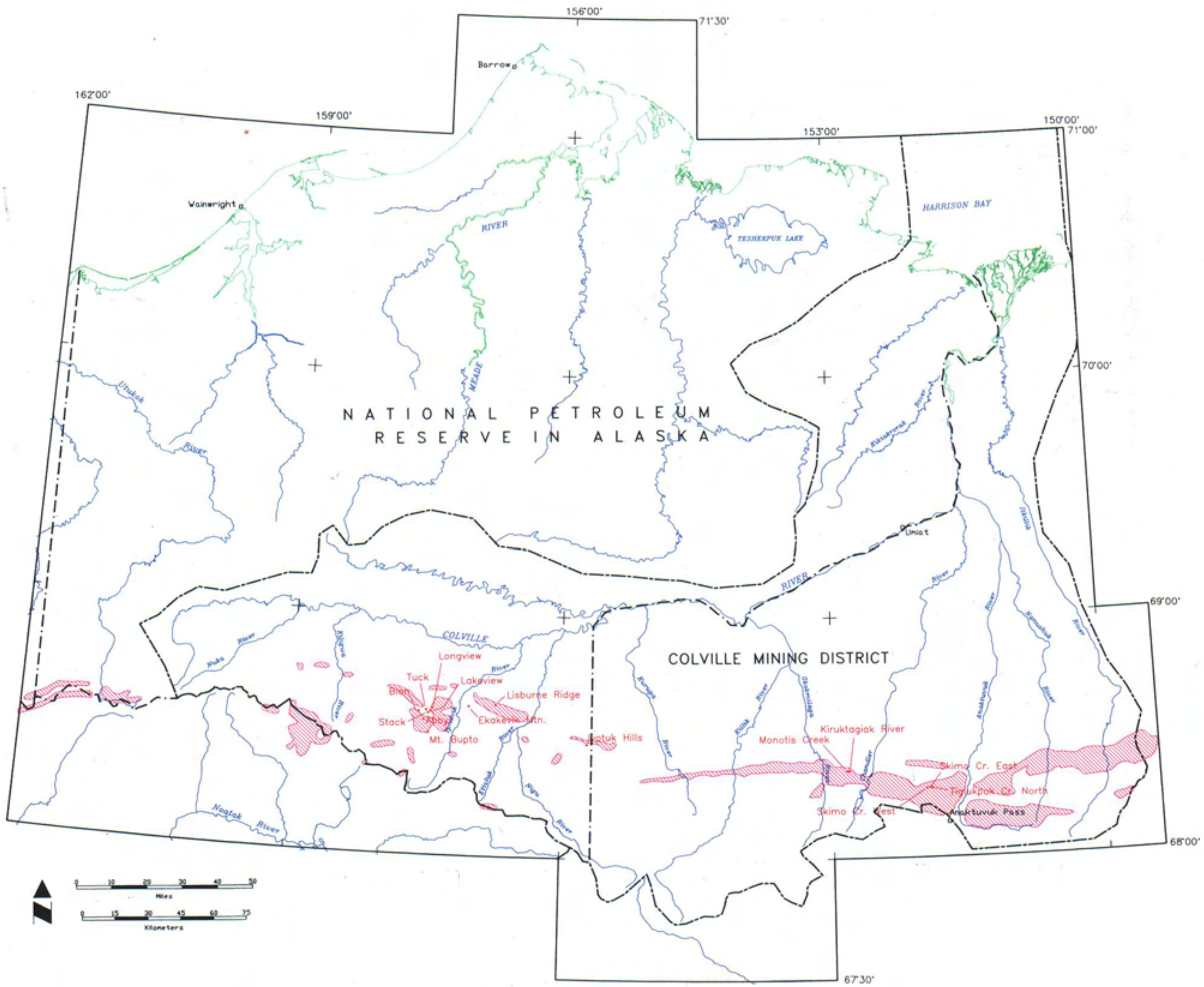


*FIGURE 9. - Industrial mineral occurrences and carbonate rock location map of the Colville Mining District, Alaska.*

areas (fig. 8). Other mineral occurrences were examined in the Rampart and Wager Creek area with elevated levels of barite, manganese, chromite, titanium, and strontium concentrations (fig. 9). Samples from the Cutaway Creek and Twistem Creek contain elevated levels of barite. The Outwash Creek - Kurupa River area also contain elevated levels of barite, manganese, nickel, cadmium, arsenic, and titanium. The Koiyaktot Mountain area contains additional elevated concentrations of cadmium and antimony. The first reported quartz crystals of the Brooks Range were discovered on the southwest side of Kurupa Hills (*Meyer and Kurtak, 1992*).

During the 1992 field season the majority of sulfide minerals were found to occur as disseminations or as veinlets of pyrite within shales, cherts, wackes, and limestones. Small barite outcrops were located on the north side of Sharp Peak and within numerous small beds in the vicinity of lower Nucleus Creek. Marcasite was sampled in upper Spike Creek and its tributaries. Manganese oxide coatings on the cherts, sandstones, and wackes were noted throughout the area. High manganese values were noted in the Nuka Ridge, Sphinx Mountain, Spike Creek, and Echo Mountain areas. Additional quartz crystals were noted along the western Brooks Range from Eagle Creek east to the Mechanic Creek area. No visible lead, zinc, or copper minerals were noted along any of the Eagle Creek traverses. Analytical results confirm that no significant lead, zinc, and copper was found in any of the samples (*Meyer and others, 1993*).

The 1993 field season identified elevated levels of lead, manganese, phosphate, silver, and zinc in the area from Monotis Creek to Atigun Pass. Numerous zinc occurrences were located in concretions within the Kayak Shale extending from the Chandler Lake area eastward to the Itkillik River area. Elevated levels of lead were noted in the Siksikpuk River area while manganese was located at Cobblestone Mountain. The anomalous phosphate levels, located along the front of the Brooks Range, occur from Monotis Creek eastward to Tiglukpuk Creek (*Meyer, 1994*).

## SITE-SPECIFIC INVESTIGATIONS[5]

Site-specific investigations were conducted at nineteen of the mineral occurrences examined within the CMD. These investigations consisted of detailed geologic mapping, rock and soil sampling, geophysics, and bulk sampling.

A total of 8,295 m of grid were surveyed and used as control for geologic mapping and sampling at the Drenchwater Creek and Story Creek lead-zinc-silver occurrences. Soil sampling was used to determine possible extensions of known mineralization under tundra-covered areas. Where possible, soil samples were collected with a hand auger from the thin C horizon characteristic of arctic soils (fig. 10). The samples were collected at 30 m intervals on the grids with some at 15 m intervals over mineralized areas. If possible, both a rock and/or soil sample was collected at each sample site. This sampling resulted in the delineation of soil geochemical anomalies at both Drenchwater and Story Creeks.

Detailed geologic mapping of the Drenchwater Creek, Story Creek, Kivliktort Mountain West, and Kady occurrences was conducted by a UAF graduate student, as

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[5]*By Joseph M. Kurtak, Geologist, Alaska Field Operations Center, Anchorage Branch, U.S. Bureau of Mines, Anchorage, Alaska.*

part of an advanced degree program. This work was done with support by the Bureau. In addition, the Abby, Bion, Ekakevik, Lakeview, Longview, Safari Creek, and Tuck occurrences were mapped in detail by the Bureau. Stratigraphic sections were measured and samples collected to determine phosphorite bed thicknesses and grades at the Kiruktagiak River, Monotis Creek, Skimo Creek, and Tiglukpuk Creek.

*FIGURE 10.- Collecting soil samples through tundra cover with a hand auger at the Drenchwater Creek occurrence. (Photo: Joe Kurtak)*

Gravity, magnetic, and very low frequency (VLF) surveys were conducted at several of the occurrences (fig. 11). The USGS conducted a gravity and magnetic survey on the grid at Drenchwater Creek and also conducted gravity surveys at the Abby and Bion barite occurrences. The Bureau conducted VLF surveys at Drenchwater Creek and Safari Creek.

Bulk samples were collected at Drenchwater and Story Creeks and from the phosphate occurrences on the Tiglukpuk River and at Ivotuk Hills. The samples were analyzed at either the Bureau's Salt Lake City Research Center or Albany Research Center to determine optimum mineral recovery techniques.

## MINERAL OCCURRENCES

Nineteen mineral occurrences were examined and sampled during the 1991 regional reconnaissance. Seven previously reported occurrences include: Drenchwater Creek, Kady, Kivliktort Mountain East, Kivliktort Mountain West, Koiyaktot Mountain East, Story Creek, and Vidlee. Detailed mapping and sampling were conducted at Drenchwater Creek, Kady, Kivliktort Mountain East, Kivliktort Mountain West, Koiyaktot Mountain East, Koiyaktot Mountain West, and Story Creek. Twelve of the occurrences were previously unreported and include: Ivotuk Hills, Kakivilak Creek, Kakivilak Creek North, Koiyaktot Mountain West, Kurupa River Southwest, Outwash Creek North, Outwash Creek Northeast, Outwash Creek South, Outwash Creek Southeast, Outwash Creek South-Southwest, Outwash Creek Southwest, and Outwash Creek West (*Meyer and Kurtak, 1992*).

Twelve mineral occurrences were examined and sampled during the 1992 field season. Previously reported occurrences include Abby, Bion, Drenchwater Creek, Ekakevik, Lisburne Ridge, Stack, Story Creek, Story Creek West, and Tuck (figs. 3 and 4). Detailed mapping and sampling were conducted at Abby, Bion, Ekakevik, Lakeview, Longview, Safari Creek, Stack, and Tuck. Three previously unreported occurrences include Lakeview, Longview, and Safari Creek (*Meyer and others, 1993*).

Twelve previously unreported and seven previously reported mineral occurrences were examined and sampled during the 1993 field season. Previously reported mineralized areas include Cobblestone Mountain, Kiruktagiak River, Monotis Creek, Skimo Creek East, Skimo Creek West, and Tiglukpuk Creek.

*FIGURE 11. - USGS geologist conducting a magnetometer survey at the Drenchwater Creek occurrence. (Photo: Joe Kurtak)*

Previously unreported mineral occurrences include Anaktuvuk River East, Cockedhat Mountain Southwest, Confusion Creek, Encampment Creek, Encampment Creek East, Encampment Creek West, Ikagiak Creek East, Ipnavik River East, Ipnavik River West, Itkillik River Northwest, Kayak Creek West, Siksikpuk River, and Siksikpuk River West (*Meyer, 1994*). The occurrences are discussed below by deposit type.

## DEPOSIT TYPES[5]

Metallic and nonmetallic mineral occurrences within the CMD study area are found in a variety of deposit types (Table 2). These include sediment-hosted lead-zinc-silver, vein-breccia lead-zinc-silver, quartz-carbonate veins, metalliferous black shales, sedimentary manganese, sedimentary phosphate, stratiform barite, and fluorite veins (Tables 3 & 4). Additional industrial minerals and energy fuels include clay, limestone, sand and gravel, and coal.

Other commodities occurring in the study area as accessories to other deposit types include cadmium, chromium, copper, lanthanum, scandium, uranium, vanadium, and yttrium.

### SEDIMENT-HOSTED STRATIFORM LEAD-ZINC-SILVER DEPOSITS

Sediment-hosted lead-zinc-silver deposits consist of two types: 1) shale-hosted massive and disseminated sulfide deposits and 2) sandstone-hosted disseminated sulfide deposits. The shale-hosted types have the greatest potential in the study area to host economic mineral deposits.

*TABLE 2. - Colville Mining District deposit types and descriptions.*

| Deposit type | Description |
|---|---|
| Shale-hosted stratiform lead-zinc-silver | Massive and disseminated sulfides in Upper Mississippian to Permian shales and siliceous mudstones of the Kuna and Siksikpuk Formations and associated andesitic volcanics. Mineralogy features sphalerite, galena, and pyrite. |
| Sandstone-hosted stratiform lead-zinc-silver | Disseminated sulfides in Upper Devonian Noatak Sandstone and Upper Devonian to Lower Mississippian Kanayut Conglomerate of Endicott Mountains allochthon. Concentrated near thrust-fault contacts with Lower Mississippian Kayak Shale. Mineralogy features sphalerite and galena. |
| Vein breccia lead-zinc-silver | Massive and disseminated sulfides associated with quartz veins and breccia zones in Upper Devonian and Lower Mississippian Kanayut Conglomerate, Noatak Sandstone, and Lower Mississippian Kayak Shale. Concentrated near thrust-fault contacts. Mineralogy features galena, sphalerite, pyrite, and chalcopyrite. |
| Quartz-carbonate veins | Disseminated sulfides in quartz veins hosted by Upper Devonian Hunt Fork Shale. Mineralogy features calcite, siderite, and barite with minor chalcopyrite and galena. |
| Metalliferous black shales | Anomalous amounts of zinc with minor lead in upper black shale member of the Lower Mississippian Kayak Shale. Mineralogy features sphalerite, galena, and barite in mudstone concretions. |
| Sedimentary manganese | Silty mudstone and shale of the Lower Cretaceous Torok Formation is anomalous in manganese. Mineralogy features abundant manganese oxide staining. |
| Sedimentary phosphate | Oölitic shaley limestone and mudstone of the Upper Mississippian Lisburne Group contain phosphate beds. Mineralogy features fluorapatite with anomalous concentrations of vanadium, zinc, and uranium. |
| Stratiform barite | Structurally controlled, tabular barite bodies lie along allochthon boundaries or associated with high-angle faults. Mineralogy features barite and witherite. |
| Fluorite veins | Lenses and fracture fillings in brecciated crinoidal limestone of the Upper Mississippian Lisburne Group. Mineralogy features fluorite and calcite. |

*TABLE 3. - Sulfide and manganese occurrences as shown on Figure 8.*

| Sulfide and Manganese Occurrences | |
|---|---|
| **Shale-hosted stratiform lead-zinc-silver** | **Vein breccia lead-zinc-silver** -- continued |
| Drenchwater Creek | Outwash Creek Southeast |
| **Sandstone-hosted stratiform lead-zinc** | Outwash Creek Southwest |
| Ipnavik River East | Safari Creek |
| Memorial Creek | Story Creek |
| Safari Creek | Vidlee |
| **Vein breccia lead-zinc-silver** | **Quartz-carbonate veins** |
| Ipnavik River West | Itkillik River East |
| Kady | Itkillik River West |
| Kakivilak Creek | Nanushuk River |
| Kurupa River | |
| Kivliktort Mountain East | **Metalliferous black shales** |
| Kivliktort Mountain West | Cockedhat Mountain |
| Koiyaktot Mountain East | Siksikpuk River |
| Koiyaktot Mountain West | **Sedimentary manganese** |
| Outwash Creek West | Cobblestone Creek |

## Shale-hosted Occurrences

Shale-hosted occurrences are hosted by sooty black shales, gray-black chert or siliceous mudstone, with intercalated andesitic volcanic rocks of the Kuna and Siksikpuk Formations. Drenchwater Creek is the only known example of this deposit type within the district. Iron oxide-stained rocks were observed by USGS geologists there in 1951, but it was not until 1975 that actual zinc and lead sulfides were identified. Sphalerite and galena occur both as fracture fillings and disseminations within the chert and shale and as small massive stratiform bodies within the siliceous mudstones near the top of the volcanic section (fig. 12).

Sulfide-bearing rocks are intermittently exposed for nearly 3.2 km along strike in the Drenchwater Creek area.

Samples from deeply-weathered outcrops average 14% combined lead-zinc and 51.4 g/mt silver (*Kulas, 1994*). A soil survey conducted to test the extent of sulfide zones under tundra cover delineated a 152 x 915 m zinc and lead anomaly. A gravity survey conducted by the USGS delineated an anomaly in the same area as the geochemical anomaly (*Morin, 1991*). A VLF survey conducted by the Bureau delineated a series of subparallel anomalies that may represent underlying

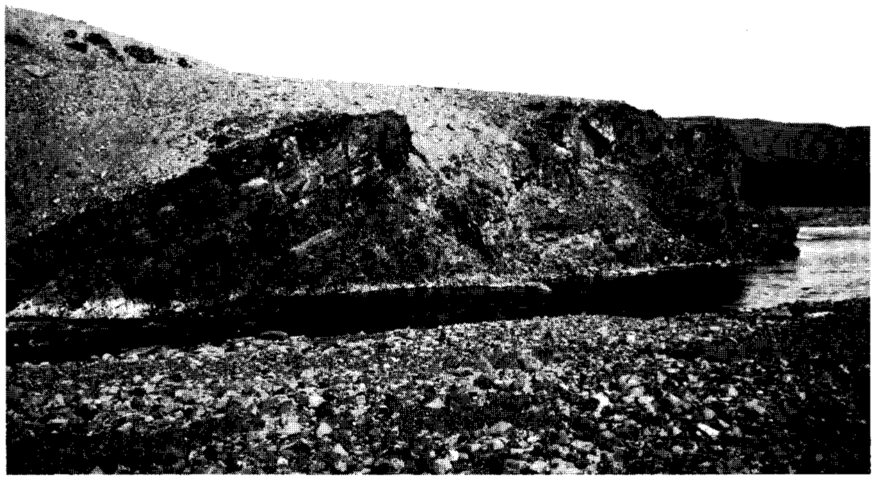

*FIGURE 12. - Interbedded sulfide-bearing siliceous mudstone and shale at the Drenchwater Creek occurrence. (Photo: Joe Kurtak)*

*TABLE 4. - Industrial mineral occurrences as shown on Figure 9.*

| Industrial Mineral Occurrences | |
|---|---|
| **Stratiform barite** | **Sedimentary phosphate** |
| Abby | Ivotuk Hills |
| Bion | Kiruktagiak River |
| Ekakevik Mtn. | Lisburne Ridge |
| Lakeview | Monotis Creek |
| Longview | Skimo Creek East |
| Stack | Skimo Creek West |
| Tuck | Tiglukpuk Creek North |
| **Fluorite veins** | |
| Mt. Bupto | |

*FIGURE 13. - Anomalous lead and zinc silica altered (light color) sandstones of the Kanayuk Conglomerate at the Safari Creek occurrence. (Photo: Joe Kurtak)*

conductive carbonaceous shales. The results of geophysical and geochemical surveys indicate potential at Drenchwater Creek for a large undiscovered lead-zinc-silver deposit. Due to lack of surface continuity, a meaningful resource estimate cannot be made without drilling.

A bulk sample of weathered material was sent to the Bureau's Salt Lake City Research Center for beneficiation testing. Grinding of the sample to -200 mesh, and the application of a standard flotation test resulted in very poor recovery. Further tests indicate that the sulfide-bearing rocks will have to be ground to at least -400 mesh for optimum recovery (*Oliver, 1992*). In this aspect it is very similar to the ore at the presently active Red Dog zinc-lead-silver mine, located 158 km southwest of Drenchwater Creek. The Drenchwater Creek host rocks are also similar to those found at Red Dog, Which has reserves totalling 70.5 mmt at 22.0% combined lead-zinc and 70 g/mt silver (*Kulas, 1994*).

<u>Sandstone-hosted Occurrences</u>

Sandstone-hosted lead-zinc-silver occurrences are confined to the Noatak Sandstone and Kanayut Conglomerate. Sphalerite and galena occur as fine-grained disseminations and fracture fillings in silica-altered, recrystallized sandstone (fig. 13). These occurrences vary widely in metal content, ranging from 572 to >20,000 ppm zinc and 379 to 1,920 ppm lead. This deposit type is much lower grade than other base-metal types in the study area, but potential exists for rather large tonnages due to the extensive outcrop area of the Kanayut Conglomerate. Occurrences are located at Ipnavik River, Safari Creek, and potentially Memorial Creek. These occurrences are concentrated along the north edge of the Endicott Mountains allochthon and potential for similar undiscovered occurrences exists along the thrust fault contact.

## VEIN BRECCIA LEAD-ZINC-SILVER DEPOSITS

Vein breccias are small, but high-grade occurrences containing galena, sphalerite, and minor chalcopyrite, hosted by the Kanayut Conglomerate, Noatak Sandstone, and Kayak Shale. Sulfides consisting of galena, sphalerite, and chalcopyrite occur in quartz veins and quartz-cemented breccia zones adjacent to the thrust fault contact at the northern edge of the Endicott Mountains allochthon. Sulfides occur within quartz veinlets less than 0.5 cm wide to breccia zones up to 36 m wide.

The Story Creek occurrence, first discovered in 1978 by Bureau geologists (*Jansons, 1982*), is the most extensive example of this deposit type (fig. 14). Here a zone of sulfide-bearing quartz veins and quartz-cemented siltstone breccia zone hosted in siltstone members of the Kayak Shale is up to 36 m wide and extends intermittently for 1,570 m along strike. Samples average 18% combined lead-zinc, and 159 g/mt silver. Select samples contain up to 30% lead, 55.6% zinc, and 696 g/mt silver. Soil samples collected along a grid surveyed over the occurrence, delineated a 284 x 424 m zone anomalous in lead and zinc. The zone appears steeply dipping and lenticular, with an unknown vertical extent. A 180 kg bulk sample from Story Creek was analyzed at the Albany Research Center. A beneficiation test, using tabling and flotation methods, recovered 96% of the zinc and 74% of the lead. These results indicate that the sulfides are amenable to traditional recovery techniques (*Summers and others, and others, 1993*).

Other, less extensive examples of this type occur at Ipnavik River, Kivliktort Mountain, Safari Creek, and the Kady occurrence on Outwash Creek (fig. 15). At

*FIGURE 14. - BLM and Bureau geologists examining sulfide breccias at the Story Creek occurrence. (Photo: Mark Meyer)*

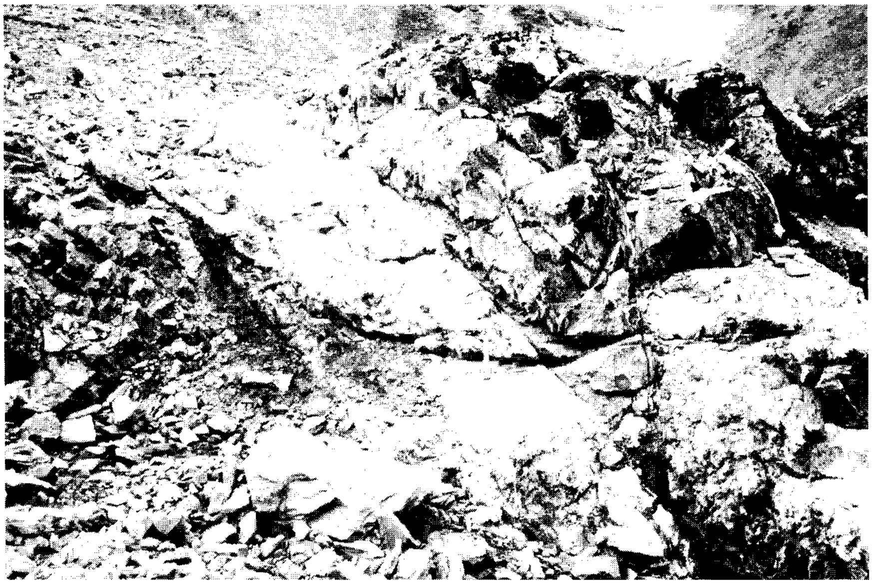

*FIGURE 15. - Vein breccia at the Kady occurrence, Outwash Creek. (Photo: Joe Kurtak)*

Itkillik River West occurrence contain up to 62% barium, 0.67% lead, 1.71 g/mt silver, and 735 ppm copper. The veins are low grade, small, and not considered to be a potentially significant resource in the study area.

## METALLIFEROUS BLACK SHALES

The 300 m thick Kayak Shale is intermittently exposed on an east-west trend for 467 km along the entire length of the southern CMD. The 43 m thick upper black shale member of the formation is anomalous in zinc. Near Cockedhat Mountain, samples of the shale contain up to 284 ppm zinc, which is over twice the average crustal abundance of zinc in similar rock types (*Levinson, 1974*).

Siltstone and mudstone septarian concretions occurring within the shales contain sphalerite, barite, and minor galena (fig. 16). Select samples of concretions from the Confusion Creek area contain up to 16,172 ppm zinc and 104 ppm lead. Sulfide-bearing concretions appear prevalent throughout the extent of the formation and were also found in the Encampment Creek, Itkillik River, Safari Creek, and Siksikpuk River drainages.

The Kayak Shale represents a potential extremely low grade, large tonnage zinc resource. Although not high grade, it may have been one of the sources from which metals were remobilized during orogenic events to form the higher-grade vein breccia occurrences.

the Kady occurrence select samples contain >2.0% copper. No VLF response was detected during a survey run across the mineralized zone at Safari Creek.

At Ipnavik River and Safari Creek the vein breccias are associated with sandstone-hosted disseminated sulfides. These disseminated sulfides may be one of the original sources of metals, which have been remobilized into the veins. This class of occurrences represents a potential high grade, low tonnage resource in the study area.

## QUARTZ-CARBONATE VEINS

Interbedded siltstone and shale of the Hunt Fork Shale hosts numerous narrow quartz veins, most of which are barren. At a few isolated locations in the Itkillik and Nanushuk River drainages, quartz carbonate veins up to 30 cm wide contain barite, calcite, and siderite along with minor chalcopyrite and galena. Samples from the

*FIGURE 16. - Sphalerite and galena-bearing concretions in the Kayak shale at Cockedhat Mountain. (Photo: Joe Kurtak)*

## SEDIMENTARY MANGANESE

In the Cobblestone Creek area the Torok Formation contains anomalous amounts of manganese. Samples collected across a 6.4 m thick section of · silty mudstone and shale contained up to 12% manganese. Specific manganese minerals have not been identified. These manganese-bearing beds are known to extend for at least 3.3 km along strike. Potential exists in the area for large tonnage sedimentary manganese deposits.

## SEDIMENTARY PHOSPHATE

Phosphate-rich oölitic shaley limestone and mudstone beds are concentrated in the Lisburne Group and to a lesser extent the Otuk Formation. These formations extend for 240 km across the study area and phosphate has been noted along this trend in numerous localities. The Bureau sampled these phosphatic rocks in the Monotis and Skimo Creek areas, Anaktuvuk Pass, Ivotuk Hills, and Lisburne Ridge (fig. 17).

The largest occurrences are to be found in the Monotis and Skimo Creek areas, where stratigraphic sections were measured and detailed sampling conducted. At Monotis Creek phosphate rock and phosphatic shale and limestone occur in bedded sequences up to 11 m thick. Samples across 6.7 m thick section of this sequence averaged 23.0% $P_2O_5$ with individual 0.6 m thick beds containing up to 30% $P_2O_5$.

Bulk samples of phosphate rock were collected at Ivotuk Hills and Monotis Creek. Examination of the material indicates that the phosphate mineral fluorapatite makes up approximately 60% of the phosphate rock with the remainder being carbonate material (*Vandel, 1993*). Samples of the phosphate rock also contained up to 2,000 ppm vanadium, 1,353 ppm zinc, and 150 ppm uranium. An indicated resource totalling 14 mmt at 6.7% $P_2O_5$ and an 11 m average bed thickness, has been delineated in the Skimo Creek area. The potential exists for more phosphate resources in rocks of the Lisburne Group throughout the study area.

## STRATIFORM BARITE

Minor occurrences of barite consist of

thin beds, nodules, and fracture fillings within the Siksikpuk Formation throughout the study area. Larger and higher grade stratiform occurrences are mostly concentrated in the Cutaway Basin area in the western part of the study area.

Seven barite occurrences were discovered by Bureau and USGS personnel in this area during the course of the CMD study (*Kelley and others, 1993*). The largest of these, the Longview occurrence, consists of a tabular bed of barite that averages 22 m thick and can be traced for 686 m along strike (fig. 18). This bed may be continuous with the nearby Lakeview occurrence with a potential strike length at least 2 km.

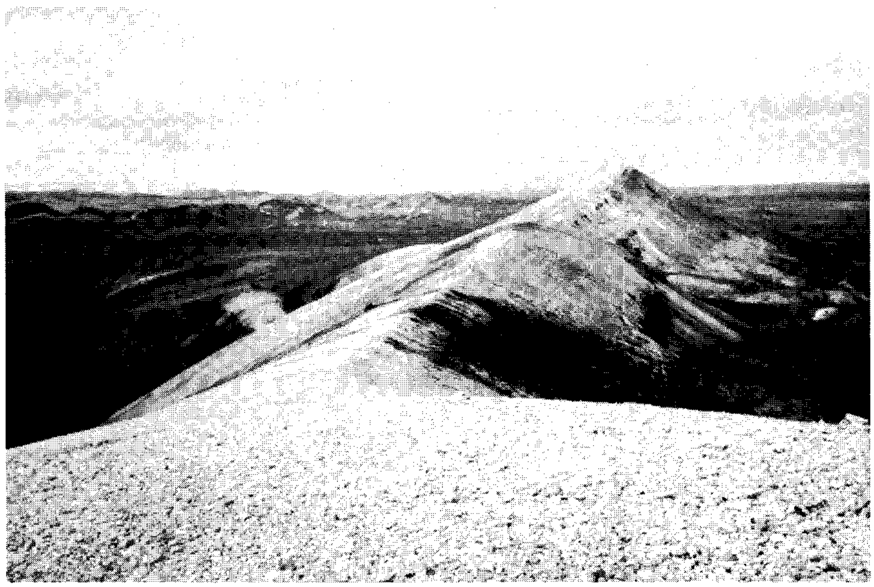

*FIGURE 17. - Westward view of Lisburne Group limestone exposed along Lisburne Ridge. (Photo: Mark Meyer)*

The barite is, for the most part, hosted by shale and chert and may be structurally controlled, lying along allochthon boundaries or lineaments that represent high-angle faults. Other barite occurrences include Abby, Bion, Ekakevik Mountain, Stack, and Tuck. The USGS conducted gravity surveys at the Abby and Bion occurrences, delineating anomalies at both sites.

The occurrences have a total inferred resource totalling 49 mmt with grades of up to 97% $BaSO_4$ and specific gravities as high as 4.3. Besides barite, one occurrence contains minor amounts of witherite

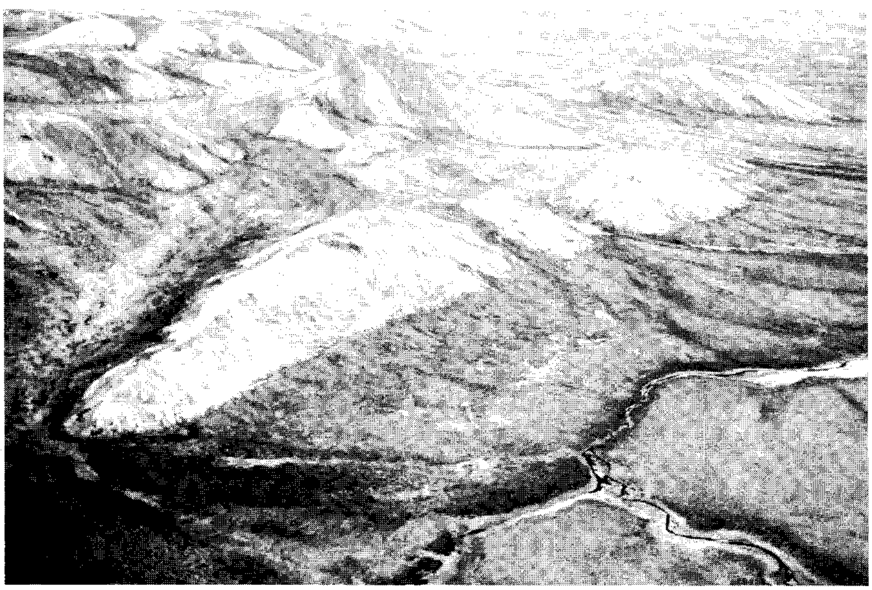

*FIGURE 18. - Stratiform barite at the Longview occurrence (light colored ridge) in the Cutaway Basin area. (Photo: Joe Kurtak)*

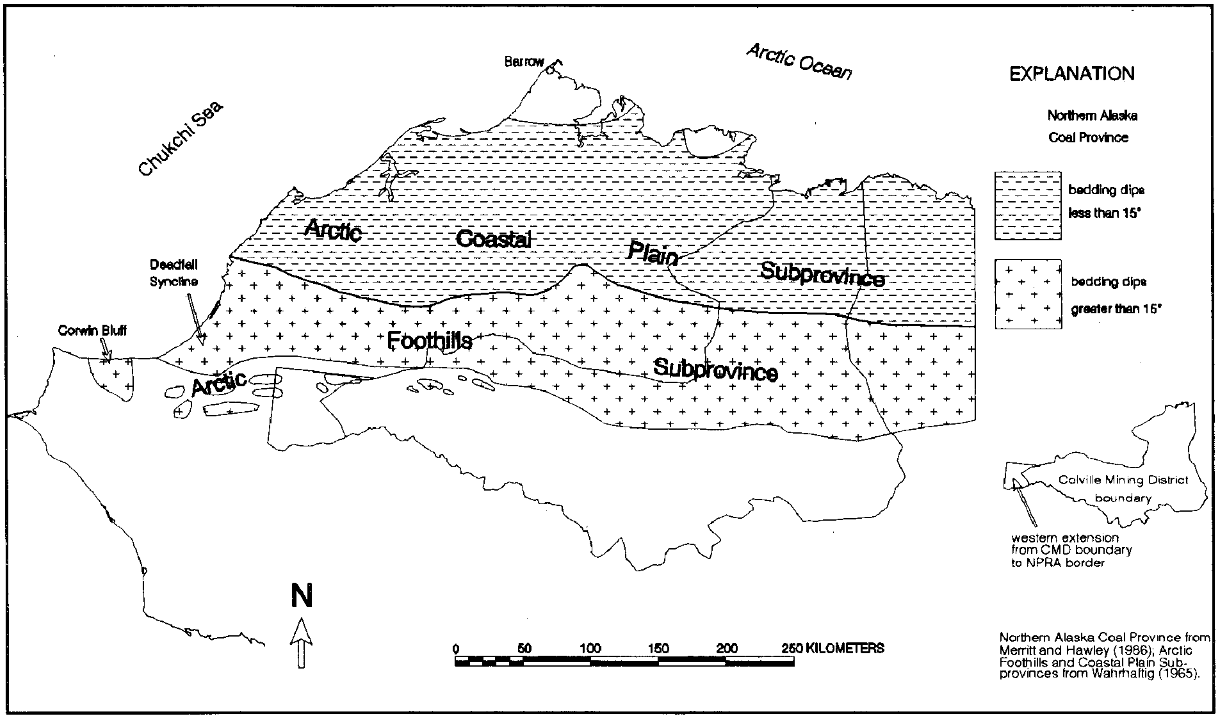


*FIGURE 19. - Location of Northern Alaska Coal Province and Arctic Foothills and Coastal Plain subprovinces, Colville Mining District, Alaska.*

($BaCO_3$). The barite at the majority of the occurrences has specific gravity that meets the minimum requirements for drilling mud grade barite. The potential for more such deposits exists along allochthon boundaries in the same area.

## FLUORITE VEINS

Fluorite, associated with calcite, occurs in lenses and fracture fillings in brecciated crinoidal limestone of the Lisburne Group on the north side of Mt. Bupto. Select samples contain up to 73% fluorite. The extent of the fluorite-bearing rocks is small, making the potential for large-tonnage resources low.

## COAL[1-2]

Coal, in the CMD, is located within the Northern Alaska Coal Province (*Merritt and Hawley, 1986*) which includes the Arctic Coastal Plain and the Arctic Foothills subprovinces as shown on figure 19. Nonmarine rocks containing coal beds include the surface to near surface Fortress Mountain Formation, Nanushuk Group, Colville Group, and the Sagavanirktok

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*[6]By James G. Clough, Geologist, State of Alaska, Division of Geological and Geophysical Surveys, Fairbanks, Alaska.*

*[7]and Gary D. Stricker, Geologist, U.S. Geological Survey, Denver, Colorado.*

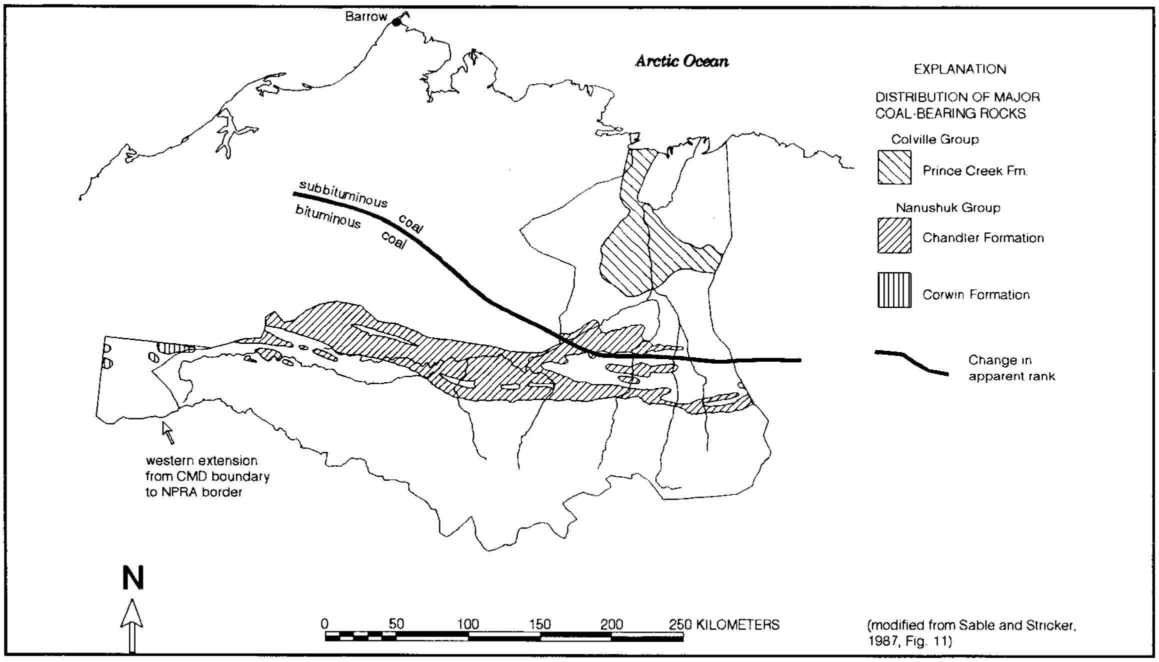


*FIGURE 20. - Distribution of minor coal-bearing rocks (Nanushuk & Colville Groups) in surface and subsurface. Lines indicate change in apparent rank (modified from Sable and Stricker 1987).*

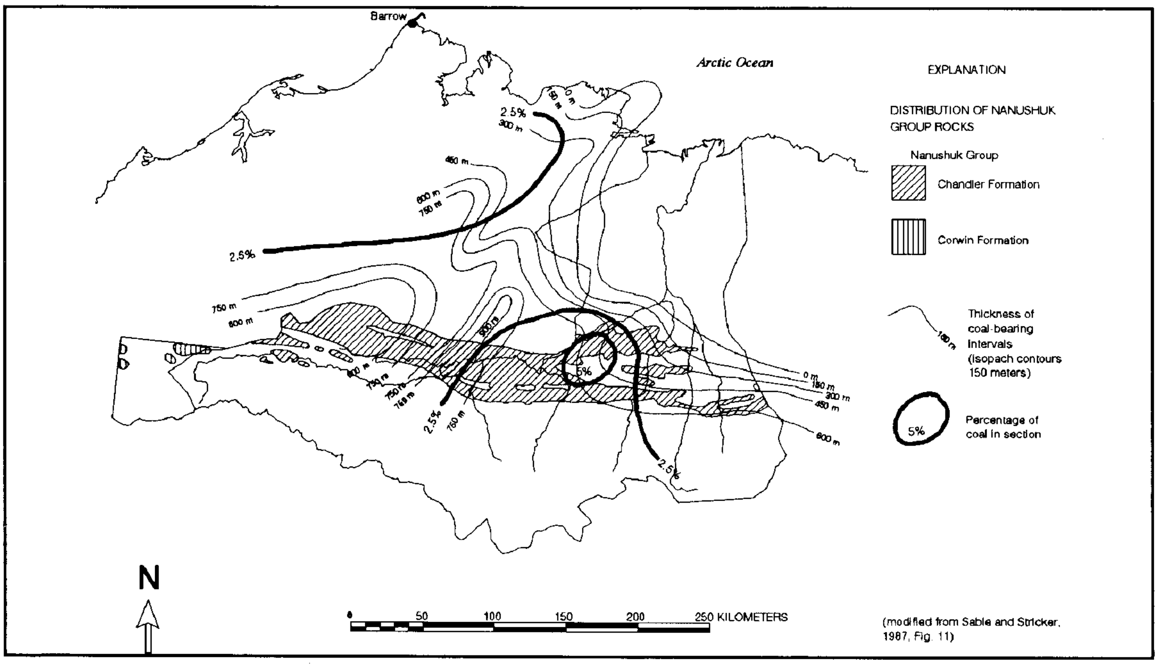


*FIGURE 21. - Thickness of Nanushuk Group coal-bearing intervals and percentage of coal in section determined from outcrop and drill hole data (modified from Sable and Stricker, 1987).*

Formation (fig. 5). The bulk of the high quality coal is found in the Nanushuk Group's two principle coal-bearing formations (fig. 20), the Corwin Formation (western CMD) and the Chandler Formation (central and eastern CMD). Major structural elements in the Arctic Foothills subprovince which control outcrop patterns, thickness of the coal-bearing interval, and minability of the coals are a series of east-west trending anticlinal-synclinal pairs. These anticlines and synclines were folded by north-vergent thrusting which occurred during the Brooks Range orogenic event. Maximum bedding dip of the local coal-bearing sedimentary rocks in the foothills fold belt are greater than 15°, whereas in the coastal plain, bedding is less than 15° (fig. 18).

Mississippian-age Kekiktuk Conglomerate occurs at considerable depth within the CMD. Although known to contain coal beds up to 1.5 m thick in the subsurface at several test well sites on the North Slope (*Sable and Stricker, 1989*), it is not considered to contain any significant minable coal resources due to its considerable depth (>3,300 m). Lower Cretaceous Fortress Mountain Formation outcrops in the Arctic Foothills subprovince and contains minor occurrences of thin, discontinuous seams of coal associated with fluvial sandstone (*Crowder, 1989*). The Fortress Mountain Formation does not contain economic quantities of coal.

The Nanushuk Group is comprised of six marine to nonmarine rock units (fig. 19) deposited in the Cretaceous-age Colville basin situated north of the Brooks Range. During Early to Late Cretaceous time the Colville basin was the site of two river delta systems, the Corwin delta (western North Slope) and the Umiat delta (central North Slope) (*Ahlbrandt and others, 1979*). These deltas may have merged during Albian time (*Molenaar, 1981 and 1985*). The Corwin Formation represents deposition in the southwest-sourced Corwin delta plain to alluvial plain depositional environments. This formation is at its thickest (3,350 m) at Corwin Bluff, which is located west of the study area on the Chukchi Sea coast, and thins eastward to zero in the subsurface near the Colville River (*Stricker, 1991*). Northwest of the CMD coal beds up to 6 m thick outcrop along the Kukpowruk River (*Warfield and Boley, 1969*). Known surface and subsurface Corwin Formation coal beds are limited to the far western end of the CMD (fig. 20). Coal-bearing rocks in the

*FIGURE 22. - Typical Corwin Formation outcrop with weathered coalbed (above snowpack), western NPRA. (Photo: Gary Stricker)*

central and eastern CMD consist of the Chandler Formation (fig. 20) which was deposited in the Umiat middle delta plain environment (*Stricker, 1991*). The Chandler Formation intertongues with marginal marine to marine rocks, and is up to 1,090 m thick with 1.7 m thick beds outcropping along the Colville River (figs. 23 and 24).

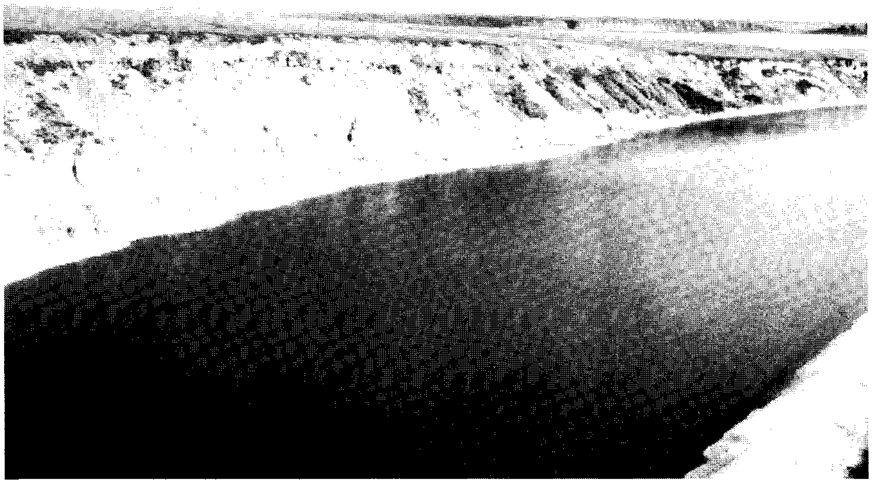

*FIGURE 23. - Exposure of coal-bearing Chandler Formation along the Colville River, central Colville Mining District (detail shown in figure 24). (Photo: Jim Clough)*

The Upper Cretaceous Colville Group (fig. 19) is a younger sequence than the Nanushuk Group and is best exposed along the lower part of the Colville River and its tributaries in the eastern part of the CMD (fig. 20). Coals of the Colville Group have been studied less than those of the Nanushuk Group because they have shown less economic potential. Outcrop descriptions of the Colville Group coals indicate that most beds are thinner and have a lower ranking than those of the Nanushuk Group (fig. 25). Many of these coals are described as "lignites and bony coals." The Colville Group contains an insignificant coal resource in the CMD.

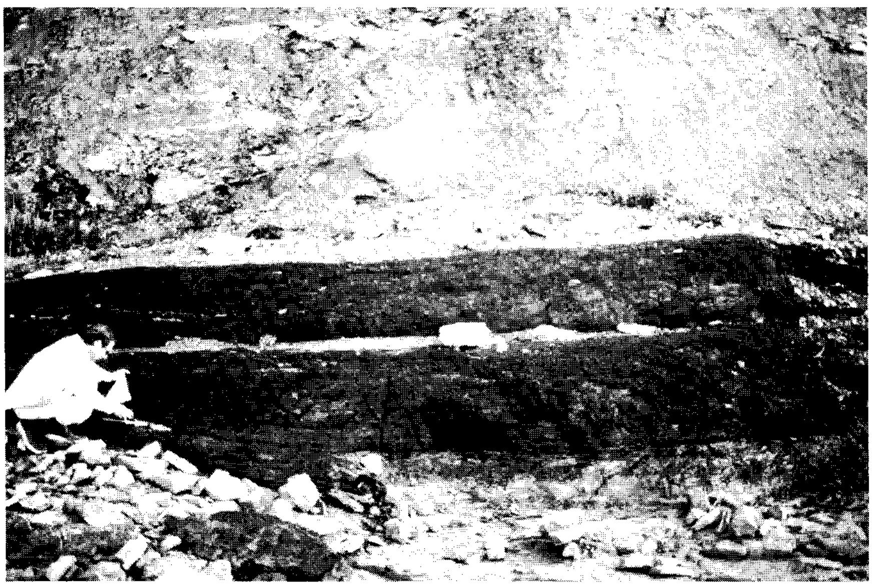

*FIGURE 24. - Coal seam in the Chandler Formation at the Colville River outcrop (shown in figure 23). Coalbed is 1.7 m thick and contains ash partings. (Photo: Jim Clough)*

Tertiary Sagavanirktok Formation (fig. 19) appears to have little or no coal potential in the CMD, but does contain some thick beds farther east (*Roberts, 1991*). Published descriptions indicate that these coals are lignitic and subbituminous in apparent rank (*Roberts and others,*

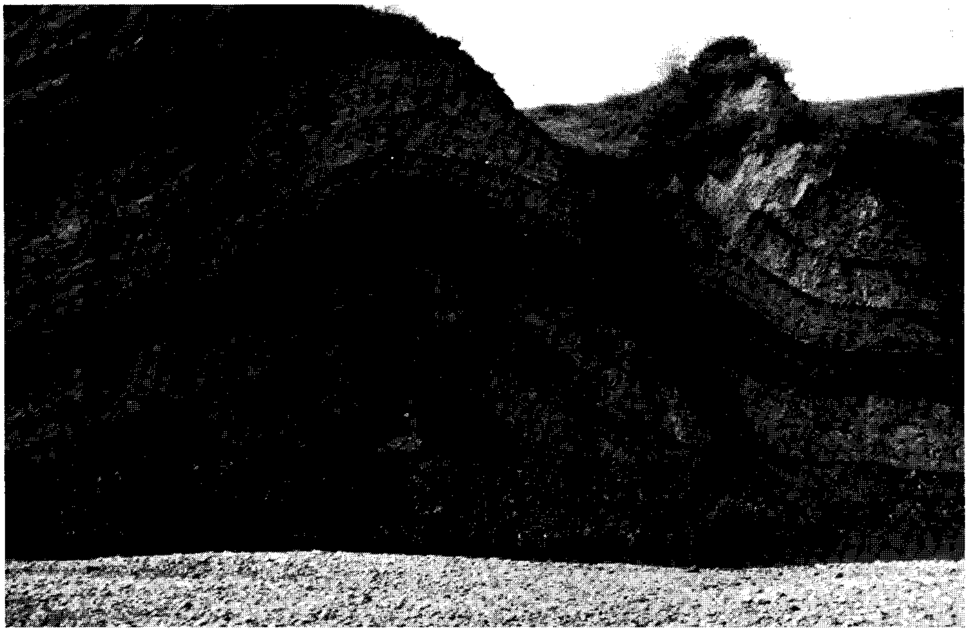

*FIGURE 25. - Thin coalbeds in exposure of the Colville Group along the lower Colville River. (Photo: Gary Stricker)*

*1990*). Detterman and others (*1975*) reported that coaly beds more than 6 m thick outcrop in the lowest member of the formation (Sagwon Member), but they are described as lignite and coaly shale of a slightly lower grade than those in the subjacent Colville Group.

Coal Resource Estimate

The USGS has divided coal resources into two categories, identified and hypothetical, which are based on available coal data (*Wood and others, 1983*). Identified coal resources are those whose location, rank, quality, and quantity are known or can be estimated from geologic evidence. Identified resources include measured, indicated, and inferred resources and also include economic, marginal economic, or subeconomic coals (*Wood and others, 1983*). By convention, identified coal resources include all the coal within a distance of 4.8 km from points of control or reliability. Points of control include outcrops, trenches, or drill holes.

Hypothetical coal resources assume a low degree of geologic assurance. Estimates of thickness, extent, rank, and quality are based on an assumption of continuity beyond the identified resource classification (*Wood and others, 1983*). By convention, estimates are made by projecting coal data beyond 4.8 km from points of control, which include outcrops, trenches, or drill holes.

Although identified coal resources could be estimated for the CMD, they were not made. The paucity of data available would produce an insignificantly small tonnage of identified coal resource. For this study, only hypothetical coal resources were assessed for the coal-bearing Corwin and Chandler Formations of the Nanushuk Group. The other coal-bearing units were determined to contain very minor to unknown quantities of coal (Kekiktuk Conglomerate and Fortress Mountain Formation), poor quality coal (Colville Group), or possess limited areal extent within the CMD boundary (Sagavanirktok Formation) to constitute significant coal resources.

Hypothetical coal resources for the

CMD were determined by calculating the areas of coal-bearing Nanushuk Group rocks and the percentage of coal in outcrop and drill holes (summarized in fig. 21) using the following formula given in Sable and Stricker (*1987*):

$$\mathbf{R} = \mathbf{A} \times \mathbf{T} \times \mathbf{C}$$

where; **R** = hypothetical coal resources for the Nanushuk Group;

**A** = areas of coal-bearing rocks determined by this study;

**T** = thickness of coals present in drill holes and measured sections;

and **C** = conversion from volume to metric tons based on coal density by rank.

Total hypothetical coal resources of the CMD are estimated to be 253 billion metric tons of bituminous coal and 47 billion metric tons of subbituminous coal (Table 5). Table 5 shows the distribution of hypothetical coal resources in the Arctic Coastal Plain and Arctic Foothills subprovinces (>15° and <15° bedding dip, respectively), total resources, and in the thickness of overburden categories (0 to 150 m, 150 to 300 m, 300 to 600 m, and >600 m). Hypothetical coal resources of the Nanushuk Group rocks in the NPRA were previously estimated by Sable and Stricker (*1989*) to be

*TABLE 5. - Summary of coal resources in the Colville Mining District, Alaska. (including the western extension to the NPRA boundary)*

| | Subbituminous coal (billion metric tons) | Bituminous coal (billion metric tons) |
|---|---|---|
| **Resources** | | |
| Coal in beds dipping >15° (Arctic foothills subprovince) | 34.05 | 252.92 |
| Coal in beds dipping <15° (Arctic coastal plain subprovince) | 12.95 | 0 |
| Total coal resources | 47.00 | 252.92 |
| **Overburden** | | |
| 0-150 Meter of overburden | 38.02 | 237.47 |
| 150-300 Meter of overburden | 4.26 | 7.03 |
| 300-600 Meter of overburden | 2.34 | 7.02 |
| >600 Meter of overburden | 2.38 | 1.38 |

2.5 trillion metric tons and total North Slope hypothetical resources may be as high as 2.9 trillion metric tons (*Stricker, 1991*).

## Coal Quality

Nineteen samples of bituminous coal and fourteen samples of subbituminous coal from the CMD were previously tested for proximate and ultimate analysis (*ASTM, 1991*) and the minimum, maximum, and arithmetic mean values of the analytical results are given in Tables 6 and 7. Nanushuk Group coals range in apparent rank from lignite A to high volatile A bituminous coal, with a mean of high volatile C bituminous coal. Total sulfur content ranges from 0.1 to 2.0% (mean

*TABLE 6. - Minimum, maximum, and arithmetic mean values of proximate and ultimate analysis of bituminous coal in the Colville Mining District, Alaska.*

| | Number of samples[1] | Minimum | Maximum | Arithmetic mean |
|---|---|---|---|---|
| Moisture (%) | 19 | 4.19 | 13.69 | 9.24 |
| Volatile matter (%) | 19 | 25.58 | 33.14 | 29.73 |
| Fixed carbon (%) | 19 | 43.50 | 60.20 | 53.86 |
| Ash[2] (%) | 19 | 2.71 | 20.20 | 7.15 |
| Hydrogen (%) | 17 | 4.59 | 5.93 | 5.36 |
| Carbon (%) | 17 | 59.48 | 70.82 | 66.56 |
| Nitrogen (%) | 17 | 0.97 | 1.76 | 1.45 |
| Oxygen (%) | 17 | 16.59 | 25.58 | 20.28 |
| Sulfur (%) | 19 | 0.10 | 0.56 | 0.33 |
| Heat-of-combustion (kcal/kg)[3] | 19 | 5,560 | 6,890 | 6,350 |
| Sulfate (%) | 17 | 0.01 | 0.04 | 0.01 |
| Pyritic sulfur (%) | 17 | 0.01 | 0.04 | 0.01 |
| Organic sulfur (%) | 17 | 0.23 | 0.55 | 0.33 |
| MMMFkcal/kg[4] | 19 | 6,180 | 7,310 | 6,890 |

[1]*Seventeen samples tested for proximate and ultimate analysis, two samples tested for proximate analysis only.*
[2]*U.S. Bureau of Mines method for ash analysis.*
[3]*Kcal/kg, Kilocalories/Kilogram (1 kcal/kg = 0.556 BTU/lb).*
[4]*Moist, Mineral Matter-Free Heat-of-combustion kcal/kg.*

value 0.33%) and ash content ranges from 2.7 to 27.3% (mean value 11.0%).

<u>Coal Resource Potential</u>

For Nanushuk Group coals in the CMD total hypothetical coal resources are estimated to be 300 billion metric tons. More than 80% of this resource is apparent high rank bituminous coal of which greater than 90% is estimated to occur near the surface in the 0 to 150 m of overburden class. Although no mining of coal has ever occurred within the CMD, the potential for producing significant tonnages of medium to high rank low sulfur coals exists (*Clough and Stricker, 1994*).

*TABLE 7. - Minimum, maximum, and arithmetic mean values of proximate and ultimate analysis of subbituminous coal in the Colville Mining District, Alaska.*

| | Number of samples[1] | Minimum | Maximum | Arithmetic mean |
|---|---|---|---|---|
| Moisture (%) | 14 | 6.09 | 33.00 | 19.57 |
| Volatile matter (%) | 14 | 22.10 | 34.60 | 27.13 |
| Fixed carbon (%) | 14 | 24.50 | 45.38 | 38.93 |
| Ash[2] (%) | 14 | 3.14 | 27.31 | 14.31 |
| Hydrogen (%) | 10 | 4.20 | 6.25 | 5.41 |
| Carbon (%) | 10 | 43.92 | 54.89 | 50.09 |
| Nitrogen (%) | 10 | 0.72 | 1.26 | 1.00 |
| Oxygen (%) | 10 | 23.63 | 39.33 | 31.80 |
| Sulfur (%) | 14 | 0.13 | 2.00 | 0.34 |
| Heat-of-combustion (kcal/kg)[3] | 14 | 3,120 | 5,120 | 4,420 |
| Sulfate (%) | 10 | 0.01 | 0.02 | 0.01 |
| Pyritic sulfur (%) | 10 | 0.01 | 0.06 | 0.03 |
| Organic sulfur (%) | 10 | 0.05 | 0.26 | 0.17 |
| MMMFkcal/kg[4] | 14 | 3,980 | 5,790 | 5,230 |

[1]*Ten samples tested for proximate and ultimate analysis, four samples tested for proximate analysis only.*
[2]*U.S. Bureau of Mines method for ash analysis.*
[3]*Kcal/kg. Kilocalories/Kilogram (1 kcal/kg = 0.556 BTU/lb).*
[4]*Moist, Mineral Matter-Free Heat-of-combustion kcal/kg.*

## INDUSTRIAL MINERALS[8]

Present within the CMD study area are potential economic sources of the industrial minerals barite, phosphate, manganese, and bentonite. Rare-earth elements, uranium, and vanadium are associated with several phosphate occurrences.

### Barite

Sediment-hosted bedded-barite deposits occur in the Etivluk and Lisburne Group carbonate rocks (*Schmidt and others, 1991*). Barium anomalies have been reported at Sorepaw Creek, Chertchip Creek, Singayoak Creek, Swayback Creek, Safari Creek, Twistem Creek, and Nigu Bluff (*Churkin and others, 1978*; *Cobb, 1975*; *Jansons and Baggs, 1980*; *Jansons and Parke, 1981*; *Tailler and others, 1976*).

Seven bedded-barite occurrences were evaluated by the Bureau during the CMD study (Table 4). They include: the Abby, Bion, Lakeview, Stack, and Tuck occurrences in the Cutaway Creek drainage; the Ekakevik occurrence in the Ipnavik River drainage; and the Longview occurrence in the Cula Creek drainage (fig. 8). These barite bodies average from 10 to 40 m in thickness, from 93.1 to 97.1% $BaSO_4$, and specific gravity averaging from 3.90 to 4.31, making them of potential commercial importance (*Meyer and others, 1993*).

Indicated resources for the deposits have been identified by the Bureau and USGS (*Meyer and Kurtak, 1992*; *Kelley and others, 1993*) to include: Abby containing 406,080 mt, Bion containing 10,051,470 mt, Ekakevik containing 2,275,560 mt, Lakeview containing 3,773,788 mt, Longview containing 29,494,395 mt, Stack containing 2,851,223 mt, and Tuck containing 155,160 mt.

### Phosphate

Phosphate deposits with associated uranium occur within the Lisburne Group carbonate rocks (*Schmidt and others, 1991*). Phosphate deposits have been reported at Mt. Bupto, Chandler Lake, Kanayuk River, Fay Creek, Hardway Creek, Ekakevik Mountain, Nigu River, Oolamnagavik River, Kiruktagiak River, Natvakruak Lake, Tiglukpuk Creek, Anaktuvuk River, and Tulugak Lake and are listed in Table 4 (*Cobb, 1975*; *Cobb and Kachadoorian, 1961*; *Grybeck, 1977*; *Patten and Matzko, 1959*; *Tailleur and others, 1976*; *USBM, 1978 and 1979*).

The Bureau has identified eight oölitic phosphate occurrences (fig. 8) located at Anaktuvuk River East, Kiruktagiak River, Lisburne Ridge, Monotis Creek, Skimo Creek East and West (fig. 26), and Tiglukpuk Creek North, One of the phosphate occurrences is associated with the Otuk Formation is at Ivotuk Hills (*Meyer and others, 1993*; *Meyer and Kurtak, 1992*).

The Bureau evaluated the occurrences during the CMD study. Samples of the oölitic phosphate taken from the occurrences contain from 0.03 to 36.61% $P_2O_5$, which falls just short of deposits that are commercially mined worldwide (*Meyer and others, 1993*). Ivotuk Hills contain the highest phosphate values while Lisburne Ridge phosphate was traceable for 5 km. No potential resource

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[8]*Coauthored by DeAnne S. Pinney, Geologist, State of Alaska, Division of Geological and Geophysical Surveys, Fairbanks, Alaska.*

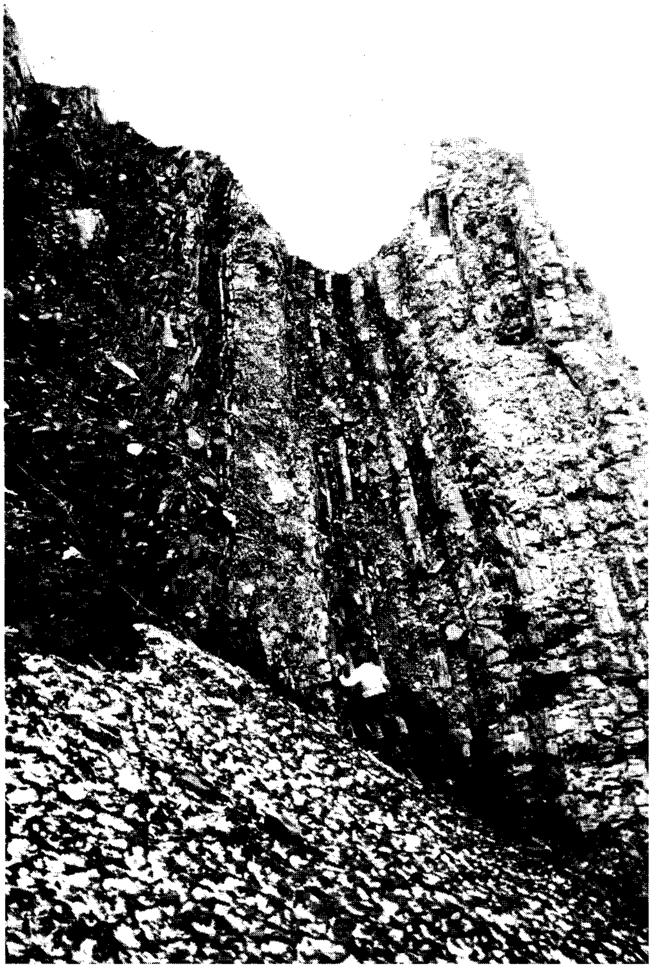

*FIGURE 26. - Steeply dipping sedimentary phosphate beds along Skimo Creek. (Photo: Joe Kurtak)*

estimates were made for these occurrences.

Many of the phosphate deposits also exhibited enriched concentrations of uranium. High uranium values are reported at Mt. Bupto, Kiruktagiak River, Chandler Lake, Natvakruak Lake, Tiglikpuk Creek, and Anaktuvuk River (*Cobb, 1975*; *Cobb and Kachadoorian, 1961*; *Grybeck, 1977*; *Patton and Matzko, 1959*; *Tailleur and others, 1976, USBM, 1978 and 1979*). The Bureau identified associated uranium at the Ivotuk Hills and Lisburne Ridge occurrences as well as vanadium along Lisburne Ridge.

### Manganese

Manganese occurs within the Etivluk and Lisburne Group siliceous rocks (*Schmidt and others, 1991*). Manganese anomalies have been reported at Mt. Bupto, Twistem Creek, and Isikut Mountain but have not been closely studied and are likely not of commercial grade (*Churkin and others, 1978*; *Cobb, 1975*; *Cobb and Kachadoorian, 1961*; *Jansons and Baggs, 1980*; *Jansons and Parke, 1980*; *Patton and Matzko, 1959*; *Tailleur and others, 1976*; *USBM, 1979*).

One manganese occurrence has been identified by the Bureau (Table 3, fig. 7) during the CMD study. Cobblestone Creek contains 0.51 to 11.69% manganese (*Meyer, 1994*).

### Bentonite

Beds of nearly pure bentonite that may be suitable for drilling mud are exposed along the Chandler and Colville Rivers and at Schrader Bluff on the Anaktuvuk River (*Cobb, 1975*; *Detterman and others, 1963*). The proximity of these deposits to North Slope oilfields and their location on rivers that could easily serve for transport make these clays a potential viable commercial resource.

## GEOLOGIC MATERIALS[8]

Geologic materials in the CMD include limestone, quartzose rock, basalt/greenstone, sand, and gravel as shown in figure 8. Analysis of published geologic maps by the ADGGS indicates that the CMD includes approximately 125,537 hectares of land underlain by carbonate rock (including limestone and dolomite), 163,663 hectares of land underlain by quartzose rock (including sandstone, quartzite, and conglomerate), and 1,380 hectares of land underlain by basalt and greenstone (Table 8). Also mapped in the area are more than 263,546 hectares of sand and almost 1,204,933 hectares of sand and gravel. Although distance to present construction sites renders much of this material subeconomic, future development in the CMD will be aided by these ready supplies of geologic materials.

## GEMSTONE

Gemstones in the CMD study area consist of quartz crystals weathered out of both cherts and wackes. The crystals were located along a 3 km wide zone 5 km north of the southwestern study area boundary (fig. 27). The Bureau has identified this zone to extend from the Eagle Creek area eastward at least to the Kurupa Hills area. Most crystals were located along the ridge lines, but occasional crystals were found within stream drainages. The crystals range from 0.6-cm clear double-terminated crystals, through 5-cm smokey crystals, up to massive 15-kg milky quartz clusters (*Meyer and others, 1993*). A few small crystals were noted east of Kurupa Hills during 1993.

*TABLE 8. - Aerial extent of geologic materials in the CMD by quadrangle (Hectares).*

| Quadrangle name | Carbonate rock | Quartzose rock | Basalt/ Greenstone | Sand | Sand and gravel |
|---|---|---|---|---|---|
| Chandler Lake | 87,940 | 23,679 | 0 | 9,898 | 235,251 |
| Harrison Bay | 0 | 0 | 0 | 41,686 | 103,179 |
| Howard Pass | 16,657 | 2,723 | 0 | 0 | 192,191 |
| Ikpikpuk River | 0 | 0 | 0 | 70,398 | 45,446 |
| Killik River | 12,434 | 48,123 | 1,380 | 2,342 | 347,155 |
| Misheguk Mountain | 125 | 30,951 | 0 | 0 | 43,826 |
| Philip Smith Mountains | 8,113 | 0 | 0 | 8,836 | 11,740 |
| Survey Pass | 268 | 55,873 | 0 | 0 | 9,691 |
| Teshekpuk | 0 | 0 | 0 | 9,922 | 1,034 |
| Umiat | 0 | 2,314 | 0 | 120,464 | 209,228 |
| Utukok River | 0 | 0 | 0 | 0 | 6,192 |
| Total area | 125,537 | 163,663 | 1,380 | 363,546 | 1,204,933 |

*FIGURE 27. - Typical location containing quartz crystals weathered out of the host rocks in the Nucleus Mountain area. (Photo: Mark Meyer)*

## MINING FEASIBILITY STUDIES[9]

Mining prefeasibility investigations for the CMD study were conducted for three mineral deposit models (*Coldwell and Gensler, 1994*). The models were based on both actual deposits that occur within the study area and hypothetical deposits. Mine models were developed for application to the mineral deposit models and capital and operating costs were estimated using the Bureau's Cost Estimation System (CES II). Published cost information drawn from industry publications, permitting documents, and environmental impact statements was also used. All costs were escalated by factors which reflect the higher cost of labor, transportation, and electricity in Alaska.

The cost data for each mine model and long-term average commodity prices were used to perform a cash flow analysis for each mine model, and the discounted cash flow rate of return (DCFROR) was calculated. The goal of the prefeasibility study was to determine the break-even price per metric ton of minable ore that would cause the simulated cash flow of each of the

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[9]*By J. R. Coldwell and E. C. Gensler, Mining engineers, Alaska Field Operations Center, Juneau Branch, U.S. Bureau of Mines, Juneau, Alaska.*

mine models to achieve a 15% DCFROR economic threshold. The 15% DCFROR threshold was selected as the minimum return on investment that would be considered acceptable.

Based on the prefeasibility studies, none of the deposits investigated in the CMD study area are economic at the present time. Economic development in the district is hampered by the area's remote location and the high costs of developing transportation infrastructure. For a model to successfully amortize all of its capital costs and the continuing expense of transporting the commodity to market requires an exceptional deposit. Due to the lack of infrastructure in the arctic, shipment of the commodity would be made through a 100 day window when the Chukchi Sea is ice-free. Large tonnage, high grade, massive sulfide deposits may be economically feasible if additional work proves the existence of sufficient reserves amenable to open pit mining methods and current milling technology. There are innumerable variables that effect the economic viability of an ore deposit.

One possible use of the mining prefeasibility study would be to compare the results of the economic analysis of a deposit model to an actual deposit possessing similar geological and structural attributes. The results of this mining prefeasibility analysis could then be used, in a preliminary manner, to evaluate the mining potential of actual deposits with the deposit models.

*FIGURE 28. - Bureau geologist examining sulfide mineralization along a tributary of the Anaktuvuk River. (Photo: Mark Meyer)*

## PROBABILISTIC MINERAL ASSESSMENT[10,11,12,13]

Mineral resources in the southeastern part of the CMD were assessed using a modified version of a computer simulation model. Based on the results of field work by the Bureau and the ADGGS, the

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[10]*By Rainer Newberry, Professor of Geology, University of Alaska, Fairbanks, Alaska.*

[11]*and Melanie B. Werdon, Graduate Student, University of Alaska, Fairbanks, Alaska.*

[12]*and Laurel E. Burns, Geologist, State of Alaska, Division of Geological and Geophysical Surveys, Fairbanks, Alaska.*

[13]*and C. G. Mull, Geologist, State of Alaska, Division of Geological Surveys, Fairbanks, Alaska.*

probabilistic resource assessment covers only the part of the CMD occurring within the Howard Pass, Killik River, and Chandler Lake quadrangles. The assessment was accomplished as part of a cooperative agreement between the Bureau and the ADGGS. An assessment committee was composed of geologists and engineers from the Bureau, ADGGS, and UAF. The committee members were participants in geologic mapping, sample collection, and analysis during the field investigation of the CMD study, and are intimately familiar with the district. Documentation for this summary is presented in Werdon and others (*1994*). The computer model (ROCKVAL) used in this assessment was developed jointly by the Bureau and ADGGS (*White and others, 1987*).

Although there are a large number of well-documented prospects and deposit types in the CMD, none of the various non-fuel mineral prospects have been drilled or trenched, and consequently their three-dimensional extent is unknown. Under these circumstances ROCKVAL is a useful resource endowment computational tool, because different mineral deposit "types" have relatively consistent and documentable sizes, grades, and by-product commodities. The computer simulation made extensive use of such "generic" deposit-based models (i.e. models constructed from world-wide data sets) for initial estimates of deposit parameters. The number of mineral deposits and their associated grades and tonnages were estimated using generic probability distributions for particular deposit types, based on compilations derived from world-wide literature. Specific knowledge about the occurrence of deposits within the CMD was used to modify these parameters, where appropriate, by the assessment committee. The results of the assessment represent a mineral endowment for the CMD. The assessment results can be used to derive an estimate of the economic value of the mineral resources in the study area, using appropriate economic models.

The results of the ROCKVAL analysis can be described in several ways. In order to show and compare the contribution of the various deposit types to the overall metal endowment of the CMD, contained metals are presented on a deposit type by deposit type basis (Table 9). This tabulation provides a measure of the relative value of each deposit type, highly simplified because the elements are not necessarily present in high enough concentrations or appropriate mineralogy for presently economic extraction and beneficiation, and because different commodities have different intrinsic prices. The results shown in Table 9 are arranged in descending order of endowment (using current commodity prices) for the 90% probability level.

The areas judged favorable for the various deposit types are shown on figures 29-35, rated by favorability. The favorability is a number that denotes the probability that the deposit type is present as a prospect or better in the particular area. Areas given high favorability are based upon the presence of identified mineral occurrences and/or strong geochemical anomalies; these regions are given >95% favorability. Areas of moderate favorability are based upon the occurrence of appropriate rock types and geochemical anomalies; assigned favorability ranges between 90 and 55%. Areas of low favorability are based upon the presence of permissible rock types but do not necessarily contain and significant geochemical anomalies or surface occurrences of mineralization; assigned favorability ranges

TABLE 9. - Estimated summary endowment for the Colville Mining District, by deposit type.

| Deposit type/Contained metal (units) | Probability fractile | | |
|---|---|---|---|
| | 90th | 50th | 10th |
| **Sedex Pb-Zn** | | | |
| Tonnage ($10^6$ tons) | 5.4 | 140 | 530 |
| Zinc ($10^6$ tons) | 0.4 | 11 | 50 |
| Lead ($10^6$ tons) | 0.2 | 5.4 | 30 |
| Silver ($10^6$ oz) | 3 | 190 | 1300 |
| **Vein breccia Pb-Zn-Ag** | | | |
| Tonnage ($10^6$ tons) | 13 | 24 | 59 |
| Zinc ($10^6$ tons) | 1.0 | 2.5 | 5.3 |
| Lead ($10^6$ tons) | 0.7 | 1.6 | 3.6 |
| Copper ($10^6$ tons) | 0.000 | 0.001 | 0.007 |
| Silver ($10^6$ oz) | 24 | 62 | 130 |
| Gold ($10^6$ oz) | 0.0 | 0.004 | 0.027 |
| **Bedded barite** | | | |
| Tonnage ($10^6$ tons) | 55 | 150 | 310 |
| Barite ($10^6$ tons) | 40 | 110 | 260 |
| **Sedimentary phosphate** | | | |
| Tonnage ($10^6$ tons) | 120 | 460 | 1400 |
| Phosphate ($10^6$ tons) | 27 | 110 | 330 |
| Uranium ($10^6$ tons) | 0.01 | 0.05 | 0.12 |
| Vanadium ($10^6$ tons) | 0.09 | 0.36 | 1.00 |
| **Disseminated Pb-Zn** | | | |
| Tonnage ($10^6$ tons) | 3.6 | 100 | 510 |
| Zinc ($10^6$ tons) | 0.04 | 1.1 | 7.3 |
| Lead ($10^6$ tons) | 0.00 | 0.09 | 1.5 |
| Silver ($10^6$ oz) | 0.01 | 2.8 | 58 |
| **Sedimentary manganese** | | | |
| Tonnage ($10^6$ tons) | 1.4 | 44 | 440 |
| Phosphate ($10^6$ tons) | 0.00 | 0.001 | 0.1 |
| Manganese ($10^6$ tons) | 0.4 | 13 | 160 |

between 40 and 10%.

Different deposit types have different grade, tonnage, surface area, and by-product characteristics which also vary differently with probability fractile, hence, a "high" for arenite-hosted disseminated lead-zinc deposits has a significantly different metal endowment than a "high" for sediment-hosted massive sulfide lead-zinc deposits (Table 9).

The estimated endowment at the 90% probability level, as presented in Table 9, is biased towards those deposit types with the greatest certainty of existence (i.e. known prospects with mapped areal extent and sampled grades). These include massive sulfide and vein breccia lead-zinc-silver deposits, and sedimentary phosphate and barite deposits. Manganese is not a major contributor because raw manganese ores

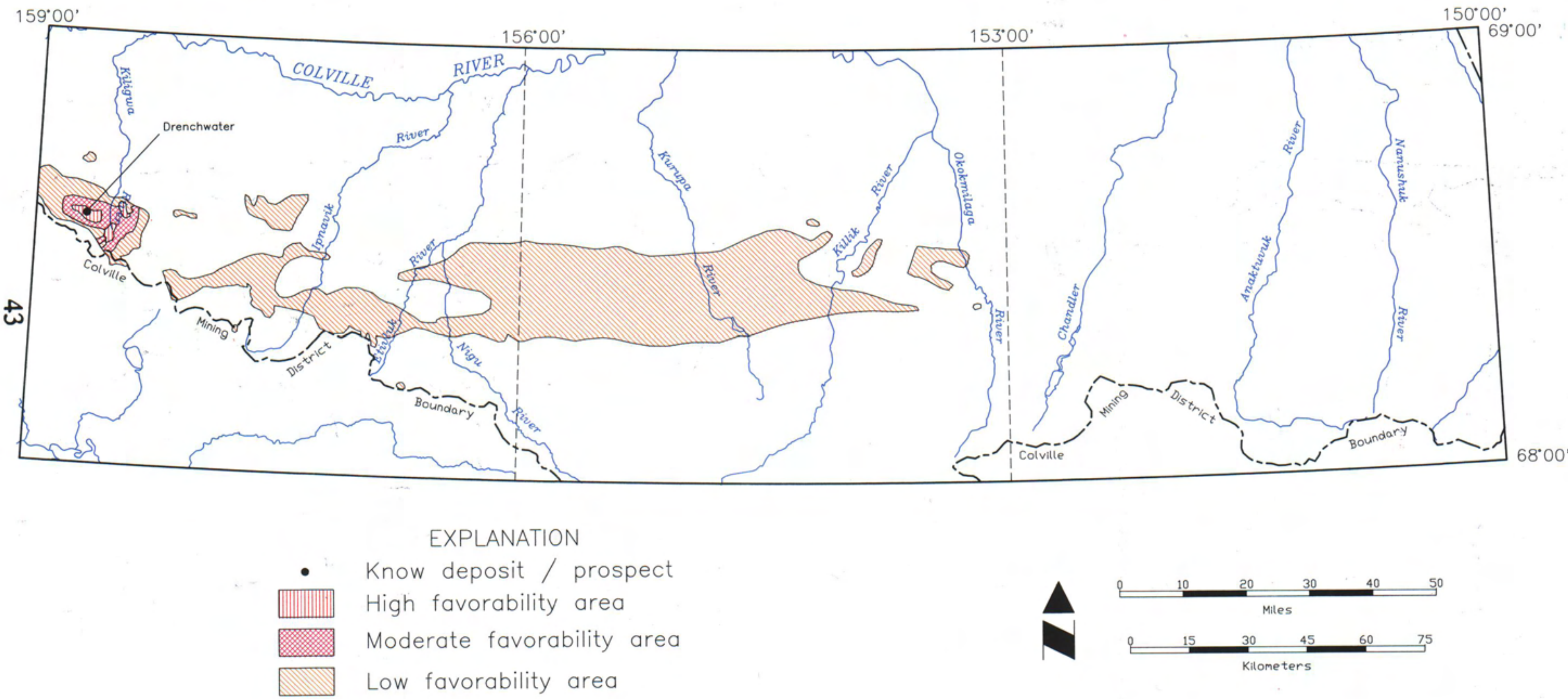


*FIGURE 29. - Regions favorable for the occurrence of sediment-hosted stratabound ("sedex") lead-zinc-silver.*

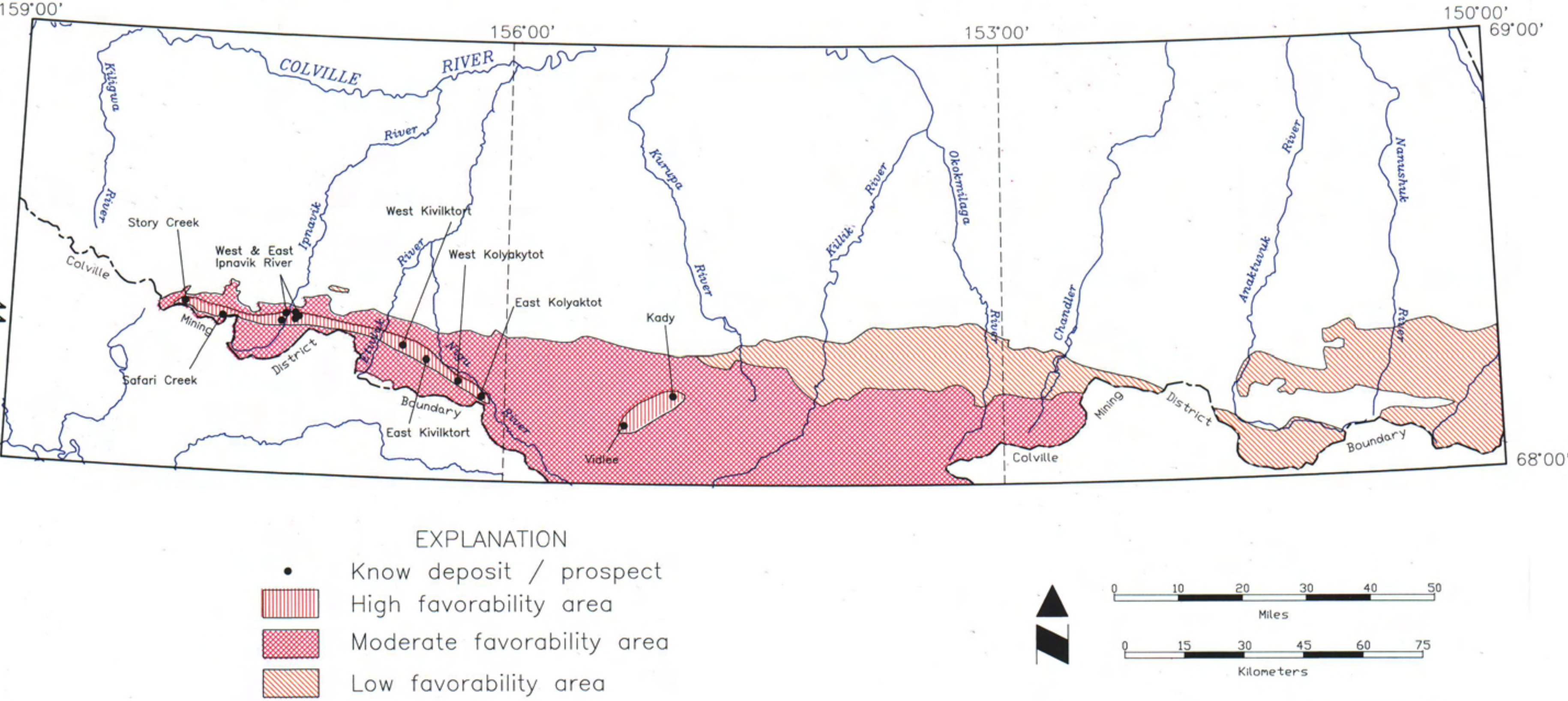


*FIGURE 30. - Regions favorable for the occurrence of western Brooks Range vein breccia lead-zinc-silver.*

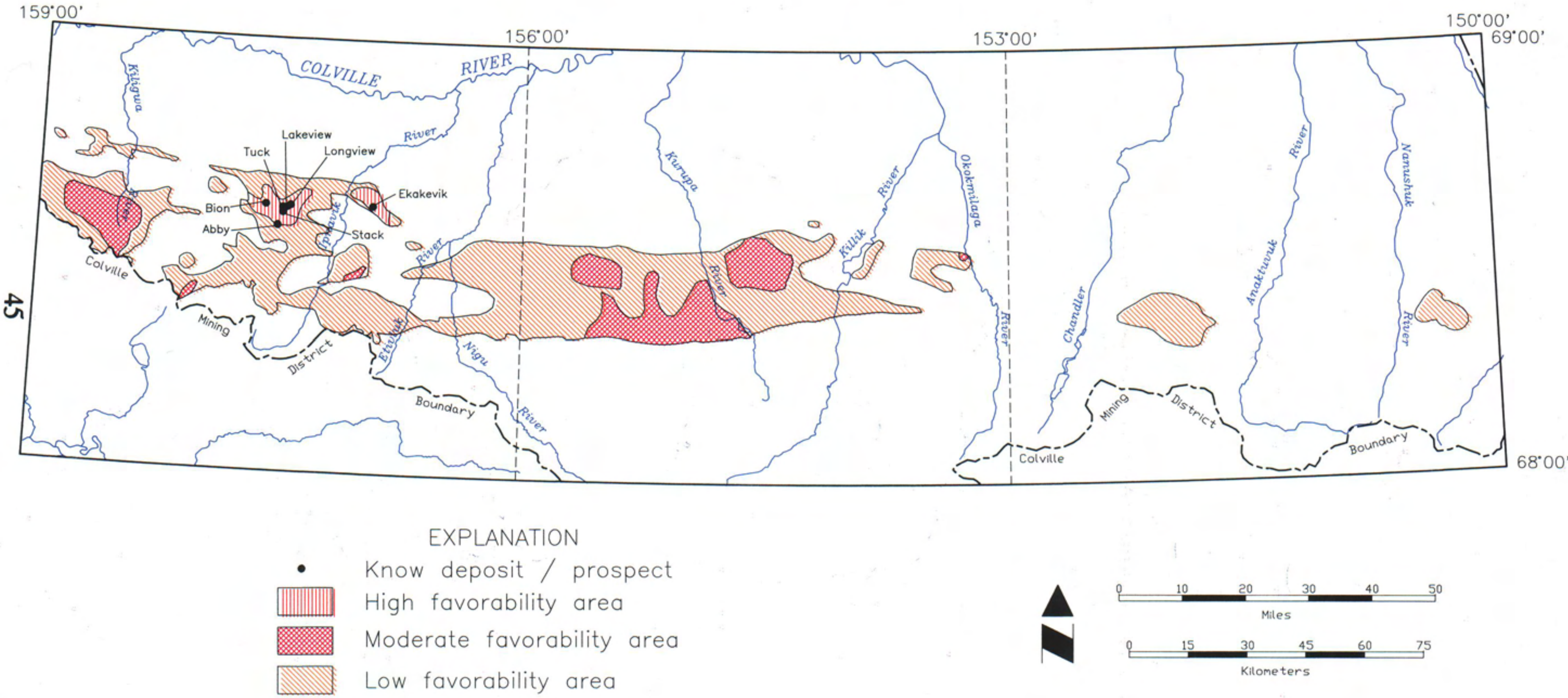


*FIGURE 31. - Regions favorable for the occurrence of bedded barite.*

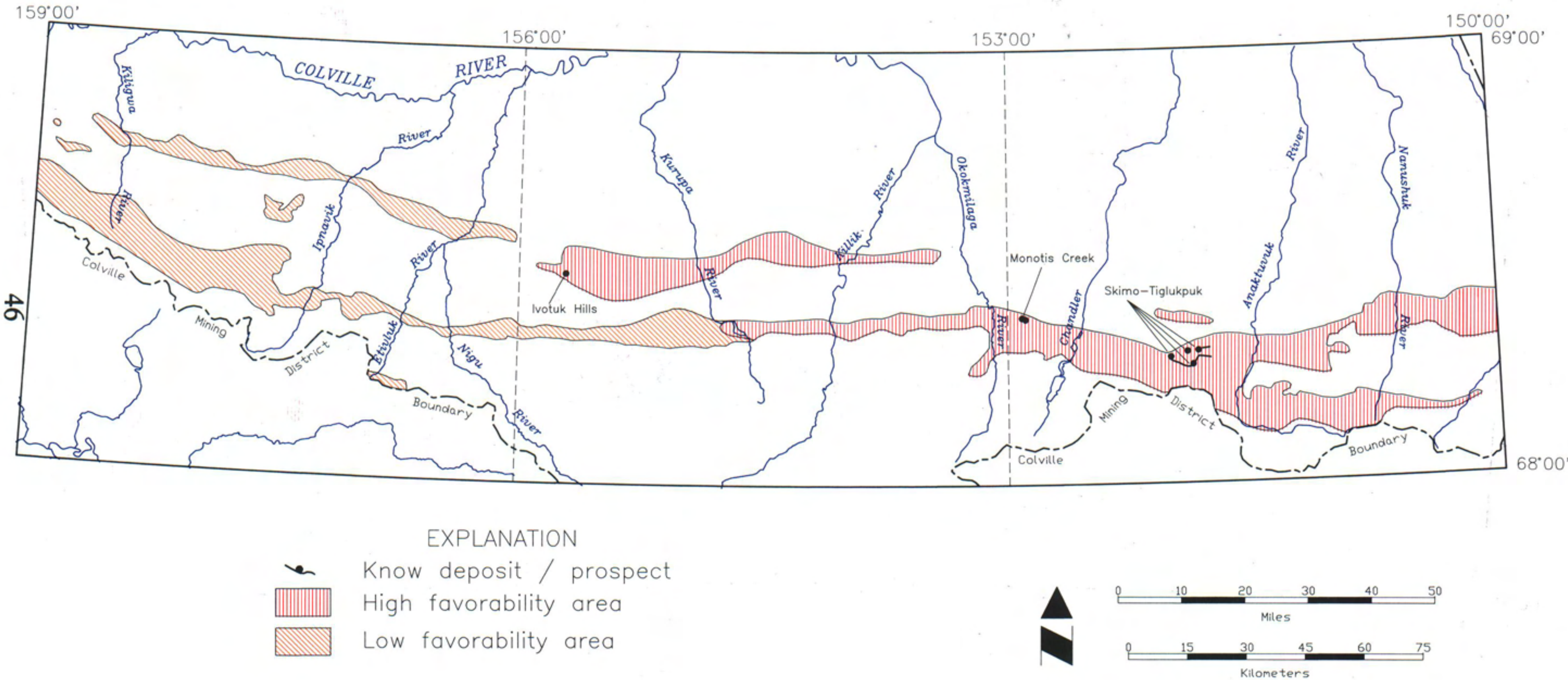


***FIGURE 32. - Regions favorable for the occurrence of sedimentary phosphate.***

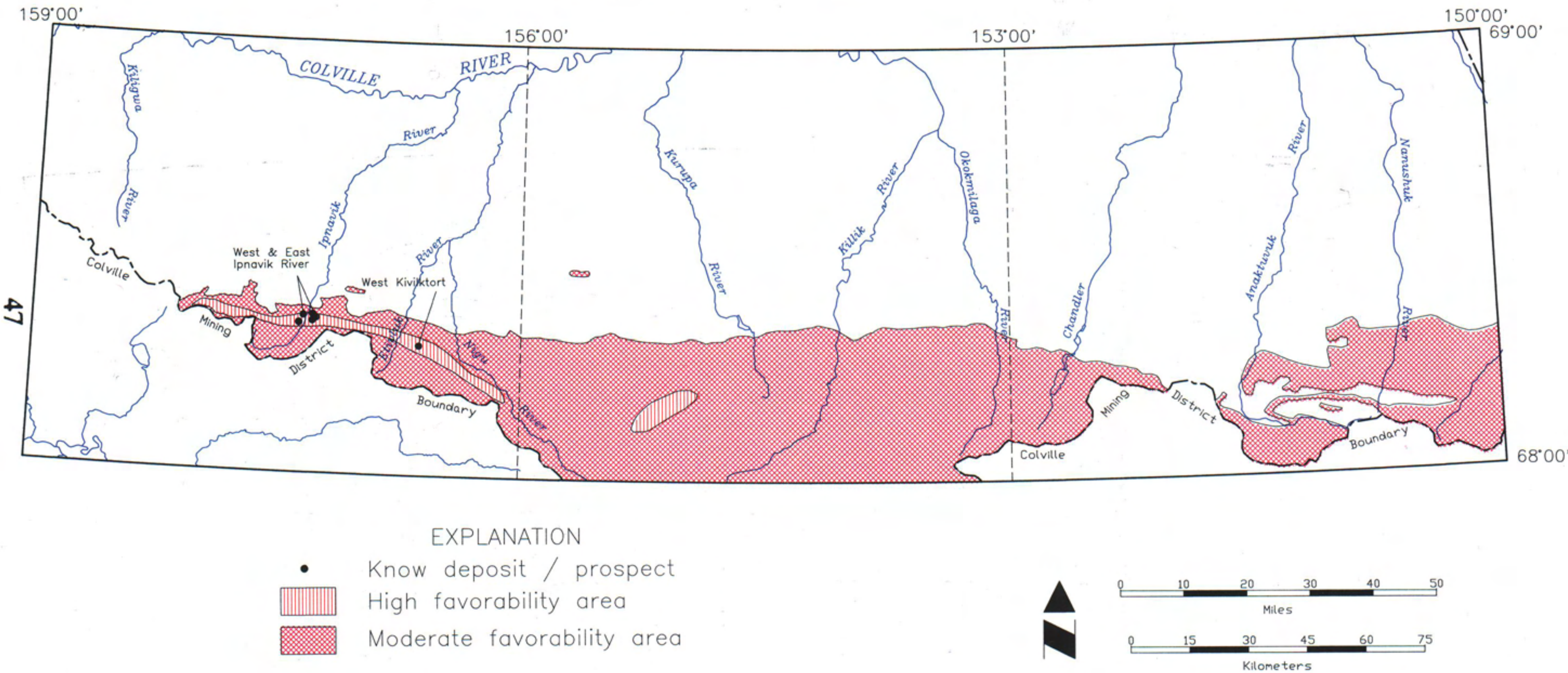


*FIGURE 33. - Regions favorable for the occurrence of disseminated arenite-hosted lead-zinc-silver.*

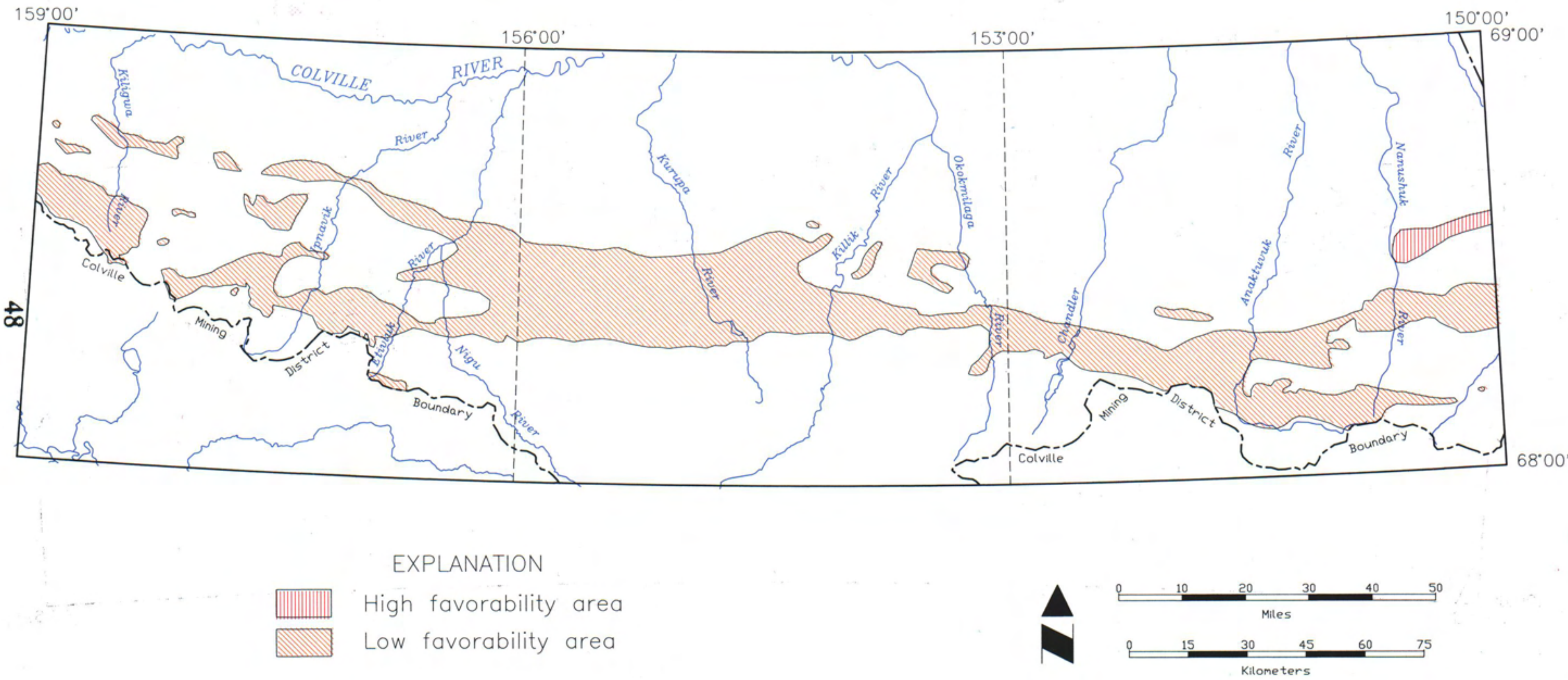


*FIGURE 34. - Regions favorable for the occurrence of sedimentary manganese.*

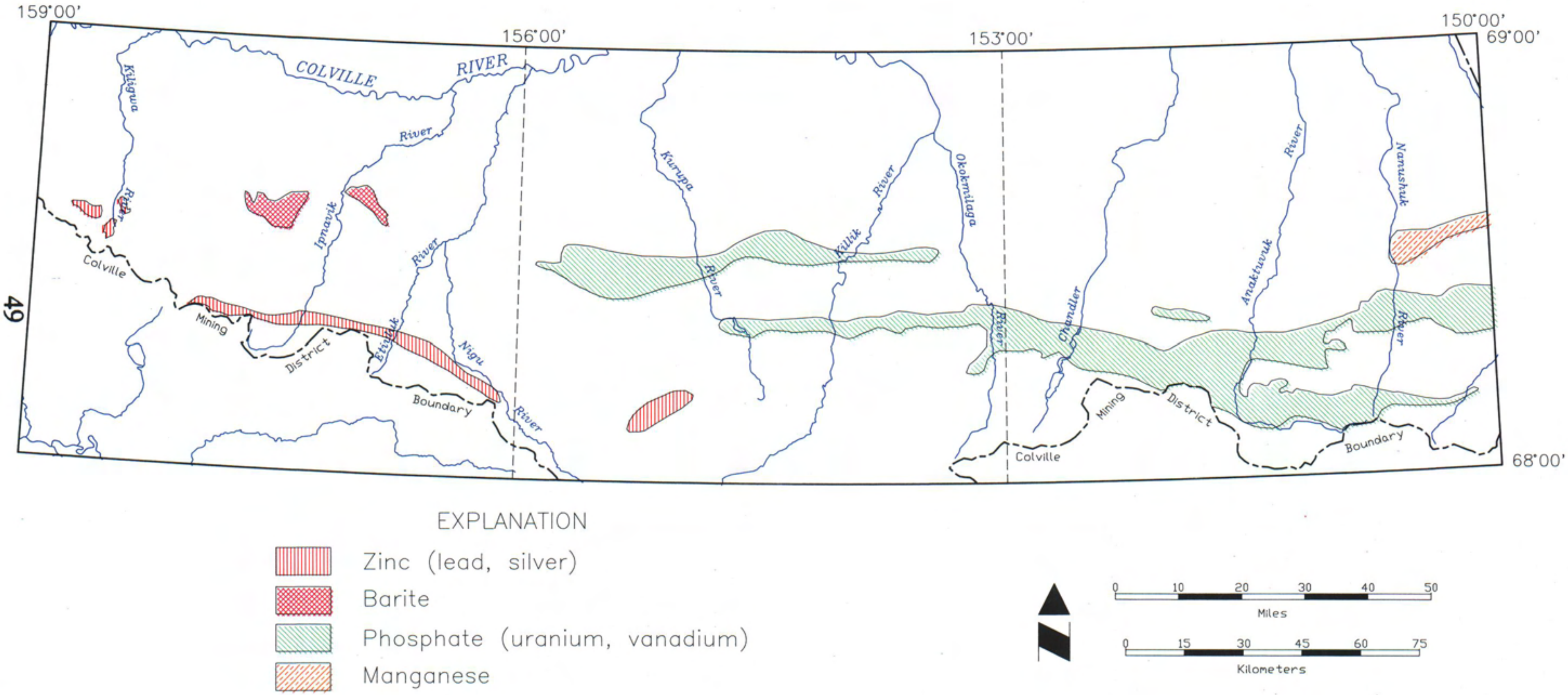


***FIGURE 35. - Regions of calculated high mineral endowment.***

have a low unit value (present metal prices) relative to the other commodities in the CMD. At the lower probability levels more speculative deposit types, especially those with potentially large tonnages (e.g., arenite-hosted, disseminated Zn-Pb deposits) play a significant role in the endowment.

As a summary of the metal endowment of the CMD, Table 10 gives the total estimated endowment for each major element present in major concentrations at three probability levels. Figure 35 shows the locations of the highest endowment areas (90 percent probability fractile) for the CMD. Table 10 indicates that zinc (Zn) is the element of greatest significance (at present day metal values), accounting for approximately 1/2 of the present day gross mineral value of the CMD. This is a reasonable conclusion, given the CMD's close proximity to the world-class Red Dog Zn-Pb-Ag deposit. The occurrence of host rocks with similar ages and lithologies to Red Dog and of a major Red Dog-type zinc prospect within the CMD makes for a very likely zinc endowment. At high probability fractiles (high levels of certainty), barite ($BaSO_4$) and phosphate ($P_2O_5$) deposits also make an appreciable contribution to the district mineral endowment. Secondary (by-product) commodities in zinc deposits, including lead (Pb) and silver (Ag) and secondary commodities vanadium (V) and uranium (U) in phosphate deposits also add significantly to the endowment. Finally, there is a small (in world-wide terms) manganese endowment and a small chance for a significant placer platinum (Pt) endowment. In terms of present-day mineral prices, approximately 2/3 of the mineral endowment is derived from Zn-(Pb-Ag) deposits; the remaining 1/3 is equally split between barite and phosphate deposits; Mn and Pt make little contribution.

## RECOMMENDATIONS

During the 1991-93 study of the CMD, the Bureau identified 48 mineral deposits and occurrences, 27 of which were new discoveries. Due to the immense size, extreme remoteness, harsh climate, and land policies little was known about the mineral potential of the CMD. With the recent work being completed by the cooperative agencies, there is now an abundance of new information on favorable mineralogy and geology to suggest the potential for the identification of still more mineral deposits and occurrences in the CMD.

TABLE 10. - Estimated total endowment for the most significant metals in the Colville Mining District.

| Element (units) | Probability fractile | | |
|---|---|---|---|
| | 90th | 50th | 10th |
| Zinc ($10^6$ tons) | 4.1 | 18 | 59 |
| Lead ($10^6$ tons) | 2.1 | 8.7 | 31 |
| Phosphate ($10^6$ tons) | 27 | 110 | 290 |
| Barite ($10^6$ tons) | 39 | 120 | 210 |
| Silver ($10^6$ oz) | 66 | 300 | 1500 |
| Manganese ($10^6$ tons) | 0.36 | 11 | 160 |
| Uranium ($10^6$ tons) | 0.012 | 0.046 | 0.11 |
| Vanadium ($10^6$ tons) | 0.08 | 0.34 | 0.87 |
| Gold ($10^6$ oz) | 0.00 | 0.006 | 0.047 |
| Copper ($10^6$ tons) | 0.000 | 0.001 | 0.006 |

Areas in the central and eastern CMD have the highest potential for future mineral discoveries. Work completed, for this study, indicates that the following mineral deposit types have the highest potential for discovery; shale- and sandstone-hosted stratiform lead-zinc-silver ("sedex") deposits, vein breccia lead-zinc-silver deposits, quartz-carbonate vein and metalliferous black shale lead-zinc-silver (arenite-hosted) deposits, sedimentary manganese and phosphate deposits, and stratiform (bedded) barite deposits. Mining feasibility studies of the coal, lead-zinc-silver, and barite (industrial minerals) deposits found that no deposit type was economically feasible at the present time. This economic outlook could change if there is a change in the tonnage/grade of a deposit or in the infrastructure of the study area. Those favorable deposit types deserving special attention are mentioned here.

Zinc-lead-silver deposits have the greatest potential for discovery in the study area. The sediment-hosted stratabound ("sedex") type deposits have a high favorability for discovery. This deposit type includes Drenchwater Creek as well as the Red Dog deposit. The immediate area surrounding the Drenchwater Creek deposit has the highest potential while the potential lessens as you move away from the area. Moderate potential exists along an east-west trend within the central part of the study area. Western Brooks Range vein breccia type deposits, including the Story Creek and Kady deposits, also have a high potential for discovery. The highest favorable area extends along a trend from Story Creek to Koiyaktot Mountain and the Vidlee to Kady area. Areas surrounding the known deposits, as well as extending to the east, have high discovery potential with the potential lessening as you approach the eastern boundary of the study area. Disseminated arenite-hosted deposit types, such as those located at Ipnavik River and Kivliktort Mountain, have high favorability for discovery along a east-west trend extending from the Ipnavik River to the eastern boundary. The potential lessens as you travel eastward.

Bedded barite deposits have a high potential for discovery in the CMD. Numerous deposits, including the Abby, Bion, and Stack deposits, have been located in the Cutaway Basin area. Cutaway Basin has the greatest potential for discovery of new deposits while lesser potential extends to the west and eastern part of the central CMD study area. Potential for the discovery of sedimentary phosphate occurs along a trend extending from the central to eastern parts of the study area. The highest potential exists to the east where deposits, including Monotis Creek and Skimo Creek, have been discovered. Potential lessens toward the west-central part of the study area. Sedimentary manganese contains high potential along the east part of the study area. Lesser potential exists along a trend extending to the west-central CMD.

Coal occurs with great abundance within the CMD. Hypothetical resources are estimated to be 253 billion metric tons of bituminous and 47 billion metric tons of subbituminous coal located in the central and eastern part of the study area. Higher grade coals of the Nanushuk Group occur to the south of the lower grade Colville Group coals. Several areas along the Colville River have been prospected in the past. Coal has a high development potential for use in the local area.

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ABOVE - Southern flank of Cockedhat Mountain showing area of lead and zinc mineralization. (Photo: Mark Meyer).

BACK COVER - U.S. Bureau of Mines geologist examining geologic outcrops along Kushman Creek. (Photo: Mark Meyer)