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EVALUATION OF THE MINERAL RESOURCES OF THE PIPELINE CORRIDOR
PHASES I AND II

by

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EVALUATION OF THE MINERAL RESOURCES OF THE PIPELINE CORRIDOR

PHASE I AND II

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Introduction

In accordance with U.S. Bureau of Mines (U.S.B.M.) Grant No. G0166180 entitled, "Evaluation of the Mineral Resources of the Pipeline Corridor", the Mineral Industry Research Laboratory (M.I.R.L.), of the University of Alaska, completed an examination of the mineral resource potential of the federal utility corridor established for the trans-Alaska pipeline. The contract was completed under the direction of the Principal Investigator, Paul A. Metz and the Associate Investigator, Mark S. Robinson.

The scope of work of this project was defined in an M.I.R.L. proposal dated May 1976 and included the following:

1. Perform literature survey for published and unpublished material.
2. Perform geologic field mapping work in the area during the 1976 field season.
3. Collect and analyze bedrock and alluvial samples in available excavations.
4. Produce a geologic strip map of the area and plot the sample sites on the map.
5. Produce a written general geologic and mineralization report of the area.

Item 1. was completed prior to the field investigations and is represented by the bibliographies for each of the 1:250,000 quadrangles traversed by the pipeline. Item 2. was conducted during July, August, and September 1976 and 1977 and is represented by the geologic overlays for the various 1:63,360 quadrangles (see Part II). These geologic maps were compiled from the work of Ferrians (1971), Weber (1971), and Kachadoorian (1971) and were field checked during this investigation. Item 3. was initiated by M.I.R.L. and U.S.B.M. personnel during the 1976 field season and continued during the 1977 field season. A total of 1,196 rock and stream sediment samples were collected. The samples were analyzed by emission spectrochemical methods for 42 elements by the U.S. Bureau of Mines laboratory in Reno, Nevada. Item 4., the geologic and base maps showing the sample localities are attached as Part II for each of the quadrangles. Item 5. is fulfilled by the following report.

Summary and Conclusions

The 800 mile long trans-Alaska pipeline crosses fourteen of the 1:250,000 U. S. Geological Survey quadrangles. According to the U.S. Bureau of Land Management, Land Status Map, dated March 1974, the Federal pipeline corridor includes approximately 7500 square miles. The pipeline transects most of the major geologic features of south central, interior and northern Alaska. From Valdez to Prudhoe Bay, the pipeline crosses the following physiographic and structural features:

1. Chugach Mountains
2. Copper River Basin
3. Alaska Range
4. Middle Tanana Basin
5. Yukon Tanana Uplands
6. Yukon Basin
7. Brooks Range
8. North Slope Basin

The general geology of the Pipeline Corridor is summarized by the individual 1:250,000 quadrangles. Each quadrangle description includes the following information: 1) previous investigations, 2) regional geology and petrology, 3) structural geology, 4) geochemistry, 5) mining activity and economic geology, 6) references cited, 7) bibliography. Several geologic terranes were defined in this investigation to facilitate the analysis of the geological and geochemical data. These terranes were defined on the basis of similarities in the rock type, age, and structural form of the major rock units. From south to north these terranes are:

1. Chugach
2. Amphitheatre
3. Birch Creek
4. Rampart
5. Kanuti
6. Brooks Range

Although these terranes may be congruent in part with metamorphic belts and physiographic provinces previously defined, they should not be confused with these other subdivisions. The terranes are named for major defined stratigraphic or physiographic units. The Chugach terrane extends from Valdez to the Border Ranges fault; the Amphitheater terrane from the Border Ranges fault to the Denali Fault; the Birch Creek from the Denali Fault to Washington Creek; the Rampart from Washington Creek to the Ray River; the Kanuti from the Ray River to the Jim River, and the Brooks Range from the Jim River to Galbraith Lake. The major geochemical sampling for this examination terminated at Galbraith Lake therefore no terrane was established for the North Slope Basin.

The Chugach terrane is composed primarily of metamorphosed sedimentary and volcanic rocks, principally greenstones, of Cretaceous age. The Amphitheater terrane is dominated by mafic volcanic and felsic igneous rocks of various compositions. The igneous rocks are interbedded with and intrude sedimentary rocks and the entire sequence is metamorphosed in part. Rocks of the Birch Creek terrane are primarily Yukon-Tanana Uplands Schist. The dominant rock types include; mica schists, quartz mica schist, micaceous quartzites, and gneisses of various compositions. The Rampart terrane consists of Paleozoic, principally Permian, sedimentary and mafic igneous rocks. The Kanuti terrane is the most heterogeneous of the terranes and includes upper PreCambrian(?) or lower Paleozoic metamorphic rocks and Paleozoic and Mesozoic sedimentary and volcanic rocks. Mafic-ultramafic complexes and large, felsic plutonic complexes also occur in the Kanuti terrane. The Brooks Range terrane contains a wide variety of rock types that include; medium-grade metamorphic rocks, conglomerates, sandstones, shales and limestones of various compositions.

Rock and stream sediment samples were grouped by terrane and the sample means, variances and standard deviations were calculated for each element analyzed. Anomalies were defined as those elemental values that were greater than 1.645 standard deviations from the mean. The sample data and statistical reduction are included in Appendix A to this report.

A simplified one-way analysis of variance was done on the sample data in an effort to determine if there is a significant difference in the variances of the concentrations of the trace elements between adjacent terranes. F-statistics were calculated for each of the 42 elements that were analyzed for. Using a hypothesis that there is no difference in the variance between terranes, it was found that the ratio of the variances of several of the elements exceeded the critical value of the F-statistic and therefore it has been shown that there is a difference in the variance of several elements. The following table summarizes the F-statistic test results and indicates which elements show a difference in their variances.

Chugach terrane
Ca,Fe,K,Mg,Mn,Na,Ti

Amphitheater terrane
Al,Ca,Fe,Mg,Na,Ti

Birch Creek terrane
Ca,Fe,K,Mg,Mn,Na

Rampart terrane
Ca,K,Mn,Na,Ti

Kanuti terrane
Ca,K,Mg,Mn,Na,Ti

Brooks Range terrane

The F-statistic test is somewhat misleading in that it tests only for a difference in the variance, and not necessarily a difference in the mean value of the concentrations in a particular terrane. To illustrate the misleading nature of results of the F-statistic, one can examine the threshold values for the various elements in different terranes. The following table illustrates the problem quite well:

Element	Chugach terrane* threshold values Confidence levels 90%	95%	98%	Element	Amphitheater terrane* threshold values Confidence levels 90%	95%	98%
Cu	91	100	109	Cu	201	228	254
Mo	26	29	31	Mo	44	49	54
Pb	298	338	374	Pb	96	99	102
Zn	518	609	693	Zn	77	87	96

*Rock sample threshold values from Table 3 and Table 11, Appendix A.

By examining the figures in the above table, it can be seen that there is a difference in the mean value of the concentrations between the two terranes for these elements, and differences between other elements also occur. The reason that the F-statistic was not sensitive to the differences in mean value concentrations is that although one terrane may have a higher or lower mean trace element concentration, the variability of the trace element content is low.

Sample descriptions, trace element levels of detection, and threshold values for samples collected during this study may be found in Appendix A to this report. The threshold values for the 90%, 95% and 98% confidence intervals were derived from a statistical analysis of the raw geochemical data. Sample means, variances and standard deviations were calculated at the arithmetic mean plus 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation for the 90%, 95%, and 98% confidence intervals respectively. It should be noted that sample analyses from the 1976 and 1977 field seasons have different levels of detection and therefore may not be compatable. Each years' geochemical analyses were treated as separate data sets and the anomalous concentrations in Appendix A represent values at the 90%, 95%, and 98% confidence levels of each data set. 524 of the 1,196 samples collected contain weakly anomalous, anomalous, and strongly anomalous concentrations in at least one element, and many of the anomalous samples were anomalous in several elements.

The following is a tabulation of the number of samples from within and without the pipeline corridor from each terrane and the number of samples with one or more anomalous elements.

1. Chugach

a. Total number of samples	70
b. Number of anomalous samples	28

2. Amphitheatre

a. Total number of samples	89
b. Number of anomalous samples	23

3. Birch Creek

a. Total number of samples	186
b. Number of anomalous	84

4. Rampart

a. Total number of samples	301
b. Number of anomalous samples	120

5. Kanuti

a. Total number of samples	130
b. Number of anomalous samples	67

6. Brooks Range

a. Total number of samples	420
b. Number of anomalous samples	202

The known mineral occurrences as defined by E.H. Cobb of the U.S. Geological Survey, and all of the mineral occurrences found during this study in the pipeline corridor have been plotted on the base maps of each of the 1:63,360 quadrangles. Mineral deposit information on each occurrence has been collected and entered in the U. S. Bureau of Mines Mineral Availability System(MAS) format and can be found in Appendix B to this report.

According to E.H. Cobb, the following mineral resources have been identified in the past in the pipeline corridor:

1. Antimony
2. Bismuth
3. Chromium
4. Clay
5. Coal
6. Gold
7. Lead
8. Molybdenum
9. Nickel
10. Nuclear fuels (uranium,thorium)
11. Phosphate
12. Silver
13. Tungsten
14. Zinc

The following mineral resources have been identified by M.I.R.L. personnel during the current study:

1. Antimony
2. Barite
3. Chromium
4. Coal
5. Copper
6. Lead
7. Molybdenum
8. Nickel
9. Phosphate
10. Zinc

No mineral deposits of obvious economic significance were found in the pipeline corridor during the current study, however, several mineral occurrences that were found during field work indicate that some rock units in the corridor and trending through the corridor have high mineral potential and may contain significant mineral resources. The commodities that have been produced in the study area include antimony, coal, copper, gold, sand and gravel and silver.

The geologic potential for future production can be qualitatively estimated by the examination of the geologic environments and corresponding rock units that are found in the corridor. There is great diversity of rock types and geologic environments along the pipeline route. Most geologic time periods from the upper Precambrian to the Tertiary are represented in the stratigraphic record.

Stanton (1972) and others have developed a number of ore mineral and rock associations which relate mineral deposits to the rocks which enclose or include them. Some of these associations not only define the type of rocks that enclosed a particular type of ore but in some cases the associations can be limited to specific periods of geologic time. These well defined tectonic and depositional environmental associations can then be utilized in both regional exploration and site specific evaluations of mineral occurrences. With the exception of the sedimentary iron and manganese association, all the major ore associations of Stanton (1972) are found within the study area. Examples of these associations are given in Table I.

Not all of the ore mineral associations are equally distributed through geologic time, therefore depending on the age and type of rocks that occur, some mineral commodities will not have the same probability of occurring as others.

TABLE I Known Rock and Ore Mineral Associations in and along the pipeline corridor

Ore Associations (after Stanton, 1972)

I. Ores in Igneous Rocks

Ores of Mafic and Ultramafic Association:

a) Bernard Mountain chromite occurrence, Valdez quadrangle
b) Caribou Mountain chromite and asbestos occurrences, Bettle quadrangle

Ores of Felsic Association:

a) Wilbur Creek copper porphyry occurrence, Livengood quadrangle
b) Hess Creek copper porphyry occurrence, Livengood quadrangle

II. Stratiform sulfides of marine and marine-volcanic association

a) Midas Copper Mine(?), Valdez quadrangle
b) Willow Mountain copper occurrence, Valdez quadrangle
c) Hogan's Hill copper occurrence, Gulkana quadrangle
d) Barite occurrences of the Atigun River area, Philip Smith Mountains quadrangle

III. Ores of Vein Association

a) Gold-quartz veins of the Valdez district, Valdez quadrangle
b) Gold-quartz veins of the Mt. Tiekel area, Valdez quadrangle
c) Gold-quartz veins of the Gunnysack Creek area, Mt. Hayes quadrangle
d) Gold-quartz veins of the Tenderfoot district, Big Delta quadrangle
e) Gold-quartz and base metal sulfide veins of the Pedro Dome-Cleary Summit area, Livengood quadrangle
f) Base metal sulfide veins of the Shorty Creek area, Livengood quadrangle
g) Base metal veins of the Wiseman area, Wiseman quadrangle

IV. Ores of Sedimentary Affiliation

Placer Deposits

a) Gold placer deposits of the Valdez district, Valdez quadrangle
b) Gold placers of the Tenderfoot district, Big Delta quadrangle
c) Gold placers of the Pedro Dome-Cleary Summit area, Fairbanks and Livengood quadrangles
d) Gold placers of the Livengood area, Livengood quadrangle
e) Gold placers of the Wiseman area, Wiseman quadrangle

V. Ores of Metamorphic Affiliation

a) Disseminated sulfide occurrence near Wiseman, Wiseman quadrangle
b) Contact metamorphic tungsten occurrences near Gilmore Dome, Fairbanks quadrangle

The geologic potential for future production may also be estimated in a semi-quantitative manner. Appendix B indicates that there are approximately 150 claim groups or prospects within the pipeline corridor. In addition, this examination has delineated 50 additional mineral occurrences. If the number of occurrences that trend into the corridor are added to this figure, there are over 400 mineral occurrences in or approximate to the study area.

Bailey (1964) estimates that the discovery of a single ore body in western Canada in 1964 required the examination of at least 461 prospects. These estimates are based solely on the geotechnical and economic feasibility of a mining operation. The number of mineral occurrences within the study area is approaching this figure, thus we might expect one of these occurrences to become a viable mining operation all other things being equal to Bailey's model. However, it should be noted that most of the mineral occurrences in the pipeline corridor are occurrences or geochemical anomalies and are not necessarily prospects or ore bodies. This estimate does not indicate which mineral occurrences or even which commodities may be produced. There are many factors that will affect the economic viability of a mining operation within the study area, such as supply and demand of the various commodities, the availability of transportation and energy, the final classification of the land, and the levels of state mining taxation. These variables are beyond the scope of this investigation.

Finally, we may compare historic productions in the rest of the world and Alaska and extrapolate the potential for future production in Alaska based on current production in other parts of the world. Many of the historic precious metal mining districts of the world have in recent years become major base metal producers. Some examples of these districts are the porphyry copper districts of Canada, Chile, Iran, Peru, Spain, Turkey, and the U.S.; the Cu-Pb-Zn provinces of Australia, Canada, Ireland, and the U.S. These districts have had major historic gold and silver productions. The significant gold and silver production in the Fairbanks, Livengood and Wiseman areas may be an indication of future base metal resource areas.

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Valdez Quadrangle

Previous Investigations

Two non-scientific reconnaissance expeditions by the United States Army, one in 1885 under Lt. Henry T. Allen and another in 1891 under Lt. Frederick Schwatka, were the first American penetrations into the Valdez quadrangle and the Copper River region. The Copper River military expedition in 1898 and 1899, directed by Capt. W.R. Abercrombie, produced the first geologic reports on the region. One leg of the expedition under Frank C. Schrader went from Valdez across the Valdez Glacier to Klutina and returned to Valdez via the Copper, Tasnuna, and Lowe Rivers.

The first geologic surveys and geologic maps of the Copper River region were made by Schrader and Spencer in 1901 and Mendenhall in 1902. Subsequently, numerous surveys and mineral investigations were conducted in the region, highlighted by the work of Fred H. Moffit. All of these men were with the U.S. Geological Survey.

Recent work includes regional studies (Berg, Jones, and Richter, 1972), geologic mapping (Nichols and Yehle, 1972; Ferrians and Kachadoorian, 1971) geochronology (Marvin, 1974), structural geology (Andresean, et. al. 1964; Barnes, 1967; Gedney, 1970; Berg, 1973; Freeland and Dietz, 1973; MacKevett and Plafker, 1974; Richards, 1974; and Brogan, et. al., 1975) and mineral resources (Berg and Cobb, 1967; Heiner, Wolff and Grybeck, 1971; Cobb, 1972, 1973; Bottge, 1974; and Mulligan, 1974). The quadrangle has not been completely mapped on any scale nor has there been any major regional geochemical investigations in the area.

Regional Geology and Petrology

The predominant geological feature of the Valdez quadrangle is the Chugach Mountains which forms a major physiographic province in south-central Alaska. Rocks of the Chugach Range are composed primarily of a thick sequence of graywacke, shale, and volcanic rocks of Jurassic and Cretaceous age that have been metamorphosed from the zeolite to lower greenschist facies. The north-flank of the Chugach Range contains minor volumes of sandstones, shales, and volcanic rocks of Permian age that have been metamorphosed from the greenschist and blueschist facies to the granulite facies. These rocks are in turn overlain by sedimentary and volcanic sequences that range from Triassic through Quaternary in age. The sedimentary metamorphic and volcanic rocks are intruded by igneous rocks that range from dunite to granite in composition and range from Jurassic to Quaternary in age (Moffit, 1938; MacKevett and Plafker, 1974; Metz, 1975).

The Border Ranges Fault is the major structural feature in the region and it can be traced along the north-flank of the Chugach Mountains from the St. Elias Mountains to the southwest end of Kodiak Island, a distance of approximately 1,000 kilometers (625 miles). The fault has been interpreted as a possible Mesozoic plate boundary and is marked by numerous occurrences of ultramafic rocks north and west of the fault. North and west of the Chugach Mountains the Gravina-Nutzotin terrane and the Alaska-Aleutian Ranges form a high temperature, low pressure metamorphic belt that parallels the Chugach Mountains. Preliminary evidence indicates that the Gravina-Nutzotin belt formed as a result of a middle and upper Mesozoic thermal event. The existence of the low temperature-high pressure metamorphic belt of the Chugach Mountains and the high temperature-low pressure metamorphic belts of the Alaska Range provides additional evidence of major underthrusting from the south and southeast during the upper Mesozoic (Reed and Lamphere, 1973; Metz, 1975).

The oldest rocks in the Valdez quadrangle are Permian(?) or upper Palezoic regionally metamorphosed graywacke, shale, limestone, volcaniclastics and basalt that contain greenschist and blueschist facies, mineral assemblages (Metz, 1975). These rocks were originally designated as the Strelna Formation and were assigned a Mississippian age (Moffit and Mertie, 1923, Moffit, 1938). The rocks have subsequently been correlated with the Permian(?) and Permian Skolai Group of Smith and MacKevett (1970) and with the Mankomen Formation (Churkin, 1973: MacKevett and Plafker, 1974). At the type locality, the Strelna Formation includes metamorphosed gabbro, chert, silicified limestone, basalt, shale and tuff. Moffit and Mertie (1923) reported the following partial reference section of the Strelna Formation in the Nugget Creek valley.

	Feet	Meters
Fined-grained basalt	360	110
Water-laid and subaerial tuff	886	270
Fine-grained basalt	450	137
Shaly, argillaceous beds	403	123
Siliceous beds	10	3
Fine-grained basalt	450	137
Silicified limestone	7	2
Gabbro with some tuffaceous beds	403	123
Chert	226	69
Gabbro	650	198
Total	3,845	1,172

Rocks of the Strelna Formation have been studied in some detail in the Bernard Mountain area, about 8 kilometers (5 miles) south of the Tonsina Roadhouse, Mile 79 on the Richardson Highway. At Bernard Mountain, the Strelna Formation is represented by a complex sequence of weakly metamorphosed slate, greenstone, arkosic sandstone and marble. The slate unit of Hoffman (1974), consists of about 65% dark-gray to black slate containing well-developed sericite and chlorite grains that parallel the slaty cleavage. The slate also contains accessory magnetite, pyrite, apatite and hematite. The remaining 35% of the slate unit is composed of medium-to dark-gray phyllite. Petrographically, the phyllite consists of 70% to 90% clay and silt-sized grains of sericite and chlorite, and 10% to 30% strained quartz. Accessory magnetite, pyrite, zircon, and sphene are also present. Minor amounts of graywacke sandstone and siltstone are also present in the slate unit. The graywacke is poorly sorted and consists of angular and subangular grains of quartz, plagioclase and lithic fragments set in gray, clay matrix. The plagioclase is partially altered to clay minerals and the quartz grains are strained. The lithic fragments are composed of shale and minor volcanic rock fragments (Hoffman, 1974).

The greenstone unit of the Bernard Mountain area is composed of weakly metamorphosed basalt, volcaniclastics and agglomerates. The basalt is typically dark-green to reddish-brown, fine-grained and massive. Petrographically, the basalt is composed of 10% to 40% phenocrysts of augite-diopside, plagioclase (An_{10}), and olivine, and amygdules of calcite, quartz, chlorite and epidote are common. The phenocrysts and amygdules are set in a cryptocrystalline groundmass that comprises as much as 50% of the rock locally. The volcaniclastics of the greenstone unit are composed of a poorly sorted mixture of angular volcanic rock fragments composed of angular grains of plagioclase, chlorite, calcite and epidote along with scattered grains of altered plagioclase, pyroxene and quartz that are set in a cryptocrystalline matrix. The agglomerates of this unit are mainly light-to dark-green rocks composed of angular rock fragments 10 to 50 centimeters (4 to 127 inches) in diameter. The rock fragments are set in a fine-grained matrix of volcanic rock fragments (Hoffman, 1974).

The arkosic sandstone unit is composed chiefly of arkosic sandstone with minor phyllite and marble. The arkosic sandstones are weakly metamorphosed and consist of gray to white, poorly sorted, medium-to coarse-grained, massive sandstone. Petrographically, the arkose is composed of 20% to 50% angular and subangular quartz grains, 20% to 50% plagioclase and 5% to 20% lithic fragments set in a matrix of silty-clay. The phyllites are typically black, very fine-grained rocks with well-developed, close-spaced cleaveage. Fine-to medium-grained, highly recrystallized marble is fairly common in the Bernard Mountain area and generally consists of light-gray to white, non-fossiliferous, homogeneous marble composed of a mosaic of anhedral, twinned calcite grains (Hoffman, 1974).

The correlative Skolai Group has not been mapped in the Valdez quadrangle, however, the type section defined by Smith and MacKevett (1970) is only a few kilometers to the east in the McCarthy C-4 quadrangle. The Skolai Group is divided into two formations and several members. The older Station Creek Formation is divided into two informal members while the younger Hansen Creek Formation includes the Golden Horn Limestone Lentil.

The volcanic flow member, the lower member of the Station Creek Formation, is composed of approximately 1,200 meters (3,937 feet) of basalt and basaltic andesite flows. The rocks are altered and contain abundant amygdule fillings of albite, chlorite, calcite, quartz and zeolites. Other constituents include prehnite, pumpellyite, actinolite, biotite, clinozoisite, hematite, sphene, and ilmenite. The mineral assemblages may indicate a transitional Alpine to Barrovian metamorphic sequence. The metavolcanic rocks have a chemical composition of undersaturated olivine tholeite of Yoder and Tilley (1962)(Smith and MacKevett, 1970).

Overlying the volcanic flow member of the Station Creek Formation is the volcaniclastic member composed of a heterogeneous mixture of volcaniclastic rocks ranging from coarse volcanic breccia to delicately laminated volcanilutite. Fine-grained volcaniclastics are more prevalent near the top of the member and the upper 150 meters (492 feet) is nearly all volcanic siltstone and volcanilutite. The contact with the underlying flow member is gradational through several thousand meters. The volcaniclastic rocks range from mafic to intermediate in composition. Petrographically, the volcaniclastics are dominantly coarse tuff-breccia, thin-bedded graywacke, and volcanilutite that contains glassy clasts which have been recrystallized to mosaics of xenoblastic quartz and feldspar. The groundmasses have been recrystallized and contain chlorite, epidote, and calcite. The other constituent minerals include albite, sericite, pumpellyite, prehnite, sphene, augite, hornblende, potassium feldspar and opaques (Smith and MacKevett, 1970).

The Early Permian Hansen Creek Formation conformably and gradationally overlies the Station Creek Formation. The formation consists of a mixture of thin-bedded chert, black shale, sandstone, carbonaceous bioclastic limestone, and minor conglomerate. Chert is the dominant rock type near the top of the formation and is commonly red, black, and green. The chert forms beds ranging up to 15 centimeters (6 inches) thick. Petrographically, the chert is composed of a poorly crystalline matrix of quartz and chalcedony containing silica-filled radiolarian tests, sponge spicules and detrital grains of muscovite, chlorite, feldspar, and quartz (Smith and MacKevett, 1970).

The Golden Horn Limestone Lentil conformably overlies rocks of both the Station Creek Formation and the Hansen Creek Formation. Maximum thickness of the Golden Horn Limestone is about 270 meters (886 feet). Individual beds range up to 3 meters (10 feet) thick and can be traced laterally for only several hundred meters. The limestones are mainly bioclastic grainstone, packstone, wackestone; and minor arkose occurs locally. The bulk of the bioclastic material is crinoid stems, brachiopod shells, and bryozoan fragments. The unit has been assigned an Early Permian age (Smith and MacKevett, 1970).

Unconformably overlying the Strelna Formation and its correlative rocks is the Nikolai Greenstone. The unit consists of approximately 1,000 meters (3,281 feet) of altered basalt containing primary plagioclase, augite, relict olivine, opaques, sphene, and apatite and secondary chlorite, epidote, clay minerals, calcite, sericite, prehnite, ferruginous serpentine minerals, pumpellyite, quartz, native copper, and zeolites. The Nikolai Greenstone contains abundant amygdules that are filled with quartz, calcite, chlorite and native copper. The unit has a wide geographic distribution in the Wrangell Mountains area and in the western Yukon Territory. The age of greenstone has been established stratigraphically as Middle or early Late Triassic (MacKevett 1970, 1971).

The Chitistone Limestone disconformably overlies the Nikolai Greenstone and consists of limestone, dolomite, and minor chert. Moffit (1938) did not differentiate between the Chitistone Limestone and the overlying Nizina Limestone in the Valdez quadrangle. Armstrong and others (1970) described the Chitistone Limestone in detail, however their work was concentrated on exposures in the McCarthy quadrangle. The mudstones and wackestones of the Chitistone Limestone are dark greenish-gray, dark-gray, or dark-medium gray on unweathered surfaces and gray to brown on weathered surfaces. In addition to calcareous mud the matrices contain pyrite, iron oxides, quartz, chalcedony and clay minerals. The packstones and grainstones are medium-gray to medium dark-gray and are composed of lime pellets, ooids, and bioclastics. The crystalline carbonates include dolomite, dolomitic limestone and limestone. The crystalline rocks range from light-to medium gray on fresh surfaces to light brownish-gray on weathered surfaces. These rocks are composed of interlocking carbonate grains with minor opaques and clay minerals. Chert is associated with the wackestones and occurs as grayish-black lenses and nodules.

Armstrong and others (1970) feel that the Chitistone Limestone resulted from deposition in an intertidal and supratidal depositional environment. This interpretation indicates that a low energy restricted marine environment was present during the Late Triassic.

Gradationally overlying the Chitistone Limestone is the Nizina Limestone. The unit consists of fine-grained, dark greenish-gray grainstone, mudstone, and wackestone that weather brownish-gray. The Nizina Limestone ranges in thickness from 100 to 380 meters (328 to 1,247 feet) and occurs in beds from 15 centimeters to a meter thick (6 inches to 3 feet). The mudstones and wackestones are composed primarily of pellets 0.05 to 0.2 millimeters in diameter of lime mudstone and fossil fragments with minor quartz, plagioclase, and opaque minerals. Matrix material consists of carbonaceous matter, silica and clay minerals. Chert is present in the form of dark-gray or black lenses and nodules. The Nizina Limestone has been assigned a Late Triassic age.

The McCarthy Formation conformably overlies the Nizina Limestone and is divided into two informal members. The lower member conformably overlies the Nizina Limestone and includes approximately 300 meters (984 feet) of calcareous, carbonaceous shale, impure limestone and impure chert. The rocks are dark-gray, dark greenish-gray, or grayish-black on fresh surfaces and weather dark-brown. The shales are composed of calcite, carbonaceous material, clay minerals, chlorite, quartz, chalcedony, dolomite, pyrite and secondary iron minerals. The cherts are chalcedonic rocks with minor carbonaceous material, quartz, plagioclase, dolomite, pyrite, apatite, biotite and fragments of radiolaria tests and sponge spicules. The limestones are wackestones composed of grains of bioclastic calcite in a matrix of calcareous mud. The unit has been assigned a Late Triassic or Early Jurassic (?) age based of pelecypods of the genus Monotis (MacKevett, 1971).

The upper member of the McCarthy Formation gradationally overlies the lower member and includes approximately 600 meters (1,970 feet) of chert, spiculite, shale, and impure limestone. The rocks are dark-gray and weather dark yellowish-brown. The chert and spiculites are chalcedonic rocks containing clasts of calcite, quartz, plagioclase, dolomite, apatite, carbonaceous matter, pyrite, hematite, potassium feldspar, ilmenite, leucoxene, chlorite, biotite and clay minerals. The cherts and spiculites grade into impure limestones as the calcite content increases. The shales are composed of clay minerals, quartz, chalcedony, calcite, carbonaceous matter, plagioclase, dolomite, opaque minerals, and carbonate flourapatite. These quiet water sediments may range in age from latest Triassic through Early Jurassic (MacKevett, 1971).

Moffit (1938) defined a tuffaceous shale sequence that he considered correlative with the Middle Jurassic Tuxedni Group of the Matanuska Valley and Cook Inlet areas. The sequence includes approximately 200 meters (656 feet) of sandstone, shale, and conglomerate with a large fragmental volcanic component. The sandstone contains quartz, feldspar, and biotite with calcareous cement. The conglomerate is composed of pebbles and cobbles of argillite, diorite, greenstone, and quartz in a tuffaceous matrix. The stratigraphic position of the unit is in doubt due to apparent fault contacts. The age assignment of the unit was made based on pelecypods of the genus Inoceramus.

In the Stuck Mountain and Willow Mountain areas, there is a thick sequence of metamorphosed volcanic flows, volcaniclastics and sedimentary rocks of Jurassic(?) age (Ferrians and Kachadoorian, 1971). The contact with the Strelna Formation to the south is covered and the stratigraphic position is not definitely known. The rocks are andesitic or basaltic in composition and contain chlorite, plagioclase, calcite, quartz and epidote. Intercalated with the volcanics and volcaniclastics are red and green cherts. The volcanic and sedimentary rocks contain abundant disseminated pyrite and minor chalcopyrite locally. The rocks are highly fractured and contain anastomosing quartz veins. The tuffaceous shale sequence of Moffit and the above sequence may be correlative and both may be correlative with the Nizina Mountain Formation of MacKevett (1969).

Stratigraphically above the Nizina Mountain Formation is the Kotsina Conglomerate, however the contact between the two units is indefinite (Imlay and Detterman, 1973). Moffit (1938) described the unit as 600 to 800 meters (1,970 to 2,625 feet) of massive, dark pebble-to boulder-conglomerate. The predominant pebbles include greenstone, limestone, granodiorite, and quartz and are included in a shaly and arkosic matrix. The unit was assigned to the Middle Jurassic based on fossil fragments.

The Kotsina Conglomerate is unconformably overlain by a sequence of sandstone, shale, conglomerate, and limestone, 1200 meters (3,927 feet) thick. Moffit (1938) mapped this sequence and assigned it to the Jurassic or Cretaceous. These rocks are probably correlative with the Root Glacier Formation of MacKevett (1969). The shales, mudstones, and siltstones are composed of clasts of quartz, calcite, and plagioclase set in a microcrystalline matrix. The sandstones include graywacke, wacke, and arenite and are composed of quartz, plagioclase, clinopyroxene, biotite, potassium feldspar, hornblende, calcite, opaque minerals and lithic fragments. The impure limestones are detrital rocks with calcite cement. The Root Glacier Formation has been assigned to the Late Jurassic based on pelecypods of the genus Buchia (MacKevett, 1971).

The Kennicott Formation unconformably overlies the Jurassic and older rocks of the Wrangell Mountains area. The unit includes 30 meters (98 feet) of basal conglomerate and approximately 180 meters (590 feet) of sandstone, siltstone, and shale. The pebbles and boulders of the conglomerate are predominantly dark greenish-gray greenstone of the Nikolai Greenstone set in a matrix of coarse-grained sandstone. The sandstones are feldspathic wacke, arenite, and arkosic wacke. The well sorted, subangular clasts include quartz, plagioclase, glauconite, chert, opaque minerals, chlorite, biotite, calcite, epidote, and garnet. The matrix consists of chlorite, chalcedony, sericite, calcite, secondary iron minerals, montmorillonite, kaolinite, and zeolites. The siltstones are finer grained equivalents of the sandstones. The shales are composed of clay minerals and quartz. The formation has been assigned an Albian age based on the ammonite Brewericeras hulenense (Anderson)(MacKevett, 1971).

South of the Border Ranges Fault the Chugach Mountains are composed of a thick flysch-like sequence of rocks known as the Valdez Group. The sequence includes interbedded slate and graywacke, volcanic flow rocks, and minor conglomerate. The graywacke is light-to medium-gray, fine-to coarse-grained, feldspathic wacke composed of subangular clasts of plagioclase, quartz, sericite, chlorite, and biotite. The slate is a very fine grained rock that has incipient-to well-developed cleavage (MacKevett and Plafker, 1974). The rocks have been metamorphosed to the lower greenschist facies and have been highly deformed locally. Veinlets of quartz less than 2 centimeters (.8 inches) wide are present in two prominent trends, one parallel to east-west cleavage planes and one in a north-south direction, parallel to a major joint set. The Valdez Group is assigned a Late Cretaceous age based on fossils collected in the Valdez area (Moffit, 1914) and in the Turnagain Arm area (Park, 1933; Clark, 1972).

Unconformably overlying the Cretaceous rocks north of the Borders Range Fault is a sequence of 300 to 600 meters (984 to 1,970 feet) of sandstone, conglomerate, shale, clay and coal (Moffit, 1938). This sequence is correlative with the Frederika Formation of MacKevett (1970). The unit gradationally underlies and is intercalated with flows of the Wrangell Lava. The conglomerates range from pebble-to boulder-conglomerates and are composed of clasts of greenstone of the Nikolai Greenstone, volcanic rocks of the Wrangell Lava, chert, quartz, granitic rocks, shale and limestone. The matrix is poorly sorted, calcite-cemented, arkosic sandstone. The sandstones are light-brown, buff, and light greenish-brown feldspathic and arkosic wackes. They are composed of poorly sorted, angular grains of quartz and plagioclase set in a matrix of chlorite, and clay minerals. The sandstones have calcite and silica cement and contain minor potassium-feldspar, biotite, magnetite, ilmenite, apatite, pyrite, and hematite. The siltstones and shales are light-to dark-gray and weather to various shades of brown. The siltstones are compositionally fine-grained equivalents of the sandstones while the shales are composed primarily of quartz and clay minerals with minor biotite, muscovite, and opaque minerals. Lignite is present locally and occurs as finely laminated dark-gray to black layers that grade into carbonaceous shale. A Tertiary age has been assigned to the formation based on abundant plant material (MacKevett, 1971).

Intrusive rocks in the quadrangle range in composition from dunite to granodiorite. Ultramafic rocks are present north of the Borders Range Fault and have been mapped in the Valdez quadrangle at Spirit Mountain (Herreid, 1970), Bernard Mountain (Hoffman, 1974), and at Chitina (Metz, 1975).

At Spirit Mountain, an intrusive complex composed of quartz diorite, hornblendite, peridotite and gabbro intrudes the graywacke, greenstone, slate, and limestone of the Strelna Formation. Herreid (1970) describes the quartz diorite and hornblendite as a

> "Fine to medium-grained, medium-dark-gray to greenish-black rock composed of widely varying

> proportions of sericitized oligoclase-hornblende-quartz-phlogopite-clinopyroxene with accessory sphene and zircon."

The peridotite occurs as an unbanded, medium-to coarse-grained, black dike rock composed of antigorite after olivine, fosterite, tremolite, and diopside, with massive and disseminated nickel sulfides. The gabbro is a medium-grained rock composed of olivine, pyroxene, garnet, and magnetite (Herreid, 1970).

Hoffman (1974) described in detail the Bernard Mountain ultramafic complex that crops out about 8 kilometers (5 miles) south of Tonsina. The complex includes dunite, clinopyroxenite, and hornblendite. Dunite comprises the bulk of the ultramafic body and generally occurs as a green to olive-green, fine-grained and massive rock. Major mineral constituents include: olivine, enstatite and chromite. The ultramafic body consists of about 75% dunite, 15% harzbergitic dunite and 5% harzbergite. The remaining 5% of the rocks in the complex are chromite bearing. The complex exhibits local zonation, however it also contains characteristics of alpine-type ultramafic bodies. Hoffman (1974) has classified the Bernard Mountain complex as an alpine-type ultramafic that was emplaced in the late Mesozoic or early Cenozoic between the Permian(?) Strelna Formation to the south and a Jurassic amphibolite and granulite terrane to the north.

Approximately 2 kilometers (1.25 miles) northwest of Chitina a serpentinite body 4 kilometers (2.5 miles) long and several hundred meters wide occurs in an east-west striking fault zone that dips to the south. The ultramafic body is associated with granulites and amphibolites that occur south of the fault zone and with blueschist facies metamorphic rocks of the Strelna Formation that occur both north and south of the fault zone. The ultramafic is composed of serpentine after olivine and clinopyroxene (Metz, 1975; 1976).

Numerous small plutons of Tertiary and Quaternary age intrude the Paleozoic and Mesozoic rocks in the Valdez quadrangle. Most of the plutons are less than a few hundred meters in diameter, however several plutons are up to 16 kilometers (10 miles) across. They range in composition from quartz diorite to granodiorite. The largest body of quartz diorite is located at Spirit Mountain and has been described previously (Herreid, 1970). Two small bodies of altered granodiorite and quartz diorite occur near Chitina and are composed of sericite after potassium feldspar, quartz, and plagioclase. One of the bodies contains north-south striking quartz veins that contain minor gold mineralization. The pluton has been dated at 45.5±1.4 m.y. BP (Metz, 1975).

The Wrangell Lava (Mendenhall, 1905) conformably overlies the Frederika Formation however some of the older flows are intercalated with the Miocene rocks. The lavas are a subaerial sequence of flow, pyroclastic, vitrophyre, and conglomerate with a total thickness of approximately 1,500 meters (4,921 feet). Individual flows range from 0.3 to 8 meters (1 foot to 26 feet) thick and are composed of andesite, basaltic-andesite, rhyodacite, and basalt. The andesites and basaltic andesites are the predominant rock types and are dark-gray to greenish-gray on fresh surfaces and medium-brown on weathered surfaces. The rocks are composed of sodic labradorite, calcic andesine, augite, hypersthene with minor pigeonite, olivine, magnetite, hornblende, biotite, quartz, and glass. Secondary minerals occur as amygdules and include; calcite, chlorite, siderite, ankerite, and zeolites. The rhyodacites are light-gray or buff on fresh surfaces and weather light-brown. The rocks are porphyritic in part with plagioclase phenocrysts to 2.5 millimeters (0.1 inches) in length. The groundmass is composed of quartz, biotite, potassium feldspar, magnetite, ilmenite, glass, sphene, and zircon. Secondary minerals include chlorite, calcite, clay minerals, leucoxene, sericite, chalcedony, and iron oxides. The vitrophyre occurs as lava domes composed of green-to black rocks that contain quartz and plagioclase phenocrysts in a glassy groundmass. The pyroclastic rocks are light-brown to red-brown tuffs and volcanic breccias. The conglomerate occurs in lentils and is similar in composition to the conglomerate of the Fredericka Formation. The Wrangell Lavas range from Miocene to Holocene in age (MacKevett, 1971).

Although there is a great lithologic diversity in the geology of the Valdez quadrangle only the Strelna Formation, the tuffaceous shale unit of Moffit and its correlatives, the Valdez Group and the mafic and ultramafic rocks of the Bernard Mountain complex have been mapped in the corridor. All of the units in the quadrangle including those in the corridor have not been mapped in detail.

Structural Geology

The Border Ranges Fault (MacKevett and Plafker, 1974) dominates the structural geology of the rocks in the Valdez quadrangle. The fault has been interpreted as representing a Mesozoic plate boundary that seperates a northern block, composed predominantly of Paleozoic and Mesozoic metamorphic rocks, from a southerly block composed of flysch-like sediments of late Cretaceous age. The Border Ranges Fault can be traced from the St. Elias Mountains on the east, to the southwest end of Kodiak Island, a distance of about 1,000 kilometers (625 miles)(MacKevett and Plafker, 1974). The fault was first recognized by Capps (1937) on Kodiak Island, where a large, vertical, northeast-striking fault separates a greenstone-schist complex on the north from a thick sequence of graywacke, slate and argillite of Mesozoic age on the south. Later workers also recognized the fault further to the east and Moffit (1914) delineated the contact between the upper Paleozoic rocks and the Valdez Group rocks in the Copper River Region. Although Moffit did not map the contact as a fault, he interpreted the contact as a fault locally. MacKevett and Plafker interpret the tectonic implications of the Border Ranges Fault as follows:

> "The Border Ranges Fault is interpreted to mark a plate boundary that developed near the close of the Mesozoic or in the early Tertiary. During this time, the deep-water deposits of the Valdez Group buckled against, and probably locally were subducted beneath, terrane underlain by an upper Paleozoic island arc that previously had accreted to the continent. The island arc terrane is believed to have formed directly on the oceanic crust (Richter and Jones, 1971; Jones and others, 1971). Its superjacent rocks consist of subaerial volcanic rocks and widespread fossiliferous, largely clastic, Mesozoic rocks that were deposited on the continental shelf or in shallow epicontinental marine embayments. Some of these rocks are coeval with the Valdez Group. The Valdez Group reflects rapid turbidite-type sedimentation, probably largely on oceanic crust in a deep marginal trench.
>
> Activity of the Border Ranges Fault apparently waned after the early Tertiary, with subsequent uplift and emergence of the Valdez Group and its accretion to the continental margin. However, at least local post-early Tertiary activity on the fault cuts Tertiary rocks near the Matanuska Glacier."

Rocks of the Strelna Formation have a general east-west strike and dip moderately to the north, small-scale folds with northeast-trending axes are transected by a strongly-developed north-south cleavage. Abundant quartz stringers cut the greenstones and slates of the Strelna Formation. Although some of the stringers are parallel to the north-south cleavage, the bulk appear to be east-west striking.

The structure of the rocks in the Valdez Group is similar to that of the Strelna Formation. The rocks have an average east-west strike and dip moderately to the north. Minor folds are present locally and indicate that the almost constant northward monoclinal dips are the result of compressed folds overturned to the south (Brooks and others, 1911).

Geochemistry

Geochemical reconnaissance in the Valdez quadrangle during the present study consisted of the collection of 46 rock samples and 23 stream sediment samples (See Tables 1 and 2, Appendix A) along the pipeline corridor between the Alyeska Pipeline Terminal, south of Valdez and Willow Mountain on the north. Statistical analysis of the geochemical data has shown that 28% of the rock samples collected are strongly anomalous (98% confidence level) in at least 1 element, 13% of the rock samples contain anomalous (95% confidence level) concentrations of at least one element, and 24% of the rock samples were weakly anomalous (90% confidence level) in at least one element. Sixty-one percent of the stream sediment samples collected contain weakly anomalous, anomalous and strongly anomalous concentrations of at least one element. Most of the samples collected contain anomalous concentrations of more than one element and several samples were anomalous in more than 8 elements. Threshold values (See Tables 3 and 4, Appendix A) for the 90%, 95%, and 98% confidence intervals for each element were derived from a statistical analysis of the raw data and the calculation of concentrations of the elements at the arithmetic mean plus: 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation for the 90%, 95% and 98% confidence levels respectively. Where the analystical variability is zero or near zero, the threshold values for the confidence levels are either the detection level or nearly the same value.

Samples of graywacke and metagraywacke in the southern part of the quadrangle contain strongly anomalous concentrations of bismuth, antimony, potassium, yttrium, zirconium, and phosphorous. The strongly anomalous values in the area seem to be related to small fractures, shear zones and quartz veins that may have formed during a regional metamorphic event that has metamorphosed the rocks in the region to the upper zeolite and lower greenschist facies.

To the north, near Wortmann Creek, samples of metagraywacke and slate with quartz veining contain strongly anomalous concentrations of barium, gallium, molybdenum, titanium, zinc, lead and silver. A stream sediment sample from Sheep Creek contains strongly anomalous concentrations of molybdenum, lead and zinc, and anomalous concentrations of chromium, iron and nickel. Although no mineralization was found in the area during the current study, several claims were staked in the past near the mouth of Sheep Creek. This area clearly needs further work to determine the bedrock source of the anomalous metal values.

A sample of interbedded graywacke and slate near the mouth of Cascade Creek contains strongly anomalous concentrations of calcium, chromium, copper, iron, manganese, nickel and scandium. The chromium, copper, nickel and iron association suggests that there may be an unknown mafic or ultramafic igneous rock component in the area.

A sample of graywacke collected near mile 40 of the Richardson Highway contains strongly anomalous concentrations of silver. Stream sediment samples from the area also contain high silver values. Moffit (1935) describes a gold-quartz lode at Mile 40 of the Richardson Highway known as the Townsend and Holland prospect. The gold mineralization is contained in at least two veins that cut shattered slate. The anomalous silver values in the rock and stream sediment samples from the area are probably related to gold-quartz vein mineralization. Moffit (1935) suggests that the gold quartz veins in the region are genetically related to the intrusion of granite and quartz diorite dikes that are younger than the abundant small quartz veins that are developed in the slate and graywacke. The presence of intrusive rocks in the region may explain the scattered anomalous concentrations of tin, potassium, zirconium, and gallium, in both stream sediment samples and samples of slate and graywacke.

Samples of chert and metavolcanic rocks collected in the Willow Mountain area contain abundant disseminated pyrite. The metavolcanics are probably altered basalt and contain strongly anomalous concentrations of barium, bismuth, gallium, phosphorous, antimony, tin, zinc and zirconium. Although no significant mineralization was found in the Willow Mountain area during the current study, the region clearly needs further work to fully assess its resource potential.

Mining Activity and Economic Geology

Prospecting in the Valdez quadrangle has been underway since the early days of the Klondike stampede. As early as 1897 some of the streams in the Valdez area were known to contain gold-bearing gravels and some were mined. Mining and prospecting in the Valdez area continued at a slow pace until 1910 when the Cliff Mine, located about 10 kilometers west of Valdez became productive and stimulated the search for other gold-quartz veins in the region. In a short time, about 30 promising lodes had been found, and by 1914 nine mills of various types were in operation in the Port Valdez district. At least two distinct types of lode deposits are known in the area. The gold quartz veins are mainly fissure-type veins that show little if any alteration of the wall-rock. Locally, the country rock near the veins is impregnated with pyrite and arsenopyrite and some alteration is present. The mineralogy of gold-quartz lodes is fairly simple and includes gold, quartz, calcite, and minor pyrite and arsenopyrite. The other type of deposit known in the area is characterized by the copper deposit at the Midas Mine on Solomon Gulch, south of Valdez. The Midas Mine has produced over 1,000,000 pounds of copper and therefore is one of the major copper producers in the Prince William Sound area. The original claims at the Midas Mine were located in 1901 and by 1911 considerable development work had been done on the property. The mineralization at the Midas, known as the Jumbo lode is restricted to narrow veins adjacent to a shear zone in the slate and graywacke. The veins cut the foliation in the mine area. High-grade mineralization is composed of pyrite, with smaller amounts of pyrrhotite, chalcopyrite, sphalerite and minor galena. Samples collected by A. W. Rose (1965) and by M. W. Jasper (1953) contained copper concentrations as high as 5%. The Jumbo lode is in close proximity to a fairly large greenstone body and the copper mineralization may be related to the greenstone.

The Cliff Mine, located about 8 kilometers (5 miles) west of Valdez, near Shoup Bay, was the most productive gold-quartz lode in the Valdez district. The property was located in 1906 and the first production occurred in the spring of 1910. The ore body at the Cliff Mine is fairly typical of the gold-quartz lodes in the Valdez area. The mineralization is found in several persistant fissure veins that transect the foliation of schistose graywacke (Johnson, 1922; in Brooks, 1922). The metasediments and metavolcanic rocks of the Valdez district contain a well-developed cleavage that early investigators recognized. The north-south cleavage is parallel to many of the gold-quartz veins of the region. The fissure-vein system at the Cliff Mine was traced underground for 275 meters (825 feet) and varied from 15 centimeters to a meter (6 inches to 3 feet) wide. The ore is contained in bluish-white quartz with minor amounts of calcite, albite, chlorite and brownish-weathering carbonate. The ore contained only about 3% to 5% sulfides including pyrite and arsenopyrite with minor sphalerite and galena. The gold for the most part was free milling and early reports (Brooks, 1911) indicate the average gold content was approximately 2 ounces per ton. Ore shoots containing up to 10 ounces per ton gold were known. Several mining operations in the Mineral Creek and Valdez Glacier area produced gold and minor silver. The deposits are similar to the gold-quartz veins in the Shoup Bay area and are generally fissure veins cutting slate, argillite and metagraywacke.

Placer gold was known in the Valdez district as early as 1897, however, only limited production from relatively small placers on Mineral Creek, Gold Creek, Solomon Gulch, and from the Lowe River has occurred. The deposits appear to be of fluvioglacial origin and no large commercial deposits are known in the Valdez district.

North of Valdez in the Mt. Tiekel area, gold lodes have been known since the early days and are mainly quartz veins, closely associated with quartz diorite and quartz diorite porphyry that cut argillite, graywacke, quartzite, and minor limestone of the region. Several promising prospects were found on Hurtle Creek, however only minor production has occurred. The quartz veins on Hurtle Creek exhibit several generations of quartz. Near the margins of the veins, the quartz is mainly milky-white, bull quartz with little mineralization. Near the center of most of the larger mineralized veins, a zone of vuggy quartz containing sulfides and gold is usually present. The sulfide minerals include pyrite, aresonpyrite, galena, sphalerite and chalcopyrite. Gold usually occurs as free gold and is generally free milling. Assays of high-grade ore from the Wetzler claims on Hurtle Creek ran as high as 7 ounces of gold and 12 ounces of silver per ton. However, gold contents of less than 1 ounce are the rule. Northeast of Mt. Tiekel near the head of Fivemile Creek at Chitina, a mineralized quartz diorite intrusive contains disseminated arsenopyrite and gold (Metz, 1975). Quartz veins near the margins of the quartz diorite also contain gold-bearing mineralization. Assays range between 0.18 and 3.0

ounces per ton gold and up to 4.2 ounces per ton silver. Other mineralized intrusives occur in the Chugach Range and there is a high probability that unknown mineralized stocks and sills are present in the region.

South of Tonsina, at Bernard Mountain, the dunite contains segregations and discontinuous pods of chromite. The chrome does not appear to be of economic tenure at this time. Minor concentrations of chalcopyrite occur in the clinopyroxenite in the mafic-ultramafic complex, however the copper concentrations do not appear to be significant.

At Spirit Mountain, Herreid (1970) sampled a peridotite dike that ran 0.88% nickel and 0.89% copper, however the mineralized body is relatively small. The Spirit Mountain occurrence is similar to the mafic and ultramafic complex at Bernard Mountain however the economic potential of these occurrences is limited by their small size.

The Jurassic or younger volcanic rocks of the quadrangle contain zeolite minerals. The economic potential of these rocks is indeterminate at this time but they are important targets for future examinations.

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Gulkana Quadrangle

Previous Investigations

Early investigations in the area include the Copper River military expedition in 1898 and 1899 and a traverse by Mendenhall (1905). Recent work includes regional studies (Berg, Jones and Richter, 1972; Grantz, Jones, Lanphere, 1966), geologic mapping (Nichols and Yehle, 1969; and Ferrriano, 1971), geochronology (Marvin, 1974; and Grantz, Jones and Lanphere, 1966), structural geology (Andreasen et al, 1964; Barnes, 1967; Gedney, 1970; Berg, 1973; Freeland and Dietz, 1973; Richards, 1974; and Brogan et al, 1975) and mineral resources (Berg and Cobb, 1967; Richter and Matson, 1968; Heiner, Wolff and Grybeck, 1971; and Mulligan, 1974). The quadrangle has not been completely mapped on any scale nor has there been any major regional geochemical investigations in the area.

Regional Geology and Petrology

The rocks in the southern part of the Gulkana quadrangle are dominately metavolcanic and metasedimentary rocks of Jurassic age. The volcanic rocks are generally altered andesite and basalt flows, tuffs and breccias that have been regionally metamorphosed to the lower greenschist facies. The greenstones are fine-grained rocks containing chlorite, sodic plagioclase, calcite, quartz and epidote. The metavolcanics are interlaminated and interbedded with volcanoclastics and cherts. The Jurassic rocks have been tentatively correlated with the Talkeetna Formation of lower Jurassic age. The entire sequence is highly fractured and jointed and is cut locally by randomly oriented quartz veinlets. The volcanic rocks contain disseminated pyrite and euhedral cubes of pyrite to 10 millimeters (0.4 inches) on an edge are present locally. Minor chalcopyrite is also present.

To the north, sedimentary rocks of the Copper River Basin dominate the geology. Rocks of the Matanuska Formation, of upper Cretaceous age are also present. The Matanuska Formation has been traced from the lower Matanuska Valley to the Copper River region (Grantz et al, 1960). The unit is composed of a thick sequence of dark-gray siltstone and shale interbedded with light-colored sandstone and conglomerate, all of marine origin. The shale and siltstone are generally dark-gray to black, thin-bedded, nodular shale and siltstone. The sandstones are mainly well-indurated, fine-grained, thinly laminated micaceous and flaggy sandstones that are arkosic in part. Conglomeratic sandstone beds occur throughout the sequence.

Unconformably overlying the rocks of the Matanuska Formation is a sequence of non-marine sedimentary rocks known as the Gakona Formation, of Eocene age. The Gakona Formation is composed of a basal section of coarse conglomerate that is overlain by a sequence of slightly indurated clayshale containing lignitic coal. The base of the Gakona Formation is marked by a greenish conglomerate layer composed of rounded pebbles of quartz and greenstone set in a feldspathic sandstone matrix. The overall thickness of the Gakona Formation, probably does not exceed 600 meters (2,000 feet)(Andreason et al, 1964).

Rocks along the northern margin of the Copper River Basin are part of a sequence of weakly metamorphosed basalt, andesite and tuffaceous rocks of the Amphitheatre Group of middle-to late Triassic age. Rocks of the Amphitheatre Group have been traced from the Gakona River westward to the Susitna River, a distance of about 160 kilometers (100 miles). The Paxson Mountain Basalt is the dominant rock found in the Paxson Mountain area and generally consists of green to olive-green basalt with minor maroon amygdaloidal basalt near the base of the unit. Locally, dark-green to olive-green basalts occur higher in the volcanic sequence and form massive, resistant outcrops with few amygdules. The basalt is entirely recrystallized and plagioclase feldspar is completely altered to albite and primary augite has been altered to chlorite and actinolite. Locally, in the Paxson Mountain Basalt, zones of amygduloidal basalt are present. The amygdules contain a wide variety of minerals including epidote, pumpellyite, prehnite, quartz, calcite, laumontite, clinozoisite and albite. The total thickness of Paxson Mountain Basalt is not known; however, a maximum of 3,000 meters (10,000 feet) of basalt is exposed in the Paxson Mountain area (Stout, 1976).

The Tangle Lakes Formation (Stout, 1976) at its type locality, on the south limb of the Amphitheatre syncline near Tangle Lakes consists of about 4,000 meters (11,500 feet) of andesite, agglomerate and siliceous tuff. About 1,000 to 1,500 meters (3,000 to 4,000 feet) of the Tangle Lake Formation consists of diabase and diorite sills. Near the base of the Tangle Lakes Formation several thousand meters of well-bedded, siliceous tuff and tuffaceous sediments crop out. Petrographically, the tuffs and tuffaceous sediments consist of alternating siliceous layers and layers composed of plagioclase feldspar. Agglomerate layers consist of angular volcanic clasts to a meter (3 feet) in diameter. Clasts of andesite, siliceous tuff, agglomerate and tuffaceous limestone are set in a light-to dark-green aphanitic groundmass. Near the top of the section, a sequence of andesite flows are interbedded with chert, black-siliceous argillite and shale and are interbedded with thin tuffaceous limestone and dolomitic limestone. At the very top of the Tangle Lakes Formation is a distinctive pillow andesite sequence about 500 meters (1,500 feet) thick. This sequence marks the top of the Tangle Lakes Formation and contains well-developed, nested pillows locally.

Overlying the Tangle Lakes Formation is a thick, approximately

6,000 meters (18,500 feet,) sequence of interlayered green basalt and amygdaloidal basalt known as the Boulder Creek Volcanics. The Boulder Creek Volcanic sequence bears a strong resemblance to the Paxson Mountain Basalt. Amygdaloidal members range from thin layers with less than 10% amygdules, to layers containing up to 75% amydules filled with epidote, quartz, pumpellyite, chlorite, prehnite and calcite.

The greenstones at Hogan's Hill, in the central part of the quadrangle are altered basaltic or andesitic volcanic rocks that are cut by a stockwork of anastomozing quartz veins. The greenstones are completely shattered and cut by numerous transecting fracture systems. Petrographically, the greenstones are composed of a fine- to medium-grained intergrowth of chlorite, epidote, plagioclase feldspar, quartz, sphene, actinolite and amphibole (hornblende?). The rocks exhibit a well-developed foliation locally.

Structural Geology

The structural geology of southcentral Alaska in general and in the Gulkana quadrangle in particular may be the result of interaction between the North American Plate and the Pacific Plate, from the late Paleozoic to the Tertiary. Richter and Jones (1973) summarized the structure and tectonic history of southern Alaska as follows:

> "The eastern Alaska Range and contiguous terrane to the south and southwest have acted as a fairly cohesive block that, until late Cenozoic time, responded to variable rates of tectonic stress mostly directed northward. In general, these stresses have been relieved by rupture in the pre-Jurassic rocks and by plastic deformation in the thick basinal Jurassic and Cretaceous strata."

Richter and Jones go on to say:

> "Three distinct types of faulting have been recognized in the post-middle Triassic rocks: 1) north- to northwest-trending high-angle reverse and normal faults generally with the southwest block down; 2) low-angle thrust faults with northeast dip; and 3) linear, northwest-trending, right-lateral strike-slip faults."

East and northeast-striking faults, fault blocks and large open folds dominate the structure in the west-central part of the quadrangle, and northwest-to west-trending folds are restricted to the Triassic and older rocks. Thrust faults are known in the region and are usually associated with isoclinal-to overturned folds. Locally, the greenstone sequences are highly fractured and are cut by several distinct joint sets. At Hogan's Hill, in the north-central part of the quadrangle, the greenstones are highly fractured and are cut by many quartz veins.

Geochemistry

Geochemical reconnaissance in the Gulkana quadrangle during the current study consisted of the collection of approximately 30 rock samples (see Table 5, Appendix A) from the northern part of the quadrangle. The sampling was centered in an area of the inner pipeline corridor between Hogan's Hill and Paxson Lake. The rocks of the region are dominantly altered, mafic volcanic rocks of the Amphitheatre Group and mafic to silicic intrusive rocks of Mesozoic age.

Statistical analysis of the geochemical data has shown that 73% of the samples collected contained weakly anomalous, anomalous and strongly anomalous trace element concentrations in atleast one element. The threshold values (see Table 6, Appendix A) for the 90%, 95% and 98% confidence intervals for each element were derived from a statistical manipulation of the raw data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation, for the 90%, 95% and 98% confidence levels, respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are either the detection level or nearly the same value.

Trace element geochemistry of the rocks in the region reflect the mafic volcanic nature of much of the bedrock. Strongly anomalous concentrations of copper, chromium, cobalt, magnesium, nickel and titanium are commonly associated with the altered basalt, andesite and tuffaceous rocks in the area. No ultramafic rocks are known to occur in the pipeline corridor. The chromium and nickel values are thought to be tied up in silicate minerals. Sporadic occurrences of chalcopyrite, malachite and minor azurite were found during the course of field work in the Hogan's Hill area, however the copper concentrations are relatively low and do not appear to be of significance. The chalcopyrite occurs with abundant pyrite in a stockwork of anastomozing quartz veins that cut altered basalt. The quartz vein material also contains zinc, silver and gold values along with minor concentrations of molybdenum, tin, tungsten and cobalt. This area clearly needs further work to determine the potential for economic mineralization.

Mining Activity and Economic Geology

Mining in the Copper River region began as early as 1900, when gold-bearing gravels were located in the Chistochina district. The first locations in the area were made in 1898 on the Chisna River, and production from the district has continued to date. A total of about 141,000 ounces of gold has been produced from the placers in the area. Gold was discovered in the Nelchina area in about 1914, however, the bulk of gold production from the region has come from the Chistochina area. Lode deposits in the Nelchina district have been prospected for gold, silver, manganese and chromite. The gold lodes are mainly gold quartz veins that contain minor chalcopyrite, galena and sphalerite. Only minor production from the gold quartz vein deposits has occurred in the district.

Rocks along the northern margin of the Copper River basin are mainly part of a east-southeast trending belt of greenstone and chert of the Amphitheatre Group. The Amphitheatre Group basalts and other metavolcanic rocks in the region contain low-grade copper mineralization locally. The copper occurrences are generally restricted to fracture veins and mineralized breccia zones in the metavolcanics. Minor concentrations of chalcopyrite, bornite, chalcocite and chrysocolla are known. However, none appear to be of significance.

Metavolcanic rocks near Hogan's Hill, in the north-central part of the quadrangle contain abundant pyrite and minor chalcopyrite, generally restricted to a stockwork of anastomozing quartz veins. Minor gold and silver values were also detected in samples of the vein material, none appear to be significant.

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Mount Hayes Quadrangle

Previous Investigations

The Mount Hayes quadrangle has been the site of extensive geologic investigations since about 1896 when J. E. Spurr and F. C. Schrader of the U. S. Geological Survey traversed the area enroute to the Yukon gold district. A. H. Brooks (1903-1923) also of the U. S. Geological Survey contributed much to the description of the mining activity throughout most of Alaska. Brooks also conducted basic geologic investigations in the region. F. H. Moffit (1912, 1954) conducted detailed geologic investigations in the central Alaska Range, and his early work in the Alaska Range has served as a base upon which most of the later investigators have built His later work resulted in a better understanding of the bedrock geology and mineral deposits of the region. Geologic reconnaissance by S. R. Capps, of the Geological Survey, to the west in the Bonnifield district, tied together many of the regional investigations conducted in the Alaska Range. Detailed work by C. Wahrhaftig and C. A. Hickcox (1955) of the U. S. Geological Survey in the Jarvis Creek area, centered on the Tertiary coal-bearing sequence there. Geologic investigations by T. L. Pewe and W. Holmes (1964, 1965) of the Geological Survey in the northern part of the Mt. Hayes quadrangle have resulted in two, 30 minute geologic maps with a scale of one inch equals one mile.

Detailed geologic investigations by L. G. Hanson (1963) of the University of Alaska, centered in the Rainbow Mountain area of the Central Alaska Range. Later work by G. C. Bond (1965), Petocz (1969) and Gebhardt (1972), all of the University of Alaska have led to a better understanding of the geology and stratigraphy of this part of Alaska.

In the early 1960's, the Alaska State Division of Geological and Geophysical Surveys initiated the first of a series of geologic investigations in the Mount Hayes quadrangle. The state investigations are generally resource oriented programs in areas that may have good potential for hard-rock mineral deposits. Work by A. W. Rose and R. H. Saunders (1965) near Paxson was undertaken to evaluate the bedrock geology and known hardrock mineral deposits of the area. Later work by A. W. Rose (1966) in the Amphitheatre Mountains outlined the geology of the area and investigated many of the geochemically anomalous areas that had been outlined during previous investigations. Still later work by A. W. Rose (1966, June) in the Eureka Creek and Rainy Creek areas resulted in a fairly detailed map of this part of the Alaska Range as well as baseline geochemical data related to the mineral occurrences in the area. Similar work in the upper Chistochina River area by A. W. Rose (1967) has resulted in a bedrock geologic map of the area as well as some fairly detailed descriptions of the mineral occurrences in the region. Recent work by Smith (1972) in the western part of the Mount Hayes quadrangle has lead to a better understanding of the rocks in the MacIaren metamorphic belt, and other work by Smith and Turner (1974) has resulted in a paleo-reconstruction of central Alaska with implications as to be possible offset along the Denali fault. Work by J. H. Stout et al (1973) in the central Alaska Range has shown evidence of Quaternary movement along the McKinley Strand of the Denali Fault. Other work by Stout (1976) has resulted in a better understanding of the geology, structure and mineral deposits of the Eureka Creek area in the east-central Alaska Range.

Regional Geology and Petrology

The oldest rocks to cropout in the northern part of the Mount Hayes quadrangle consist of metasedimentary and metaigneous rocks of the Birch Creek Schist unit of Precambrian or early Paleozoic age. The Birch Creek Schist occupies an extensive area north of the north-flank of the Alaska Range and is composed of quartz-mica schist, quartzite, micaceous quartzite, gneiss, amphibolite with minor slate, phyllite and crystalline limestone. The metamorphic rocks have been subjected to at least two metamorphic events and range in grade from the greenschist to the amphibolite facies of metamorphism. The quartz-mica schists of the region vary greatly in composition and show a wide range in the degree of metamorphism. Moffit (1942) describes the schists and gneisses of the region as follows:

> "They occur in great variety, as would be expected in view of their origin, and show a wide range in degree of metamorphism. The colors are dominantly gray in varying shades but include green and black and segregatons of pink and lavendar. Some of the more siliceous varieties have a bright silvery aspect, but the darker grays are more common. The texture grades from that of fine slate with planer cleavage and constituent minerals so small as to be unidentifiable in the hand speciman, to that of coarse, crinkly schist and gneiss with easily recognizable mineral components. Garnet is a common constituent of the schist and occurs in bodies of all sizes from tiny, well crystallized grains hardly visible with a hand lens to imperfect crystals almost an inch in diameter. Other metamorphic minerals are present also, such as hornblende, which occurs in one locality in thin blades several inches long associated with great numbers of tiny red garnets."

The schists of the region are typically pelitic schists. In general, they are garnetiferous quartz muscovite and biotite schists of polymetamorphic character. One phase of metamorphism is represented by euhedral grains of muscovite parallel to the S_1 plane and a second (later?) phase that defines an S_2 plane that transects the earlier

S_1 foliation. The S_2 foliation contains subhedral, faintly pleochroic biotite laths. Higher-grade rocks in the northern part of the quadrangle include calcic amphibolite, hornblende schist and gneissic rocks of various compositions. The amphibolites are predominantly fine-to medium grained, subidioblastic to granular calcic amphibolites. Petrographically, the amphibolite is composed of up to 60% actinolitic hornblende, 10% to 15% plagioclase (An_{15} to An_{10}), 10% quartz, 5% biotite, 5% chlorite, 2% clinozoisite, and accessory sphene and calcite. Locally, fine to medium-grained quartz biotite hornblende schist is present. The schist contains up to 40% quartz, 25% biotite, 15% plagioclase, 10% clinozoisite, 5% hornblende and minor chlorite, sphene and calcite. Gneissic rocks west of Donnelly Dome are coarse-grained gneissic granitic rocks that Moffit (1942, 1954) believes represent metamorphosed intrusives.

About 5 miles southeast of Donnelly Dome in the Mount Hayes C-4 quadrangle, a sequence of Tertiary rocks crop out. The Tertiary section lies between the drainage of the Delta River on the west and Jarvis Creek on the east. Wahrhaftig and Hickcox (1955) of the U. S. Geological Survey conducted detailed geologic investigations in the area between 1946 and 1951. The Tertiary sequence is composed of a basal section, 152 meters (500 feet) thick, composed of micaceous sandstone and quartz conglomerate, derived from a southerly source area (Wahrhaftig and Hickcox, 1955). The basal section is overlain by a middle unit composed of 137 to 213 meters (450 to 700 feet) of buff, arkosic sandstone, from a northerly source area. The arkosic rocks are interbedded with shale and coal. The upper unit, about 275 meters (900 feet) thick, is composed of dark-gray claystone, sandstone and thin-bedded coal. In detail, the basal sandstone and conglomerate sequence is coarsest and thickest in the southwestern most exposures, and thins rapidly to the west and north. The conglomerate generally occurs in well bedded layers and consists of pebbles of quartz, chert, and subordinate amounts of rhyolite, granite and schist. The middle stratigraphic unit contains a coal-bearing zone that ranges between .3 and 15 meters (1 foot and 50 feet) thick. The zone contains coal interbedded with well cemented orange-weathering shale and shaly sandstone. The upper 122 meters (400 feet) of the middle unit is composed of medium-to coarse-grained, buff, arkosic sandstone, in beds 3 to 15 meters (10 to 50 feet) thick and a zone of gray to brown, silty claystone that contains lenticular coal beds to 15 centimeters (6 inches) thick. Iron-carbonate concretions of 1.8 meters (6 feet) in diameter are known in the claystone zone. The arkosic nature of this zone indicates that the sandstones were derived from a feldspathic terrane and Wahrhaftig (1955) believes that the granite of Granite Mountain, northeast of Jarvis Creek, may be the ultimate source of the detrital material in the middle section. About 3 to 6% of the middle unit is coal. The upper stratigraphic unit of the coal-bearing sequence consists predominantly of dark-gray claystone and siltstone in beds 1.5 to 18 meters (5 to 60 feet) thick, interbedded with dark-gray sandstone, coal and bone. The sandstone occurs in lenticular beds 1.5 to 6 meters (5 to 20 feet) thick and contains concretions locally. The coal in the upper unit occurs in beds ranging from 8 centimeters to 2 meters (3 inches to 7 feet) thick. About 10% of the upper unit is coal. One exposure of the coal-bearing sequence at Jarvis Creek contains 30 coal beds ranging between 0.3 and 2 meters (1 and 7 feet) thick. Another exposure contains 14 coal beds between 0.3 and 2 meters (1 and 7 feet) thick. According to Wahrhaftig and Hickcox (1955), between 100,000 and 300,000 tons of strippable coal reserves are present in the Jarvis Creek deposit.

The intrusive rocks between Jarvis Creek and the Gerstle River to the east are dominantly coarse-grained granodioritic rocks composed of hornblende, biotite, quartz and feldspar. The intrusive rocks are probably Cretaceous in age but may be as old as Jurassic (Wahrhaftig and Hickcox, 1955). Other intrusives of the north flank vary from granite to diorite in composition and include quartz monzonite, granodiorite and quartz diorite. To the east in the Johnson River area, quartz monzonite is a common intrusive rock, and gneissic quartz monzonite is present locally. Most of the granitic rocks in the area are characteristically coarsely porphyritic and some pegmatitic phases are known.

The metamorphic rocks between Jarvis Creek and the Denali Fault to the south, are mainly interlaminated quartz muscovite schist, micaceous quartzite and hornblende schist. The metamorphic sequence also contains recrystallized limestone and greenstone. The schists of the region are highly variable in nature. They range from massive to fissile and are highly contorted. Thinly laminated, garnetiferous, quartz muscovite schist is the dominant rock type in the area, although locally, green, red, brown and gray phyllite constitute the bulk of the rocks. The micaceous quartzites of the region are mainly fine-to medium-grained micaceous quartzites in which muscovite laths define a rudimentary foliation. The metamorphic sequence also contains "slaty" schist and metagraywacke.

Rocks that constitute the bulk of the metamorphic sequence are believed to be metamorphosed clastic sediments (Moffit, 1911), although recent work seems to indicate a marked pelagic sedimentary component as well as rocks with volcanic affinities.

Metamorphosed volcanic rocks north of the Denali fault are sill-like bodies of greenstone. The greenstones are probably metamorphosed basalt sills and dikes that intruded the schist-quartzite country-rock and were subsequently metamorphosed by a late metamorphic event. The greenstones north of the Denali Fault are markedly different than the greenstones of the Amphitheatre terrane to the south. The major difference is that the greenstones to the north are clearly intrusive while those to the south occur as flows (F. Weber, U. S. Geological Survey, personal communication, 1973).

South of the McKinley Strand of the Denali Fault system and north of the Hines Creek Strand, the rocks are characterized by a pre-Mississippian sequence of phyllite and calc-phyllite with minor schist and limestone. The rocks in the wedge-shaped area between the McKinley Strand and the Hines Creek Strand are in fault contact with the medium-grade metamorphic rocks of the Birch Creek schist terrane to the north and are also in fault contact with the Pennsylvanian Rainbow Mountain Sequence to the south. A similar sequence of metamorphic rocks is present south of the McKinley strand, although the southerly metamorphic sequence is composed of schist, subordinate calc-phyllite and limestone (Hanson, 1963).

The phyllites and calc-phyllites of the region are very fine-grained, locally porphyroblastic phyllites that contain apparent equilibrium metamorphic mineral assemblages consisting of sericite-chlorite-albite-quartz; stilpnomelane-chlorite-quartz-albite; and sericite-chlorite-calcite-albite-quartz. The calc-phyllites on the other hand are characterized by mineral assemblages containing chlorite-carbonate-albite-quartz; stilpnomelane-sericite-carbonate-albite-quartz. The phyllites and calc-phyllites are probably metamorphosed sedimentary rocks and contain evidence of one and sometimes two deformational events.

The schists of the area are polymetamorphic rocks that are metamorphosed igneous and sedimentary rocks. The schists are typical greenschist facies rocks and are characterized by mineral assemblages containing chlorite-calcite-albite-actinolite-quartz; clinozoisite-quartz-albite-chlorite-actinolite; and stilpnomelane-actinolite-calcite-clinozoisite-chlorite. The schists ranges from fine-to medium-grained, granular-to granoblastic rocks in which some layers appear to reflect relict igneous textures (Hanson, 1963).

Recrystallized limestone and impure marble are rare in the area, however, carbonaceous marbles containing calcite, chlorite, sericite, quartz, and albite are present locally. Marble composed of sericite-quartz, chlorite, albite and calcite, and marble composed of albite, quartz and calcite are also present. Hanson (1963) believes that the rocks that constitute the finely laminated pre-Mississippian metamorphics were derived from a succession of interlaminated argillaceous, calc-argillaceous and impure carbonate rocks, and the massive greenschist facies rocks containing relict phenocrysts were derived from basic igneous rocks. The pre-Mississippian metamorphic sequence of Hanson (1963) has been tentatively correlated with similar rocks to the west across the Delta River.

Southeast of the Miller Roadhouse a fairly large body of quartz diorite intrudes the pre-Mississippian metamorphic sequence to the north and the Rainbow Mountain sequence of Pennsylvanian and Permian age to the south. The quartz diorite is characteristically a medium- to coarse-grained, porphyritic, altered hornblende quartz diorite. The intrusive rocks appear to have been propolytized. Petrographically, the intrusive is composed of 20% quartz, 50 to 60% plagioclase feldspar (An_{10} to An_{30}), and secondary minerals include epidote, chlorite, carbonate and some clay minerals. The age of the quartz diorite body is questionable, however, a K-argon age obtained by Kleist (1971) indicated an age of 515 ± 75 million years B.P. Kleist believes that the alteration of the quartz diorite has resulted in a spurious age determination. Hanson (1963) obtained a K-argon age date of 105 million years B.P. for similar rocks about 4 miles east of the Miller Roadhouse locality.

East of the Miller Roadhouse locality a fairly large body of serpentinized peridotite and dunite is present. The ultramafic body is elongate in a northwest-southeast direction, subparallel to the trend of the Denali Fault. The ultramafic rocks occur in two distinct types. One type, includes dikes and sills of peridotite that intrude the phyllite and schist of the pre-Mississippian metamorphic sequence. The other type includes a large mass of serpentinized peridotite and dunite that is surrounded by quartz diorite. The ultramafic dikes and sills average 2 to 3 meters (5 to 10 feet) thick although some bodies may be as much as 60 meters (200 feet) thick. The dikes and sills are generally alligned parallel and subparallel to the Denali Fault system, however, some strike west and southwest (Hanson, 1963). Petrographically, the peridotites in the sills and dikes consist of olivine (Fo70), enstatite (En 90-95) and antigorite. Minor chrysotile, iddingsite, magnetite and diopsitic pyroxene occur, accompanied by accessory carbonate, chlorite, chromite and phlogopite. The large ultramafic mass to the southeast is surrounded by quartz diorite. The ultramafic has been described by Kleist (1971) as a "dunite intrusion" and is about 2.4 kilometers (1 1/2 mile) long and 0.5 kilometers (1/3 mile) wide in outcrop. The margins of the ultramafic body are highly serpentinized and some chrysotile asbestos is present. The age of the ultramafic bodies is questionable, however, Kleist (1971) believes them to be post-Cretaceous and therefore younger than the quartz diorite of the area. However, Stout (1965), feels that the age, though questionable, is pre-Tertiary, based on the presence of dunite and peridotite clasts in Tertiary(?) conglomerates near Ann Creek, just west of the Delta River.

South of Canwell Glacier, a thick section of Pennsylvanian sedimentary and volcanic rocks crops out. The sequence, east of the Delta River is collectively mapped as the Rainbow Mountain Sequence, and west of the Delta River, the same sequence has been recognized and mapped as the Tetelna Complex as far west as Broxson Gulch. Stout (1965) originally defined eight informal formations on the basis of lithologic differences. The formations are, from oldest to youngest:

1. Andesitic flow unit
2. Interbedded siliceous tuff and tuffaceous limestone unit
3. Siltstone and mudstone unit
4. Crystalline limestone unit

5. Graywacke and dark tuffaceous sandstone unit
6. Dacite quartz porphyry
7. Calcareous shale and siltstone unit
8. Volcanic breccia and dacitic tuff

(after Stout, 1976)

The entire sequence may be as thick as 3,000 meters (10,000 feet). However, Rowett (1969) believes that there is an aggregate thickness of 2,500 meters (8,000 feet). Rocks that constitute the andesitic flow unit consist generally of thick bedded porphyritic andesite interbedded with minor porphyritic dacite and crystalline tuff. The dacitic volcanics occur in beds between 3 and 15 meters (10 and 50 feet) thick and have an aggregate thickness of less than 65 meters (200 feet). The andesitic volcanics are highly altered and contain actinolite, chlorite and epidote. Petrographically, the andesite flow unit is characterized by phenocrysts of actinolitic hornblende up to 3 millimeters (0.10 inches) in length and plagioclase laths less than 1 millimeter (0.04 inches) in length, that define a relict trachytic texture.

Conformably overlying the volcanic flow unit is approximately 370 meters (1,200 feet) of horizontally bedded, interbedded, chert and limestone. The chert and limestone unit consists of uniformly bedded chert interbedded with clastic limestone. The cherts vary in color from white to black to green and occur in beds from 0.15 to 0.60 meters (1/2 to 2 feet) thick. Total thickness of this unit is less than 45 meters (150 feet).

Next, a complexly folded and faulted sequence of siltstone and mudstone about 225 to 325 meters (700 to 1,000 feet) thick is present. Bedding over much of the sequence is nearly obliterated due to severe deformation.

Overlying the siltstone and mudstone unit is a sequence of structurally thickened crystalline limestone. Stout (1965) feels that about 275 meters (900 feet) of section may be present. The limestone occurs in a well-bedded sequence and is interbedded with recrystallized terrigenous limestone and siliceous siltstone.

Conformably overlying the crystalline limestone unit is a sequence of rocks composed of lithic graywacke and tuffaceous sandstone. The graywacke unit is at least 220 meters (700 feet) thick and is highly deformed and altered locally.

Overlying the graywacke sequence is a unit composed of at least 180 meters (500 feet) of dacite quartz porphyry. The dacite porphyry is characterized by calcic oligoclase (An_{25}), quartz, sericite and chlorite. Late calcite pervades the entire rock and is locally a major constituent. Pseudomorphs of chlorite after amphibole and pyroxene are common. Euhedral phenocrysts of quartz up to 4 millimeters (0.16 inches) in diameter are set in very fine-grained groundmass of chlorite and plagioclase. Phenocrysts of plagioclase and pyroxene are also known.

Next, approximately 600 meters (2,000 feet) of calcareous shale, thin-bedded tuff, tuff breccia and lithic graywacke overlie the dacite porphyry unit. Pervasive carbonate alteration (calcification) is a characteristic feature of the tuff and tuff breccia. The upper part of this unit is composed of thin-bedded, dark, calcareous siltstone and shale interbedded with lithic graywacke. The beds range from 10 centimeters to a meter (4 inches to 3 feet) thick and comprise about 350 meters (1,100 feet) of section (Stout, 1965). The top of the unit consists of thick bedded, massive, lithic graywacke and one andesitic flow about 15 meters (50 feet) thick.

The youngest unit in the Rainbow Mountain sequence and Tetelna Complex is a thick sequence of volcanic breccia and fine-grained pyroclastics, overlain by a quartz latite flow. The quartz latite is characterized by abundant quartz phenocrysts in a fine-grained groundmass, and by a lack of mafic minerals. The remainder of the unit consists of hard, silicified, multi-colored volcanic breccias interbedded with feldspathic graywacke.

East and south of Rainbow Mountain, the rocks include a sequence of altered Mississippian(?) sedimentary and pyroclastic rocks of McCallum Creek Sequence. Lithologically, the McCallum Creek Sequence is similar to the Rainbow Mountain Sequence and is differentiated by fossil content. The McCallum Creek Sequence is separated from the Rainbow Mountain Sequence by a high-angle fault.

South of Rainbow Mountain in the Phelan Creek area, a Tertiary coal-bearing section is well exposed where McCallum Creek and Phelan Creek have cut deep canyons through the Tertiary sequence. The base of the Tertiary section is exposed south of College Glacier, where the sequence unconformably overlies the dacitic tuff member of Stout (1965). The rocks exposed in Phelan Creek have been broken into two groups. The lower group includes beds of buff-colored conglomerate, with clasts up to 13 centimeters (5 inches) in diameter, composed of dacitic tuff, andesite tuff, granodiorite, diabase, mafic and leucocratic gneiss, porphyritic andesite and quartz diorite. The source of the material that constitutes the bulk of the conglomerate unit was probably derived from a local source area. Minor interbeds of grit, sandy shale and sandstone are also present in the lower unit. The upper unit consists of buff-colored, sandy shale and sandstone. Coal seams are present in the lower part of the upper unit and are associated with sandy shale and soft clays. The lowest coal bed in the section is about 75 centimeters (30 inches) thick and is separated from a 60 centimeter (2 foot) thick seam by 3 meters (6 feet) of sandy shale. Several other coal seams are exposed in the lower 25 meters (80 feet) of the upper unit. The coal is lignitic in grade and appears to occur in lenticular bodies. Moffit (1954) believes that the coals do not extend over a large area. West of the Delta River near Eureka Creek, similar Tertiary, coal-bearing rocks are present. However, the basal conglomerate sequence in this area contains coal-bearing sandstones. At one locality, at least 30 meters (100 feet) of dunite conglomerate is present and unconformably overlies the upper part of the Tetelna Complex (Stout, 1976).

South of the Rainbow Mountain area near Summit Lake and Paxson, a sequence of weakly metamorphosed basalt, andesite and tuffaceous rocks crop out. The rocks, first mapped by Moffit (1911), are part of the Amphitheatre Group of Middle to Late Triassic age. Rocks of the Amphitheatre Group can be traced from the Gakona River westward to the Susitna River a distance of about 160 kilometers (100 miles). The best exposure of the rocks that constitute the bulk of the group are present in the Amphitheatre Mountains north of the Denali Highway and west of Paxson. The rocks in the Paxson area are mainly dark-green, massive, fine-grained basalt. Some exposures contain hornblende phenocrysts and vesicles. Amygdules of epidote, calcite and chlorite are fairly common. Individual units are rarely discernible, however, most of the unit is believed to occur as flows (Rose and Saunders, 1965). Petrographically, the metabasalt (greenstone) of the Amphitheatre Mountain area is a fine-to-medium grained, porphyritic, chloritized basalt that contains a relict ophitic to subophitic texture and pseudomorphs of calcite after plagioclase. Amygdules of calcite, chlorite and epidote are common. Locally, fine-grains of muscovite pervade the entire rock and form an incipient foliation.

Structural Geology

The structural geology of the Mount Hayes quadrangle is dominated by the Denali Fault, a major right-lateral strike-slip fault, that separates a Paleozoic block from a Mesozoic block that dominate the geology of southern Alaska.

North of the Denali Fault, the metamorphic rocks of the Birch Creek schist terrane are polymetamorphosed, and structurally complex. The metamorphic grade of the rocks in the Birch Creek schist terrane appears to increase to the north, away from the Denali Fault. Rocks near the fault are generally lower greenschist facies grade while those to the north are upper greenschist and lower amphibolite facies grade. The structural style present in the northern tectonic block is typically isoclinal to overturned folding with superimposed open-upright folding oblique to the strike of the isoclinal folding. The coal-bearing formation near Jarvis Creek occupies an oval-shaped depression, in the Birch Creek schist, whose major axis trends north-northwest. In the northern part of the basin, small anticlines and synclines are present. Faulting in the area has resulted in the displacement of coal seams about 30 to 45 meters (100 to 150 feet) in the Little Gold Creek area (Wahrhaftig and Hickcox, 1955). Some faults in the Tertiary basin can be traced into the surrounding Birch Creek Schist. Just north of Donnelly Dome, a northwest-trending high-angle fault can be traced from the north-flank of Donnelly Dome to the southeast as far as Jarvis Creek. No apparent lateral offset exists, however, the southern block is upthrown relative to the northern block.

The dominant tectonic feature of central Alaska is the Denali Fault. The Denali Fault, a major right-lateral strike-slip fault, can be traced from the Bering Sea to southeast Alaska, a distance of more than 3,000 kilometers (2,000 miles). Offset along this fault has been postulated to be as little as 80 kilometers (50 miles)(Brew and others, 1966), and as much as 425 kilometers (265 miles)(Forbes et al, 1974). The Denali Fault in central Alaska is divided into two major strands. A northern strand, the Hines Creek Strand, was first recognized and described by Wahrhaftig (1958), and a southern strand, the McKinley Strand, named by Arthur Grantz (1966), has long been recognized as a major fault in the central Alaska Range. The two strands merge in the Canwell Glacier area, east of the Delta River. Evidence of holocene movement along the McKinley Strand (Stout et al, 1973) indicates that right lateral movements of between 5 and 60 meters (16 and 197 feet) have occurred since the end of the Pleistocene.

Rocks south of the Denali Fault are complexly folded, thrust faulted and displaced along high-angle normal faults. Rocks of the Amphitheatre Group are folded into large east-west trending open folds that plunge to the west at a low angle. Locally, near Broxson Gulch, west of the Delta River, these folds are truncated against the western extension of the Broxson Gulch Thrust Fault. Smith (1974) believes that the east-west open folds are terminated at the structural discontinuity between the Triassic rocks and the lower Jurassic rocks of the southern Alaska Range. If Smith is correct, the east-west folding occurred sometime in Middle or Late Triassic. Another folding event in the pre-late Jurassic has resulted in northwest and west-trending folds throughout the south-central Alaska Range. Evidence for a post-Oligocene folding event in the Eureka Creek area consists of folded beds of coal-bearing sandstones and conglomerates. High-angle faulting has been active throughout the region.

Geochemistry

Geochemical reconnaissance in the Mt. Hayes quadrangle during the current study consisted of the collection of 42 rock samples and 20 stream sediment samples (see Tables 7 and 8, Appendix A) from the pipeline corridor between Paxson and Big Delta. Statistical analysis of the geochemical data has shown that 55% of the rock samples collected and 50% of the stream sediment samples collected contain weakly anomalous, anomalous and strongly anomalous concentrations of atleast one element. Threshold values (see Tables 9,10, and 11, Appendix A) for the 90%, 95% and 98% confidence intervals for each element were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean, plus: 1.645 x standard deviation, 2.0 x standard deviation and 2.33 x standard deviation, for the 90%, 95% and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are either the detection level or nearly the same value. The rocks in the Mt. Hayes quadrangle have been assigned to two geologic terranes. Rocks south of the Denali Fault have been grouped with the greenstones of the Amphitheater Group. Trace element geochemistry of the rocks in the Rainbow Mountain sequence may have been over-shadowed by lumping them with the greenstone terrane to the south. The greenstones have a high background trace element content and therefore the threshold values for the various elements would be higher then those in nongreenstone terranes. The statistical analysis would be somewhat insensitive to the elemental concentrations of the rocks in nongreenstone terranes. Rocks north of the Denali Fault in the Mt. Hayes quadrangle have been grouped with rocks of the Birch Creek Schist terrane. The trace element geochemistry appears to be compatable with the threshold values obtained.

Intrusive igneous rocks collected in the Rainbow Mountain area range from quartz monzonite to hornblende diorite in composition and contain disseminated sulfide mineralization locally. Strongly anomalous concentrations of silver, bismuth, phosphorous, lead, antimony and zinc were detected in samples of altered diabase and weakly anomalous concentrations of chrome and nickel were detected in samples of lithic tuff of the Rainbow Mountain Sequence. No mineralization of obvious significance was found during the current study in the Rainbow Mountain area, however, the mineral resource potential of the area may be high.

Samples of gneissic quartzite with chalcopyrite collected near the south margin of Canwell Glacier contain copper concentrations as high as .14% and zinc concentrations to 110 ppm. The quartzite occurs in close proximity to a highly altered dioritic intrusive that contains disseminated pyrite. The quartzite is hornfelsed and the copper and zinc concentrations may be the result of contact metamorphism.

North of the Denali Fault the metamorphic rocks of the Birch Creek Schist terrane contain scattered anomalous and strongly anomalous metal concentrations.

Samples of quartz muscovite schist from several localities contain anomalous molybdenum concentrations in excess of 18 ppm. No molybdenite was found during this study and the source of the molybdenum is not known. Samples of amphibolite from several localities contain strongly anomalous concentrations of calcium, iron, titanium, vanadium, tungsten and zinc. The amphibolites may be metamorphosed basalt and the high metal values may reflect their mafic igneous rock parentage.

Mining Activity and Economic Geology

Placer gold deposits and lode deposits of gold, silver, lead, zinc, copper, nickel, molybdenum and coal are known in the Mt. Hayes quadrangle. Prospecting in the region began in the 1890's and has continued to date.

The gold placer deposits of the Chistochina district, in the southeastern part of the Mt. Hayes quadrangle were first discovered in about 1898 when gold placers were found on the Chisna River. Later, placers were found on Slate Creek and on Miller Gulch and several other creeks in the area. Extensive mining activities and production occurred in the district between 1900 and 1942. Only minor sporadic production has occurred since 1942. Total production from the Chistochina district up to 1959 is about 141,000 ounces of gold (Koschmann and Bergendahl, 1968). Most of the Mt. Hayes quadrangle was prospected for gold in the early days, however only minor occurrences of placer deposits are known outside of the Chistochina district. Minor placer deposits in the Jarvis Creek area, southeast of Donnelly Dome were discovered in the early days, however, the deposits on Little Gold Creek were not of an economic nature and little work was done.

The Mt. Hayes quadrangle contains a great variety of hardrock mineral deposits. None of the deposits have had much production, however the potential for locating unknown deposits is high.

A disseminated molybdenum occurrence is present in the northwestern part of the Mt. Hayes quadrangle, near Ptarmigan Creek. The molybdenum mineralization accompanied post-intrusive quartz veining along zones of faulting and fracturing in a granodiorite pluton that underlies Molybdenum Ridge. The pluton intrudes the Birch Creek Schist countryrock, and is generally a medium-grained, idiomorphic granodiorite. The molybdenum mineralization occurs in numerous white-to glassy quartz stringers and also in an aplite dike. Locally, the veins are abundant and constitute small stockwork-type bodies within the granodiorite. Several of the quartz stringers carry arsenopyrite and gold and are apparently later than the molybdenum-bearing stringers (Joesting, 1942). No obviously economic mineralization was found in the Ptarmigan Creek area by Henry R. Joesting (1942) of the Alaska Department of Mines, however, the only exposure of molybdenum-bearing veins in the area occurs in the canyon walls of Ptarmigan Creek. It is possible that undiscovered zones of of mineralization exist in the area and further work is clearly needed.

The coal deposit at Jarvis Creek, southeast of Donnelly Dome has produced a few hundred tons of coal for heating purposes in the past, and is now idle. The coal field occupies an area of about 16 square miles and is underlain by schist and quartzite of the Birch Creek Schist unit. The coal-bearing sequence has been warped into an oval-shaped basin with the major axis trending to the northwest (Wahrhaftig and Hickcox, 1955). Dips in the Tertiary sequence are as high as 30° but average between 5° and 10°. The coal occurs in beds to 3 meters (10 feet) thick, however, seams less than 2 meters (5 feet) thick predominate. Reserve estimates, based on surface exposures and drilling data obtained from a U. S. Bureau of Mines drilling program, indicate that there may be as much as 25,000 tons of measured reserves with a stripping ratio of 3 to 1; as much as 50,000 tons of indicated reserves with a stripping ratio of 3.5 to 1; and inferred reserves of 300,000 tons of coal with a stripping ratio of 4 to 1. Exploration of the basin continues to date, however, the results of the exploration are not known.

South of Jarvis Creek, near the Rapids Road House, Gunnysack Creek has cut a deep gorge through the Birch Creek Schist country-rock. About 0.8 kilometers (1/2 mile) above the mouth of Gunnysack Creek, a large quartz vein cuts the schist and strikes S33°W and dips about 70°NW (Capps, 1912). The vein is irregular and branching and as much as 6 meters (20 feet) thick. The vein material is vuggy bull quartz that is heavily iron-stained locally. A 9 meter (30 foot) long tunnel along the footwall of the vein revealed a stockwork of quartz stringers and several initially high gold assays were reported, however, later tests indicated only non-economic gold values.

South of the Denali Fault, and on the south margin of Canwell Glacier, some interesting nickel-copper deposits are present. The nickel-copper mineralization is associated with altered serpentinite bodies with complex structural and contact relationships with gneissose granitic rocks, phyllite, calc-phyllite and volcanic rocks of the Rainbow Mountain Sequence (Forbes, unpublished data). At one locality, small bodies of sulfide-bearing dike-rock containing pyrrhotite(?) and chalcopyrite are present. The dike appears to parallel the contact between the gneissic granite and granite of the area. Polished section examination of the rocks revealed that the pyrrhotite(?) may in fact be pentlandite. Residual soils near the nickel-bearing zones contain garnierite, a common weathering product in nickel-bearing rocks.

The Emmerick prospect, about 2.4 kilometers (1.5 miles) east of the Richardson Highway, consists of nine nickel-bearing lenses. The massive lenses range from 10 to 60 centimeters (4 to 24 inches) thick; and one lense 2.5 meters (8 feet) wide consists of basic igneous rock with sulfides disseminated throughout. The narrower lenses are mainly massive sulfides consisting of pyrrhotite-pentlandite, chalcopyrite and pyrite. Assays of the mineralized rock range between .38% and 14.02% nickel, and up to 1.46% copper (Saunders, 1961). The assay values are somewhat sporadic, and the nickel-bearing lenses are small. However, the occurrence of nickel and copper mineralization in the region is significant and deserves further investigation. The potential for finding other nickel and copper deposits in the area seems high.

West of the Delta River near the toe of Maclaren Glacier, Thomas E. Slick of Fairbanks, has staked 16 unpatented claims on a mineral show, known as the Kathleen-Margaret (K-M) prospect. The prospect is located along the west side of the Maclaren Glacier at an elevation of 1,300 meters (4,000 feet). The principal rock types in the area consist of greenstones, limestone, diorite, and a dacite porphyry dike. The mineral occurrence consists of a mineralized quartz vein in limestone. The vein is as much as 6 meters (20 feet) wide and can be traced for 80 meters (260 feet) vertically. The primary ore mineral is bornite and minor pyrite occurs locally. Ore reserves in the quartz vein may be as high as 6,500 tons of ore averaging about 5% copper and about 0.06 ounce per ton gold (C. F. Herbert, 1962). No other deposits of this type are known in the immediate area, however the probability of finding other mineralized zones in the Maclaren River area and to the east in the Amphitheatre terrane seems high. Several mineralized zones west of the Maclaren Glacier on the West Fork of the Maclaren River are similar to the K-M occurrence and may be genetically related.

East of the Maclaren Glacier a variety of mineral occurrences are present. Rose (1966) describes several mineralized zones in the Broxson Gulch area, none of which appear to be significant finds. One occurrence of chrysotile asbestos veinlets in a serpentinized peridotite intrusive near Broxson Gulch does not appear to be significant, however the occurrence does suggest that other asbestos deposits may occur associated with the ultramafic bodies in the central Alaska Range, south of the Denali Fault. Several nickel-copper deposits in the Eureka Creek area are associated with Tertiary(?) ultramafic bodies. One locality near the head of Rainy Creek consists of disseminated chalcopyrite in a light-colored gabbro porphyry (Stout, 1976). This deposit, like several others in the area, seems to be associated with the ultramafic belt and also with low-angle faulting (Stout, 1976).

There are a variety of mineral occurrences in the Rainbow Mountain area. Vein deposits containing chalcopyrite, galena, pyrite and gold and silver values were found at many localities on Rainbow Mountain by Hanson (1963). The veins generally trend to the northwest and dip at a near vertical angle. Hanson (1963) believes that the quartz veins north of the Rainbow Mountain fault are related to the thrust fault set in the area and may ultimately prove to have been the avenues for mineralizing fluids. Brecciated carbonate veins are also known in the area.

Forbes and Regan (1963, unpublished) describe the occurrence of several different types of mineralized zones in the region. One type consists of mineralized conglomerate. The conglomerate contains disseminated pyrite and chalcopyrite and some gold values. Another type of mineralization in the area consists of disseminated sulfide mineralization in a silicified granodiorite. No significant deposits of this type are known, however the occurrence indicates a relatively high probability of finding other mineralized intrusives in the area.

A body of dunite crops out north of Rainbow Mountain near the Canwell Glacier. The dunite contains crysotile asbestos veinlets and traces of chromites. No commercial deposits have been found (Hanson, 1963).

South of Rainbow Mountain on Phelan Creek a Tertiary coal-bearing sequence contains coal beds up to 76 centimenters (30 inches) thick. The coal occurs interbedded with sandy shales and soft clays. The coal is generally lignite in grade and has been correlated with other Tertiary coal-bearing sequences of the southern Alaska Range. The occurrence of coal at Phelan Creek does not appear to be economic.

Rocks of the Amphitheatre Group of Triassic age crop out in an east-southeast trending belt, that extends from the Susitna River eastward to at least the Gakona River. The Amphitheatre basalts and other metavolcanic rocks of the region contain low-grade copper mineralization at many localities. According to Rose and Saunders (1965) about a dozen occurrences of copper minerals are found on Paxson Mountain and several other occurrences southwest of Paxson Lake are known. The copper occurrences on Paxson Mountain are generally restricted to fracture veins and mineralized breccia zones in the basalts of the Amphitheatre Group. The copper minerals found in the veins and breccias are mainly chalcopyrite, bornite, chalcocite and chrysocolla as well as malachite and azurite. Locally, vesicles in the basalt contain sulfide minerals, however this type of mineralization is of low grade and generally restricted in occurrence. A mineralized zone that occurs about 11 kilometers (7 miles) west of Paxson on the Denali Highway, is generally restricted to veins and pods of quartz less than 2.5 centimeters (1 inch) wide that cut unmineralized metabasalt. One grab sample from the quartz veins contained visible chalcopyrite, bornite and chalcocite, and ran about 1.38% copper (Rose and Saunders, 1965). The vein material also contained a trace of gold and 0.3 ounce per ton silver. The zone of mineralization is small and discontinuous, however the occurrence does indicate the possibility of finding larger deposits in the region. Recent exploration activity by mineral companies north and east of the Denali Fault has indicated an area that has high potential for base metal sulfide deposits. A number of large claim blocks have been staked in the region. The mineral exploration seems to be centered in Paleozoic metamorphic rocks between Dry Tok Creek and the West Fork River. About 160 kilometers (100 miles) west of this area, near Wood River, mineral exploration activity has outlined an area that contains metamorphosed volcanogenic massive sulfide deposits. The rocks in the Mt. Hayes quadrangle that are currently of interest are probably the eastern extension of the Wood River belt and may contain similar mineralization.

In summary, the Mount Hayes quadrangle has been the site of intensive prospecting since the early 1900's. The region contains a wide variety of mineral deposits and a diverse suite of rocks, that are favorable targets for future mineral exploration. The probability of finding unknown ore deposits in the region seems high.

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Big Delta Quadrangle

Previous Investigations

The rocks in the Big Delta quadrangle have been the subject of geologic investigations since 1898, when A. H. Brooks of the U. S. Geological Survey travelled down the Tanana River. In 1903, the U. S. Geological Survey, Alaska Mineral Resource Division was established and a systematic study of the geology of the Yukon-Tanana region began. J. B. Mertie of the U. S. Geological Survey initiated his work in the region in 1911. His work culminated in the publication of U. S. Geological Survey Bulletin 872, "The Yukon-Tanana Region, Alaska." Several other workers, including Prindle (1913), Chapin (1914) and Mertie (1913-1937) produced papers describing mining activities and geology of the region. Recent work in the Big Delta quadrangle is generally restricted to work by the U.S. Geological Survey as part of their AMRAP (Alaska Mineral Resource Appraisal Program) program.

Work by R.D. Reger and T.K. Bundtzen (1977) of the Alaska Division of GEological and Geophysical Surveys in the Tenderfoot Creek area has shown that the localization of gold-bearing porphyry bodies of the region may be controlled by northwest trending lineaments.

Regional Geology and Petrology

The geology of the rocks in the Big Delta quadrangle is dominated by a PreCambrian or lower Paleozoic metamorphic complex known as the Birch Creek Schist (Mertie, 1937). The Birch Creek Schist, as Mertie described it, consists of a complexly deformed metamorphic sequence containing quartz muscovite schist, quartz mica schist, feldspathic shcist, chlorite schist and minor carbonaceous schist, calcareous schist, and limestone. Recent work by Forbes et al (1968) and Swainbank (1970) has shown that the Birch Creek Schist also contains a wide variety of gneisses, calc-mangesian schist, phyllite, calc phyllite, amphibolite and eclogite. The schists of the region are typically pelitic schist, that appear as light-to medium-gray, garnetiferrous, quartz muscovite and quartz biotite schist that contain quartz, oligoclase, potassium feldspar, garnet, clinozoisite, epidote and muscovite and biotite. Locally, the schists contain actinolitic hornblende and staurolite. The metamorphic grade of the schists ranges from the lower greenschist facies to the almandine amphibolite faces. Retrograded metamorphic rocks are common throughout the Yukon-Tanana Uplands. Rocks in the eastern part of the quadrangle, are generally higher grade metamorphic rocks than those to the west. Quartz, biotite gneiss and augen gneiss are common. The quartz biotite gneiss is characteristically, medium-grained, light-gray to medium-light-gray, very quartzitic, porphyroblastic gneiss and orthogneiss. Dark greenish-gray hornblende gneiss commonly borders augen gneiss. Locally, where the gneiss is pyroxene hornfels facies grade it contains sillimanite, cordierite and diopside. Heteroblastic augen gneiss and biotite gneiss is commonly found throughout the region. The augen gneiss is generally medium light-gray, medium-to coarse-grained gneiss with potassium feldspar augens to 10 centimeters (4 inches) in diameter. Petrographically, the augen gneiss is composed of quartz, orthoclase, albite, muscovite and biotite with accessory apatite, zircon, garnet and magnetite. Retrograde minerals include sericite, chlorite, calcite and iron oxides.

Plutonic rocks in the Big Delta quadrangle range from granite to diorite in composition. Quartz monzonite is the most common plutonic rock found and several distinct varieties have been recognized. One variety is light-gray, coarse grained porphyritic, biotite quartz monzonite, with large potassium feldspar phenocrysts. Other varieties contain small feldspar phenocrysts and traces of secondary hornblende. Locally, light-gray, medium-grained quartz monzonite containing sericite and perthite is present. Diorite intrusives, characteristically a medium-gray to medium dark-gray, fine-to medium-grained, hornblende diorite containing abundant red-brown biotite occur locally. Fine-to coarse-grained, greenish-black and light greenish-gray, serpentized peridotite, crops out near the upper Salcha River. The peridotite contains serpentine, talc, actinocite, chlorite, brucite and magnetite. Locally, massive amphibole-chlorite-magnetite rocks are present. Florence Weber, (personal communication, 1978), of the U. S. Geological Survey, believes that the ultramafic rocks may represent remnants of thrust sheets that were rafted from the south some time in the upper Paleozoic. Recent work by the U. S. Geological Survey in the upper Salcha River area has shown that the ultramafic bodies are intimately related with cherts that yield a Permian age from radiolarians.

Structural Geology

The structural geology of the rocks in the Big Delta quadrangle is dominated by thrust faults, strike-slip faults, normal faults, isoclinal overturned folding and open, upright folds. Rocks of the Birch Creek Schist unit have been affected by at least two pulses of metamorphism. The first pulse is associated with a complete recrystallization of the parent rock. The recrystallization is associated with isoclinal overturned folds about northwest-trending axes, and high-grade metamorphic minerals, including sillimanite and staurolite, are developed locally. The second metamorphic pulse mainly a retograde event, is associated with open, upright folds about northeast-trending axes, and is usually signaled by the presence of sericite, chlorite and calcite. Near the east-central part of the quadrangle, gneissic rocks are present in what may be a gneiss dome. The gneiss dome is composed of quartz-biotite gneiss and is surrounded by a border zone of sillimanite gneiss and amphibolite (F. Weber, U. S. Geological Survey, Personnal Comm., 1978). Several large northeast-trending, left-lateral faults cut the rocks in the central part of the quadrangle. One such fault that parallels the valley of Shaw Creek is known as the Shaw Creek Fault. Supporting evidence for a 40 kilometer (25 mile), left-lateral off-set on the Shaw Creek Fault, rests on an off-set hornblende quartz monzonite pluton and on an off-set sillimanite gneiss body (F. Weber, Personnal Comm., 1978). Several other large faults cut the rocks of the quadrangle, however, they are less perfectly known.

Geochemistry

Geochemical reconnaissance in the Big Delta quadrangle during the current study consisted of the collection of 7 rock samples and 14 stream sediment samples (see Tables 12 and 13, Appendix A) between Big Delta and Shaw Creek. The bedrock in the region is dominated by gneisses of various compositions and calcic amphibolites, all of the Birch Creek Schist Formation. Statistical analysis of the trace element geochemistry of the rock and stream sediment samples collected has shown that 43% of the rock samples contain strongly anomalous concentrations of at least one element, and 36% of the stream sediment samples contain weakly anomalous and strongly anomalous concentrations of at least one element. Threshold values (see Tables 14 and 15, Appendix A) for the 90%, 95% and 98% confidence intervals for each element were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation, for the 90% 95% and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are either the detection level or nearly the same value.

None of the rock samples collected in the quadrangle contain metal concentrations of significance, however recent work by the U.S. Geological Survey may show that rocks in the region have good mineral resource potential and may contain metal concentrations of unknown size and distribution. One stream sediment sample collected near Gold Run Creek contained 320 ppm lead. No bedrock source for the high lead value was found and further work is needed.

Mining Activity and Economic Geology

Mining in the Big Delta quadrangle has been limited to several placer deposits in the Tenderfoot Creek, Michigan Creek, and Salcha River areas and to several hardrock gold-quartz veins near Tibbs Creek. Mining in the Richardson district has been underway since gold was discovered on Tenderfoot Creek in 1905. Deep placers were also found on Banner Creek, Democrat Creek and Buckeye Creek soon after the initial find on Tenderfoot Creek. Total production for the Richardson district by the end of 1930, totaled more than $1,329,900

(Saunders, 1965). Only a few small operations are active in the Richardson district today. The source of the gold in the placers may be gold-quartz veins that cut the schist-gneiss country rock. Locally, rhyolite porphyry of probable Tertiary age, cut the gneissic rocks and contain anomalous gold concentrations. Recent work by the Alaska Division of Geological and Geophysical Survey has shown that the rhyolite porphyry may, upon weathering, result in residual gold placer deposits (Bundtzen and Reger, 1977). Several rhyolite porphyry occurrences are known in the southeastern part of the quadrangle, however, only minor disseminated sulfides are known. Several gold quartz veins are known in the Tibb's Creek area and minor production has occurred. The Tibb's Creek occurrences are active and some placer mining has occurred downstream from the rhyolite porphyry outcrops.

Near the head of Black Bear Gulch, a tributary of the North Fork of the Salcha River, a limestone bed containing nickel concentrations as high as .28% can be traced for almost eight miles. The bedrock in the area is dominantly quartz-muscovite schist, quartz biotite gneiss and ultramafic rocks of the Big Salcha ultramafic body. The limestone is overlain to the south by ultramafic rocks and contains secondary nickel mineralization. The secondary nickel minerals may be the result of leaching of nickel from the overlying ultramafic rocks and redeposition in the limestone, or the result of weathering of primary nickel sulfides in the limestone (Saunders, 1954). Florence Weber of the U. S. Geological Survey feels that the secondary mineralization may have resulted from leaching of the ultramafic body and redeposition by some sort of spring system within the ultramafic-limestone sequence.

In the early 1930's, gold-bearing quartz veins were discovered in the Tibbs Creek area. The area was subsequently staked and by 1941, about 400 meters (1,300 feet) of underground work had been done. The gold-bearing quartz veins are concentrated in a zone of intense shearing along the contact between granite and gneissic schist. The quartz veins vary from a few centimeters to 2 meters (few inches to eight feet) wide and consist of quartz, pyrite, arsenopyrite and stibnite. Work by the U. S. Bureau of Mines has shown that the gold content in the vein material decreases appreciably with an increase in the sulfide content. Premineral and post-mineral faulting is evidenced in the area and cross-faults displace the veins a few centimeters to a meter (inches to several feet) locally. Total production from the Blue Lead was about 132 ounces of gold and 25 ounces of silver. The vein material averages about 0.88 ounces of gold per ton. The potential for finding other mineralized veins in the area seems high.

Recent work by the U. S. Geological Survey and by the Alaska Division of Geological and Geophysical Surveys, has shown that rocks along the north-flank of the Alaska Range may be correlateable with similar rocks in the Big Delta quadrangle (Wyatt Gilbert, ADGGS, personal comm., 1977). The Totatlanika Schist and Keevy Peak Formations in the Alaska Range are the host for significant mineralization of volcanogenic lead and zinc affinities. If the rocks in the Big Delta quadrangle are equivalent to the rocks on the north-flank, there may be good potential for finding similar mineralization in the Big Delta quadrangle.

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Fairbanks Quadrangle

Previous Investigations

The Yukon-Tanana region has been the site of extensive geologic investigations since J. E. Spurr (1897) traversed Chilkoot Pass into the headwaters of the Yukon River and then travelled down the Yukon to Nulato. In 1898, A. H. Brooks, ascended the White River to its headwaters, portaged to the Tanana River and then travelled down the Tanana River to its mouth. With the establishment of the Division of Alaskan Mineral Resources by the U. S. Geological Survey in 1903, a systematic study of the geology and mineral resources of the Yukon-Tanana region began. The inital investigations of the Fairbanks district began in 1903, under the direction of Alfred H. Brooks. L. M. Prindle (1913) and others with the U. S. Geological Survey, conducted some detailed work, however, most of their work was of a regional nature. In 1911, J. B. Mertie, began intensive geologic investigations of the Yukon-Tanana Region that continued through 1936 and culminated in the publication of U. S. Geological Survey Bulletin 872, The Yukon-Tanana Region, Alaska. This work summarized all of the known geology of the region and is still the single best publication on the geology of the Yukon-Tanana Uplands area.

During the interim, Prindle (1913), Chapin (1914) and Mertie (1913-1930) produced several papers describing the lode deposits and mining activity in the Fairbanks district. The most comprehensive study of the lode deposits in the Fairbanks district was produced by J. M. Hill (1933). This study includes a brief description of the local geology and detailed descriptions of the various mining properties as well as comments on the general economic conditions affecting the mining operations. Work by Sandvik (1964) discussed the distribution of ore deposits and metals in central Alaska. Detailed geologic investigations by R. B. Forbes and J. M. Brown (1961) and J. M. Brown (1962) centered in the Cleary Summit area, and was the first real definitive work that further clarified the outcrop pattern, structure, and petrography of the calc-magnesian rocks and the surrounding pelitic schists of the area. Later work by Forbes et al (1968) in the Pedro Dome - Cleary Summit area, examined the gold-gradients in relation to the intrusive bodies and surrounding metamorphic rocks. A companion project by Pilkington et al (1969) resulted in a detailed examination of the gold mineralization in the same area.

Work by R. C. Swainbank (1971) and R. C. Swainbank and R. B. Forbes (1975) on the eclogitic rocks from the Fairbanks district has resulted in a better understanding of the tectonic framework and origin of many of the metamorphic rocks found in the area. Work by J. M. Britton (1970) has resulted in a detailed study of the rocks that constitute the Pedro Dome pluton. Work by G. A. Furst (1968) described the olivine basalts that occur in the Fairbanks area. Recent work by T. Pewe et al (1975 and 1976) on the geology of the Fairbanks area has resulted in a series of reconnaissance geologic maps for the area.

Regional Geology and Petrology

The rocks that crop out in the Fairbanks quadrangle dominate the geology of the Yukon-Tanana Uplands area. The rocks range from PreCambrian(?) to Recent in age and are represented by sedimentary, metasedimentary, plutonic, volcanic and metavolcanic rocks. The intrusive rocks are generally of two types; Paleozoic(?) ultrabasics and acid intrusives of Jura-Cretaceous and Cretaceous age. The volcanic rocks are mainly olivine basalt of Middle Tertiary(?) age. The metasedimentary rocks are metasiltstones, phyllites, eclogite, marble, quartzite, calc-magnesian schist and pelitic schist. The metavolcanic rocks may be represented by amphibolite, quartz feldspathic schist and greenstone.

The Birch Creek Formation was first described by Spurr (1896). The type locality for the Birch Creek "Schist" is located near the headwaters of Birch Creek, northeast of Fairbanks. At it's type locality, the unit is composed of quartz muscovite schist, quartz mica schist, mica schist, feldspathic schist, chlorite schist and a minor proportion of carbonaceous schist, calcareous schist, and crystalline limestone (Mertie, 1937).

Recent work by Swainbank (1971) and others has shown that the Yukon-Tanana Uplands in general and the Birch Creek schist in particular contains a wide variety of gneisses, calc-magnesian schist, phyllite, amphibolite and eclogite.

Rocks in the Fairbanks district proper that are members of the Birch Creek Schist crystalline terrane have been divided into at least two sequences that may be in thrust(?) contact (Forbes et al, 1968). The lower and older sequence, exposed in what may be a structural window, are mainly eclogites, garnet amphibolites and calc-magnesian rocks containing clinopyroxenes and amphiboles. The upper sequence is composed of younger(?) pelitic schist, crystalline schist, micaceous quartzite, quartzite and calc-magnesian schist.

The pelitic schists are typically garnetiferous quartz muscovite and biotite schists that show signs of at least two phases of metamorphism and possibly a third retrograde event.- Two phases of muscovite are present in the pelitic schists. The first phase consists of euhedral grains parallel to the primary S_1 plane and a second (later) phase that defines an S_2 plane that transects the earlier S_1 foliation. The S_2 foliation also contains subhedral, faintly pleochroic biotite laths (Brown, 1961). Locally, the pelitic schists contain deeply absorptive biotite rosettes and may represent late hornfelsing of the schists (Swainbank, 1971). Tourmaline is a common accessory mineral along with rutile, apatite and sphene. The quartz fabric of these rocks is dominantly granoblastic and may contain untwinned plagioclase porphyroblasts of albite-oligoclase composition. The presence of faintly pleochroic chlorite (pennine) usually signals retrograded rocks. The quartzites and micaceous quartzites of the area are present in both the upper and lower plate(?) sequences, however, it is the dominant unit in the upper plate sequence. These rocks are predominantly fine-to medium-grained quartzites with variable contents of quartz, muscovite, biotite, garnet, and chlorite. Accessory apatite, magnetite and zircon are common. The growth of chlorite (pennine) in the upper plate(?) sequence appears to be related to stable mineral development during the metamophic process, however, the growth of chlorite in the quartzites and micaceous quartzites of the lower plate(?) sequence appear to be in response to a retrograde event.

The calc-magnesian rocks of the Fairbanks district, generally occupy the lower plate sequence and have been broken into three calc-magnesian variants by Swainbank and Forbes (1975). One variant, a garnet-clinopyroxene rock, essentailly an eclogite varies from massive types to mylonitic bands and contain pale-pink garnets that exhibit reaction rims of blue-green amphibole. Omphacitic pyroxene is the dominant clinopyroxene and albitic plagioclase usually occurs in untwinned grains and is only found in the mylonitic varieties and is usually associated with garnet, clinopyroxene and chlorite. Quartz generally occurs in granoblastic aggregates and calcite occurs as an essential phase along with clinopyroxene and garnet (Swainbank and Forbes, 1975). Accessory apatite and sphene are also present. Calc-magnesium rocks composed predominantly of garnet, clinopyroxene and amphibole make up the second variant. This variety usually occurs in fine laminations, although massive varieties are common. The clinopyroxene is usually light-green and the amphibole may be a highly absorptive variety of hornblende. Plagioclase tends to be more calcic in these calc-mangesian rocks and generally ranges from albite to oligoclase in composition. Muscovite, when present, marks at least two pulses of metamorphism, one represented by an earlier synkinematic fabric and the other by transecting shear planes. Calcite tends to be more abundant than quartz and clinozoisite is a common mineral constituent. Accessory tourmaline, orthite and graphite are also present. Rocks of the third group are generally composed of garnet and amphibole and occur with massive fabrics and varieties that have only incipient foliation. Garnet porphyroblasts up to 8 millimeters (.3 inches) in diameter are common and exhibit euhedral overgrowths on subpoikiloblastic cores (Swainbank and Forbes, 1975). Muscovite and biotite are present in a primary synkinematic fabric and late muscovite marks a discordant S_2 plane. Clinozoisite seems to be restricted to certain compositional layers and sphene, rutile, and apatite are common accessories.

The calc-magnesian schists of the upper plate(?) sequence occur in thin, conformable layers or lenses and are relatively rare within the sequence. The upper plate sequence also contains greenschists, epidote amphibolites, calc-mica schists and impure marbles.

The intrusive rocks of the Fairbanks district for the most part range from quartz diorite to granodiorite in composition. The largest pluton in the area extends from Pedro Dome west-southwest approximately 4.8 kilometers (3 miles) to the head of Moose Creek No. 2. Several small intrusives of the same general composition are known in the district. The plutons are elongate in outcrop pattern and the direction of elongation is generally parallel to the structural fabric of the area (Britton, 1969). The plutons are predominantly fine-to medium-grained hypidiomorphic-granular quartz diorite and grandiorite although allotriomorphic-granular textures are known. Petrographically, the rocks are composed of up to 45% plagioclase feldspar (An86 to An30) in subhedral to euhedral grains, 10 to 20% subhedral biotite and 8 to 12% pyroxene, that includes major augite and trace hyperthene in subhedral grains that often have reaction rims of hornblende. Accessory magnetite, apatite, zircon and pistacitic epidote are common. Quartz monzonite stocks and dikes are common in the Pedro Dome area. The dikes and stocks cut the quartz diorite and granodiorite locally. The quartz monzonite is composed of phenocrystal to glomeroporphyritic quartz, potassium feldspar and plagioclase. Petrographically, the quartz monzonite consists of up to 36% plagioclase (An_{47} to An_{23}), up to 38% quartz with accessory hornblende, magnetite, apatite, sphene, and zircon. Epidote, clinozoisite and calcite may also be present due to alteration. Locally, intrusive rocks in the Pedro Dome - Cleary Summit area have been highly altered. At several localities, the feldspars have been totally altered to clays and accessory magnetite has been altered to ferrugenous material. North of Pedro Dome, the rocks are intensely altered and combined sodium and potassium contents as high as 13% have been detected.

At several locations in the Fairbanks area, Tertiary volcanic rocks are present. The volcanics are chiefly basaltic in composition. Furst (1968) found that the Fairbanks basalts are transitional between tholeiitic and alkali basalts. The basalts occur as flows and breccias and are characterized by pillows, pillow breccias and columnar basalts. The pillows were believed to have formed during the extrusion of the basalt in a subaqueous environment. Petrographically, the basalts are composed of 9 to 15% olivine, 20 to 49% plagioclase feldspar (An_{50} to An_{63}), 5 to 20% titaniferous augite, 17 to 20% glass and up to 5% magnetite.

Rocks near the head of Big ElDorado Creek in the pipeline trench are composed of pelitic schist, quartzite, micaceous quartzite and minor phyllite. Locally, the metamorphic rocks are highly sheared and shattered. The rocks are deeply weathered and heavily ironstained where shear zones and faults are present. The ironstaining is probably related to local mineralization, however, only minor sulfide mineralization was found during this investigation. The area is spatially related to the highly mineralized zone near Pedro Dome, to the northeast, and does contain known mineral occurrences. Between Big El Dorado Creek and Goldstream Creek, the rocks are highly variable in nature. The dominant rock type in the area is a chlorite-bearing, garnetiferous, quartz mica schist. Minor interlaminations of calc-magnesian rocks, including: garnet amphibolites, impure marbles, and eclogites, are present. The metamorphic sequence is cut by quartz diorite and quartz monzonite dikes that are highly altered and are probably genetically related to the Pedro Dome quartz diorite stock. The faults and shear zones of the area generally parallel the major fold axes, although discordant fracture systems are known. Superimposed fold axis demonstrate the polymetamorphic nature of the metamorphic rocks in the region.

The rocks present between Goldstream Creek and the head of Engineer Creek, are for the most part pelitic schist and quartzite. At one locality, opposite the confluence of Little Blanch and Engineer Creeks, a highly sericitized intrusive rock is present. The quartz monzonite(?) is altered and is now a rock that is composed of clay minerals and muscovite and contains pyrite cubes to 10 millimeters (0.4 inches) across. Locally, the clay-muscovite rock contains large, up to 10 millimeters (0.4 inches), arsenopyrite grains that may be crystals. Anomalous metal concentrations were found in these rocks. A roadcut on Hill 1558, northeast of Engineer Creek locality, contains similar rocks, but with small blebs of pyrite.

Near the head of Engineer Creek and to the east, the bedrock is composed of a monotanous sequence of interlaminated quartz-muscovite schist and micaceous quartzite. The schist is characteristically a fine-to medium-grained, garnetiferous quartz muscovite schist. The quartzite layers are generally finely laminated to massive, however, unfoliated beds up to 0.5 meters (1.6 feet) thick of fine-grained micaceous quartzite are known.

Structural Geology

Rocks of the Fairbanks district have been affected by at least two major deformational events. The first metamorphic event is associated with a complete recrystallization of the parent rock and with the development of high-grade metamorphic minerals, while a later phase of metamorphism, appears to have been mainly a retrograde event. The early recrystallization is associated with west northwest-trending folds, while the later phase is associated with folding about northeast-trending axes. Fold styles associated with the early recrystallization appear to be isoclinal and overturned to the northeast. Some folds are recumbent and arcuate (Swainbank and Forbes, 1975). The northwest-trending folds appear to be overturned and (or) recumbent, with axial planes usually dipping south. The degree and direction of overturning is variable and related to the superimposed northeast-trending structures (Swainbank and Forbes, 1975). A major structure in the northwestern part of the quadrangle that appears to have a close genetic relationship with the gold mineralization in the Cleary Summit - Pedro Dome Area was first recognized by Prindle (1913). The Cleary Anticline is a northeast-trending, arcuate, asymmetrical structure that is slightly overturned to the northwest. Fracturing along the axial trace of the anticlinal structure seems to have localized and controlled the emplacement of quartz vein systems.

Swainbank and Forbes (1975) believe that the quartz schist, micaceous quartzite, pelitic schist terrane of the Fairbanks area is in thrust(?) contact with the underlying and older eclogite-bearing terrane. The structural style present in the rocks of the lower sequence is isoclinal recumbent folding about north to northwest-trending axes. Later folding has superimposed open folds, about northeast-trending axes, on the earlier isoclinal to recumbent structures. Microstructures in the rocks of the eclogite-bearing terrane also reflect the polymetamorphic history.

Geochemistry

Geochemical reconnaissance in the Fairbanks quadrangle during the current study consisted of the collection of 40 rock samples (see Table 16, Appendix A) from the inner pipeline corridor by M.I.R.L. personnel and U.S. Bureau of Mines personnel during the 1976 field season. Statistical analysis of the geochemical data has shown that 30% of the rock samples collected contain weakly anomalous, anomalous and strongly anomalous concentrations of at least one element. Threshold values (see Table 17, Appendix A) for the 90%, 95% and 98% confidence intervals for each element were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation for the 90%, 95% and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are either the detection level or nearly the same value.

Samples of altered schist and quartzite, collected just north of Silver Gulch, near Goldstream Creek, contain strongly anomalous concentrations of silver, tin, phosphorous and sodium, that may be related to numerous quartz veins that cut the schist-quartzite countryrock. Samples of schist and quartzite collected near Murphy Dome Road contain anomalous and strongly anomalous molybdenum, zinc and chrome and nickel values. The rocks are highly altered and cut by many quartz veinlets. East of the Murphy Dome locality, at the Silver Fox Mine, a stockwork of thin quartz veins cut quartz diorite of the Pedro Dome intrusive. The quartz veins contain some disseminated molybdenite. The Silver Fox Mine locality also contains lead-silver-zinc mineralization in shear and gash zones near the contact between the schist-quartzite country rock and the Pedro Dome stock. The anomalous molybdenum and zinc values at the Murphy Dome locality may indicate the presence of Silver Fox type mineralizaton in the area.

Southeast of Goldstream Creek near the head of Engineer Creek, samples of highly altered rocks, that appears to be a sericitized quartz monzonite contains anomalous concentrations of tungsten, arsenic, zinc and lead.

Mining Activity and Economic Geology

The first actual gold discoveries in the Fairbanks quadrangle took place in the early 1870's when gold was found on the Tanana River. The first deposits exploited in the region were found on Faith, Hope and Charity Creeks and were originally located in 1898. The first placers found in the Fairbanks area proper were found by Felix Pedro in 1902 on Pedro Creek about 19 kilometers (12 miles) north of the Fairbanks town site. The stampede that ensued the discoveries resulted in the establishment of the trade center near the confluence of the Chena River and the Tanana River, that subsequently became the town of Fairbanks. Placers of the Fairbanks district have yielded about 7,239,000 ounces of gold up to 1959 (Koschmann and Bergendahl, 1968).

Lode gold production in the Fairbanks district began as early as 1910 and continues to date. The history and production from lode deposits was summarized by Bruce I. Thomas (1973) as follows:

> The 1902 discovery of the rich gold-placer deposits and the subsequent rapid development of placer mining stimulated the search for the bedrock sources of placer gold in the Fairbanks mining district. The first gold quartz claim was made shortly afterward. The gold-bearing quartz veins were not bonanzas, and lode mining developed slowly. The first stamp mill was built in 1909, and the first lode gold was produced in 1910. In 1913, six mills were operating, and more than 12,000 tons of gold ore was milled. Gold mining declined during World War I, and from 1915 to 1923, the mining of lode-gold deposits continued at less than 2,000 tons per year. Completion of the Alaska Railroad in 1923 provided a direct bulk-freight route from the coast to Fairbanks. Lode mining increased to 5,000 to 6,000 tons per year in the 1930's. The increase in the price of gold from $20.67 to $35.00 per fine troy ounce in 1934 resulted in an annual production of over 11,500 fine troy ounces by the late 1930's. During this period, production of lode gold exceeded the gross production from all placer mines in the district except that of dredges. In 1942, the production of lode gold was stopped by executive order that closed gold mines. After World War II, attempts were made to resume operations at some of the

> mines, but in most cases, increased costs made mining unprofitable. At various times during the past several years, one and sometimes two lode mines have operated for short periods, but at no time at a scale comparable with that prior to 1942.
>
> The total production from lode-gold deposits in the district is about 241,000 fine troy ounces from ore that averaged about 1.32 fine ounces per ton. The most productive sources of lode gold are veins a few inches to 3 feet wide. Although there have been as many as 10 to 12 mines operating in the district at one time, the largest single mine produced about 40 tons of ore per 24-hour day.

The general character of the gold lodes, after Hill, (1933) consist of fissure veins, that cut various types of schists, and usually in close proximity to intrusives of silicic-to intermediate composition. Veins ranging from 5 centimeters to a meter (2 inches to 3 feet) wide have been the most productive. However, zones of closely spaced quartz veinlets have been found and were rich enough to be mined over widths of 2 to 4 meters (8 to 12 feet). At several localities, namely the Ryan lode on Ester Dome, and at the Zimmerman lode, silicified schist over widths of 12 to 23 meters (40 feet to 75 feet) have been found and exploited to some degree.

The principal veins in the Pedro Dome - Cleary Summit area strike between N60°W and due west and dip between 45° and 80° south. A few of the veins strike N25°E to N45°E and dip 70° to 75° north west. Hill (1933) recognized at least four phases of silica (quartz) deposition in the region. The earliest episode introduced coarsely crystalline white quartz that is barren of metallic minerals. This quartz was later brecciated and crushed by faulting along the veins. Next, a fine-grained quartz was introduced and was accompanied by some free gold and pyrite. Continued faulting and fracturing along the vein systems resulted in more brecciation and was accompanied by fine-grained quartz and sulfides with free gold. The final pulse according to Hill (1933) was a reactivation of the faulting and the introduction of barren quartz. Sandvik (1967) also recognized four pulses of mineralization in the Pedro Dome - Cleary Summit area. The first phase was characterized by the emplacement of barren quartz veins, the second by the emplacement of quartz veins containing arsenopyrite, pyrite and gold, the third and most productive (Forbes et al, 1968) pulse of mineralization consisted of quartz-stibnite-gold ± arsenopyrite and antimony sulfosalt veins. The fourth and final phase of mineralization consists of quartz-stibnite veins with little or no gold.

The phase three veins of Sandvik (1967) have been further subdivided into three distinct mineral assemblages (Forbes et al, 1968). The most typical assemblage contains jamesonite, stibnite and gold and is characterized by the Kowalita vein near the Keystone Mines property, east of Cleary Summit. The next most important assemblage contains quartz, jamesonite, freibergite, galena and stibnite and contain significant gold values. This assemblage is characteristic of the vein at the Keystone property. The third assemblage consists of galena, sphalerite, tetrahedrite, pyrite quartz veins with subordinate gold values. This assemblage is restricted to fissure veins that cut the Pedro Dome quartz diorite stock at the Silver Fox Mine. Active mining of the gold-quartz lodes and lead-silver veins in the Pedro Dome - Cleary Summit area continues to date. The potential for finding undiscovered veins in the region seems high. Some of the previously uneconomic vein deposits may become mineable with improved mining methods and an increase in the price of gold and silver.

Several small tungsten deposits near Gilmore Dome, north of Fairbanks have produced in the past and one deposit on Gilmore Dome is being mined. The tungsten deposits are localized in limy layers within the Birch Creek Schist. The deposits near Gilmore Dome are located near the contact with the Gilmore Dome quartz diorite stock. The intrusion of the quartz diorite stock in the Cretaceous has altered the country rock and has produced calcite-epidote skarns and calcite-diopside skarns that are closely associated with the tungsten mineralization.

In summary, the Fairbanks district has produced in excess of 7,000,000 ounces of placer gold and over 200,000 ounces of gold from hard rock deposits. The potential for finding unknown gold and silver deposits and deposits of tungsten in the Fairbanks district seems high.

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Livengood Quadrangle

Previous Investigations

The Livengood quadrangle has been the site of extensive geological investigations since about 1899, when Alfred H. Brooks and others of the U. S. Geological Survey traversed the area. Much of the early literature on the quadrangle describes the mineral resources and mining activities that were in progress within the Yukon-Tanana region. Recent work in the quadrangle by Chapman and others (1971), has resulted in a regional geologic map and basic resource information. Work by Forbes et al (1968) and Pilkington et al (1969) on the gold mineralization near Cleary Summit, north of Fairbanks, has added much to the understanding of these gold deposits and to the basic geologic framework of the area. Recent work by Weber, Churkin, and Chapman, (in press) has added new information and resulted in the reassignment of the age of some Paleozoic rocks within the quadrangle. Recent geophysical work by Gedney et al (1972) and Packer et al (1975) have added information on seismicity and earthquakes within the area.

Regional Geology and Petrology

Rocks in the Livengood quadrangle have complex structural relationships. Precambrian(?) or lower Paleozoic polymetamorphic schist, phyllite and quartzite sequences are juxtaposed with Mesozoic sedimentary rocks across several large northeast-trending thrust faults and high-angle normal faults near the central part of the quadrangle.

A north trending high-angle normal fault near the Tolovana River marks the boundary between an upthrown eastern block composed dominantly of Mesozoic rocks and a western, downthrown block of dominantly Paleozoic rocks.

Rocks of the Permian Rampart Group crop out northwest of Livengood. This sequence of interbedded tuff, tuff breccia, argillite, minor chert and sedimentary rocks is cut by several northeast trending, high-angle normal faults.

A small graben-like basin between the valleys of Hess and Isom Creeks contains interbedded, coarse-grained chert-pebble conglomerate, lithic sandstone, sandstone and shale believed to be Tertiary in age.

The Rampart Group was first described by Spurr (1898). Later work by Mertie (1937), Brosge et al (1969), and Chapman, Weber and Taber, (1971) has described the Rampart Group at its type locality near Rampart, Alaska. The Rampart Group at its type locality consists mainly of bedded volcanic and sedimentary rocks of Permian age (Brosge et al, 1969). Early workers assigned a Mississippian age to these rocks based on paleontologic data, but recent work has shown these fossils to be Permian. Intrusive rocks found within the volcanic and sedimentary sequences have been dated by K-Ar methods at 205±6 million years B.P. (Brosge et al, 1969), therefore the Rampart Group is at-least Triassic in age.

The Rampart Group as Mertie (1937) described it, consists of basaltic and andesitic flows, basaltic, andesitic and rhyolitic tuffs and tuff breccias and a smaller amount of interbedded chert, shale, argillite and sandstone. The apparent lithologic sequence, at the type locality, consists of; dark greenish-gray lithic tuff and tuff breccia interbedded with siliceous argillite and minor limestone. Overlying the basal tuff unit is a sequence of brown-weathering volcanic breccia containing clasts of argillite and limestone. Next, a sequence of greenish-gray shale, dark-gray chert and interlayered basalt and lithic tuff is present, which is in turn overlain by an altered sequence of chloritic, greenish-gray vitric tuff. A suspected fault separates this lower package of rocks from a somewhat different overlying sequence.

The upper package of rocks consists of a basal unit of medium- to dark-gray, very fine-grained lithic wacke and siltstone, with shaly partings and a few silty concretions. A covered interval obscures the relation between the upper basal sequence and an overlying sequence of andesitic, basaltic and mafic-rich intrusive rocks of Triassic age. Next, a thick sequence of yellow chert and orange-weathering, sheared volcanic breccia is present which is in turn overlain by greenish-gray mottled siltstone and chloritic sandstone, which is interbedded with fine-grained crystalline pyroxene andesite.

Rampart Group rocks present in the pipeline corridor generally consists of interbedded argillite, metasiltstone, fine-grained lithic sandstone, crystal-lithic tuff and tuff breccia of basaltic composition, sill-like and clearly intrusive bodies of hornblende diorite, and basalt, dacite and diabase dikes that cut all of these rocks.

The tuff sequences generally consist of highly altered, crystal-lithic tuff that contain fragments of volcanic and sedimentary rocks, plagioclase laths and augite. The rocks are highly chloritized and at some localities, chlorite makes up as much as 30% of the rock. The volcanic rock fragments generally are rounded and subrounded clasts that contain subhedral plagioclase grains and minor augite, set in a matrix of glass and chlorite.

A typical model composition for the lithic tuff is; 30 to 40% volcanic rock fragments, 15 to 30% chlorite, 5 to 10% quartz, 0 to 20% glass, up to 30% calcite locally, and up to 25% plagioclase that ranges from andesine to labradorite in composition. Minor amounts of hornblende, sericite and sedimentary and metamorphic rock fragments are present. Alteration varies in intensity, but generally the rocks are highly chloritized and much of the plagioclase exhibits signs of sericitization. Locally, the plagioclase laths have been completely altered and pseudomorphs of calcite and chlorite or calcite and sericite after plagioclase are present.

The tuff sequences are commonly well-bedded and where in contact with interbedded sedimentary rock sequences, little or no zone of alteration is present. The contacts between the layers of tuff and tuff breccia and the sedimentary rocks are sharp and little intermixing was observed. However, tuff breccia layers contain fragments and clasts of sedimentary rocks locally. Some flow structures are present and where elongate clasts and mineral grains are present, they tend to allign themselves parallel to bedding.

Sedimentary rocks interbedded with the tuff and tuff breccia layers include shale, siltstone and medium-grained lithic sandstone. Locally, the shale and siltstone are well indurated and resemble argillites and meta-siltstone. The lithic sandstone units contain some sericite and chlorite which probably represents incipient effects of regional metamorphism.

Hypabyssal intrusives occur throughout the Rampart terrane and include sill-like bodies of chloritized hornblende diorite that appear to be in conformable contact with the enclosing tuffs and sedimentary rocks, and probably represent flows and or shallow intrusions. The contact zones between the sill-like intrusive bodies and the tuffs and sediments do not show much hornfelsing, and the contacts are sharp and distinct. The diorites are characteristically fine-to medium-grained, altered, hornblende diorite with an average modal composition of; 25 to 40% plagioclase, 20 to 30% hornblende, 20 to 25% chlorite, generally less than 5% potassium feldspar, minor quartz and accessory calcite, sericite, apatite, sphene, and augite(?). Many of the sill-like bodies have been highly altered with major chloritization and some saussuritization.

The clearly intrusive bodies of hornblende diorite crop out on many of the hill-tops north of Hess Creek. Compositionally, this variety of diorite is similar to that occurring in the sill-like bodies, however, mafic-rich zones of hornblende diorite or gabbro are present locally. Magnetite contents of these rocks may reach as much as 10%. Unlike the first variety of hornblende diorite, the contact zones surrounding the clearly intrusive variety show marked alteration.

North of Hess Creek a sequence of interbedded quartz-chert, volcanic-pebble conglomerate, sandstone, crystal-lithic tuff and tuff breccia crop out. This sequence of rock is believed to be Tertiary in age (Chapman et al, 1971). The lithic tuff and tuff breccias are similar to those that constitute the bulk of the rocks in the Permian Rampart Group. The rocks in the Tertiary sequence are well bedded. The sandstones are commonly fine-to medium-grained, lithic sandstones that contain abundant volcanic and metamorphic rock fragments. Some crossbedding and graded bedding is present within the sedimentary sequences.

Tertiary rocks that crop out about 13 kilometers (8 miles) north of Hess Creek do not contain interbedded tuffs or tuff breccias. This package of rocks contains quartz-chert, volcanic pebble conglomerate, interbedded with medium-to coarse-grained lithic sandstone, very fine-grained, dark-gray shale and siltstone. The coarse-grained sandstone contains abundant carbonaceous material. Thin zones of graphitic material generally less than 0.5 meter (1.5 feet) thick are interbedded with the sandstone and conglomerate sequence. This material, analyzed by Dr. P. D. Rao (Mineral Industry Research Laboratory at the University of Alaska) is graphite, and probably represents upgraded coal.

The conglomerate layers within this sequence of rocks generally consist of rounded to subrounded pebbles of chert, quartz and sandstone and volcanic rock fragments that range up to 4 centimeters (1.6 inches) in diameter set in a matrix of coarse-grained calcareous wacke. Some crossbedding and what appear to be channel structures are present. Elongate pebbles within the conglomerate layers tend to be alligned parallel to bedding. A typical modal composition for the conglomerate is 30% sandstone rock fragments, 15% chert pebbles, 10% volcanic rock fragments, 40% quartz pebbles and 5-10% calcareous wacke matrix.

Interbedded with the lithic conglomerates are coarse-grained, calcareous, quartz-pebble conglomeratic sandstones. These sandstones are composed of angular to subangular grains of quartz and plagioclase as well as sandstone and volcanic rock fragments.

Lower Paleozoic rocks near Livengood consist of a thick sequence of interbedded chert, thin-bedded limestone and thin layers of shale and siltstone. This sequence, the Livengood Chert, was first described by Mertie (1926). and consists predominantly of chert and chert-breccia at its type locality near Livengood. The chert occurs in a great variety of colors ranging from red to gray and green to black. Locally, thin zones of silicified limestone and dolomitic limestone are interbedded with the chert. Fossil evidence collected from shaly interbeds within the unit have shown conflicting evidence as to the age of this unit. Mertie (1937) and R. M. Overbeck of the Geological Survey collected fossils near upper Lost Creek, north of Livengood. These fossils, mostly crinoid stems and bryozoans, yielded an indicated age of Mississippian. Recent work by Chapman and Weber (in press) north of Livengood near Lost Creek, has shown these rocks to be upper(?) Ordovician in age, based on graptolites found in a thin shaley unit within the chert sequence (Florence Weber, U. S. Geological Survey, personal communications, 1977). The rock sequences in which Mertie found his fossils may indeed be Mississippian. This sequence has been reassigned to a new group and is no longer considered to be part of the Livengood Chert unit (Weber, personal communication, 1977).

The rocks themselves are highly variable in nature. At many localities within the Pipeline Corridor, highly fractured sequences of chert, shale and thin-bedded limestone that contain calcite veins are present.

The siliceous limestone beds found interbedded with the chert sequence appear to be devoid of fossils. Locally the limestone is recrystallized and silicified.

Rocks east of the Tolovana River consist of interbedded dark-gray to black shales, metasiltstones, subordinate slate and coarse-grained, pebble-to cobble-conglomerate. Well indurated rocks resembling argillites are present just east of the Tolovana River, near Shorty Creek. This sequence of rocks is a well-bedded unit of dark-gray to black metasiltstone and argillite that is highly fractured locally and shows some isoclinal overturned folding. The isoclinal overturned fold axes trend northwest and dip slightly to the east. The argillaceous rocks are highly fractured and pencil cleavage is developed locally. Interbedded with the argillite is a thick sequence of coarse-grained pebble-to cobble-conglomerate. The conglomerates contain clasts of greenstone, quartzite, dark-gray limestone, sandstone, chert, siltstone and minor dark-gray slate (Chapman, 1971). The matrix in these rocks is commonly coarse-grained lithic wacke that is calcareous in part. Bedding is well developed and generally dips to the southeast. This package of rocks is believed to be either Cretaceous or Jurassic in age, (Chapman et al, 1971) based on scant paleontologic data. Paleozoic rocks west of the Tolovana River dip generally to the northwest while the Mesozoic rocks east of the Tolovana River dip southeast. A high-angle normal fault in the valley of the Tolovana has been mapped by Chapman et al, (1971). The western block is down-dropped relative to the eastern block. Intrusive rocks east of the Tolovana River near the head of Wilbur Creek consist of light colored, fine-to medium-grained, altered intrusive rocks that vary from monzonite to quartz monzonite in composition. The intrusive rocks occur in dikes and as small intrusive bodies that intrude the metasiltstone countryrock. The rocks are highly fractured and many quartz and calcite veinlets cut the metasiltstones east of Wilbur Creek. Near the head of Slate Creek and farther to the east near Globe Creek a thick sequence of Mesozoic rocks composed primarily of shale, siltstone, quartzite, and medium-grained quartzose sandstones is present. This sequence of rocks is well bedded and exhibits graded bedding, flow casts and rill-marks (Chapman et al, 1971). The shales generally consist of medium-gray, very fine-grained rocks that are clayey in part. Medium-gray, fine-to coarse-grained lithic wacke in beds of variable thickness grade locally into conglomerate and shale. Medium-to coarse-grained quartzose sandstones near Globe Creek have been metamorphosed to at least the lower greenschist facies of metamorphism. These rocks contain abundant muscovite in the interstices between rounded to subrounded grains of quartz, potassium-feldspar and plagioclase. Incipient epidote is also present.

At Globe Creek an extensive section of Tolovana limestone crops out. This unit, first described by Brooks and Randle (1902), is a light-to medium-gray, finely-crystalline, thick and massively bedded, dolomitic limestone that is locally recrystallized and silicified.

The true thickness of the unit is unknown, but may be several thousand meters (feet) (Chapman et al, 1971). The rocks of the Tolovana Limestone unit within the Pipeline Corridor are highly fractured and recrystallized siliceous-dolomitic limestone and recrystallized limestone that contain abundant calcite and quartz veinlets. Fossils are rare within this unit, but those collected by Chapman et al (1971), chiefly corals, stromatoporoids and amphipora indicate a Silurian or Devonian age. Just northwest of Globe Creek, near Pump Station Number 7, the rocks are dark-green to black, medium-grained greenstones. The metamorphic grade of the rocks in this area is higher than the metamorphic grade of the rocks to the west. The greenstones have well-developed epidote and are probably upper greenschist facies rocks. Metamorphosed sedimentary rocks found in the area also exhibit a higher metamorphic grade than the rocks to the west. Quartzite units to the west show only incipient development of muscovite, while similar rocks near Pump Station 7 contain well-developed muscovite, epidote and incipient hornblende. Interbedded with the quartzite are dark, very-fine grained argillites. The argillites contain muscovite and incipient hornblende and an incipient foliation is present locally. All of the rocks in this area are highly fractured and contain quartz and calcite veinlets. Southeast of Globe Creek, an interbedded sequence of argillite, slate, quartzite, siltstone and limestone crops out. The argillite and slate are generally medium to very dark red or maroon, but sometimes range to light-gray to grayish-green in color. They are moderately well bedded in thin, fissile or chunky layers and form a distinctive unit throughout the area (Chapman et al, 1971). Thin layers of gray to very dark-gray, finely-crystalline limestone are interlaminated with the argillites and slates. The limestones are devoid of fossils.

Rocks near Washington Creek, south of Globe Creek, consist of interlaminated micaceous quartzite, quartz muscovite schist, argillite and minor phyllite. Minor slate interbeds are also present. Fossil evidence found in less metamorphosed sections consist of specimens of Oldhamnia, which indicate a Cambrian age (Churkin and Brabb, 1965). Although Mertie (1937), first identified these fossils and assigned the rocks to the Mississippian. This package of interlaminated quartz muscovite schist, micaceous quartzite, phyllite, slate and subordinate argillite is present southeast of Washington Creek and as far south as the Chatanika River. South of the Chatanika River, the rocks are much the same as those near Washington Creek. However, this package of rocks appears to have been subjected to some thermal metamorphism, possibly resulting from the intrusion of the Pedro Dome quartz diorite stock. The rocks in this area are highly altered locally, and contain abundant muscovite, biotite, epidote, hornblende and subordinate garnet. Veinlets of quartz and calcite are common and highly-altered sequences of rocks contain muscovite, while some small intrusive dikes show signs of sericitic alteration.

Structural Geology

The structural geology of the rocks in the Livengood quadrangle is dominated by northeast trending thrust faults and high-angle normal faults. Fold sytles in the rocks southeast of Globe Creek are isoclinal to recumbent, overturned to the northeast, while those northwest of Globe Creek are isoclinal, overturned to the northwest. Several large linear features that may be faults are present in the northwestern part of the quadrangle.

South of the Chatanika River the rocks exhibit at least two phases of metamorphism and two distinct structural trends. The earliest metamorphic pulse, up to almandine amphibolite grade, is probably early Paleozoic and is apparently associated with isoclinal recumbent folding about northwest-trending axes, while the later phase, probably mid Mesozoic, appears to be retrograde to upper greenschist facies, and is associated with open upright folds about northeast-trending axes. Euhedral overgrowths on subhedral poikiloblastic garnets in the vicinity of Pedro Dome may be evidence for a later, possibly late Mesozoic, thermal event (Swainbank and Forbes, 1975).

Several large thrust faults mapped by Chapman and others (1971) north and west of Globe Creek, separate the lower Paleozoic or Precambrian schist, grit and quartzite sequence to the southeast from a Mesozoic terrane composed of metasiltstone, argillite, metagraywacke and minor greenstone to the northwest. The northeast-trending thrust faults and associated high-angle normal faults are marked by several mafic and ultramafic bodies northwest of the zone of overthrusting.

Northwest of a high-angle normal fault, known as the Beaver Creek Fault (Chapman and others, 1971) metasiltstone, argillite, metagraywacke and pebble-to cobble-conglomerate are isoclinally folded and folds are overturned to the northwest. This Mesozoic sequence of rocks is recrystallized, and some low-grade metamorphic minerals are present. Just east of the Tolovana River a prominent escarpment parallel to the river valley is present. Chapman and others (1971) have mapped a large north-trending normal fault along the escarpment and the eastern, dominantly Mesozoic, block is upthrown relative to the western, dominantly Paleozoic block. In the valley of the Tolovana River an east northeast-trending serpentinite body is present. Chapman (1971) believes that the serpentinite may be cut by the fault mapped on the Tolovana escarpment and the body is offset not more than 1.6 kilometer (1.0 miles) (F. Weber, U. S. Geological Survey, personal communications, 1977).

Northwest of Livengood a fault known as the Victoria Creek Fault is present. The fault trends about N80°E and can be traced for about 80 kilometers (50 miles). The Victoria Creek fault separates a Cambrian sequence of quartzite and grit from a lower Paleozoic sequence of chert, dolomite and recrystallized limestone near Livengood. Northwest of the Victoria Creek Fault, Chapman and others (1971) have mapped another high-angle normal fault that is subparallel to the Victoria Creek Fault. In the northeastern part of the Livengood quadrangle, this fault separates a Cambrian sequence of grit, quartzite, slate, argillite and chert from a mid-Paleozoic sequence of chert, limestone, clastic rocks and minor volcanics. The presence of the fault to the southwest is marked by a similar discontinuity in rock type. A strong linear feature is present in the valley of Hess Creek. This feature can be traced for about 72 kilometers (45 miles) and trends sub-parallel to the Victoria Creek Fault. No offset or discontinuity in rock types has been found on opposite sides of this linear. The rocks are part of a thick sequence of interbedded sedimentary and volcanic rocks of the Permian Rampart Group. Another strong linear feature sub-parallel to the Hess Creek lineament is present in the valleys of Isom and Rogers Creeks. Rocks present on both sides of this linear are also part of the Rampart Group and no offset or discontinuity can be determined.

Just south of Isom Creek, a well-bedded sequence of volcanics and associated argillite and lithic wacke is highly folded and fractured. Small scale folds are abundant and fold axes generally trend northeast.

Geochemistry

Geochemical reconnaissance in the Livengood quadrangle during the current study consisted of the collection of 369 rock samples (see Table 18, Appendix A) from the inner pipeline corridor between Goldstream Creek, north of Fairbanks, and the Yukon River. Statistical analysis of the geochemical data has shown that 48% of the samples collected contain weakly anomalous, anomalous and strongly anomalous concentrations of at least one element. Threshold values (see Tables 19 and 20, Appendix A) for the 90%, 95% and 98% confidence intervals for each element were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation for the 90%, 95% and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are either the detection level or nearly the same value.

Bedrock south of the Chatanika River consists mainly of quartz mica schist and micaceous quartzite that are cut by quartz veins and granitic dikes and plugs. The schists and quartzites are altered to varying degrees and contain sporadic potassium, sodium and boron anomalies that may be the result of hydrothermal alteration or contact metamorphic effects associated with the intrusion of the granitic bodies. Combined sodium and potassium concentrations as high as 13% are known in samples of granite and what U.S. Bureau of Mines personnel have identified as alaskite. Minor silver and arsenic values were also detected in the granitic rocks. The rocks throughout the area are shattered and cut by faults at many localities. Limonite staining, probably associated with the alteration of pyrite and other iron-bearing minerals, is common, although no sulfide mineralization was found during the current study. North of the Chatanika River and south of Washington Creek, the bedrock consists of a monotonous sequence of quartz mica schist and quartzite. Locally, quartz veins cut the schist and quartzite oblique to the foliation and contain strongly anomalous gold and silver values. Anomalous molybdenum concentrations are also present locally. The rocks between Washington Creek and Slate Creek consist of banded slate, quartz mica schist, meta-siltstone, mafic intrusive rocks, and massive limestone. The mafic intrusives contain anomalous and strongly anomalous concentrations of strontium and weakly anomalous concentrations of calcium and molybdenum. North of Slate Creek, the shale, slate, graywacke and lithic conglomerate countryrock has been intruded by quartz porphyry and rhyolite porphyry dikes and a small granitic plug. Samples of the intrusive rocks contain visible sulfides including pyrite, chalcopyrite and minor molybdenite. Copper concentration found in samples of the mineralized intrusive were as high as 520 ppm. Zinc concentrations of 1000 ppm and molybdenum values of 12 ppm were also detected. North of Wilber Creek and south of Shorty Creek the metasiltstone countryrock is cut by sulfide-bearing veins locally. The vein material contains clots and kidney-shaped zones of massive sulfides as much as 5 inches thick. The sulfide mineralization consists of arsenopyrite(?), stibnite, galena, and chalcopyrite. Strongly anomalous concentrations of cobalt and bismuth suggest the presence of other unrecognized mineral phases.

Northwest of the Tolovana River, black chert of the Livengood Chert is intensely shattered and contains strongly anomalous concentrations of copper, zinc and molybdenum. The chert is cut by randomly-oriented quartz veinlets and contains tourquoise(?) and faustite. No primary sulfide mineralization was found during the current study.

Scattered, weakly anomalous and strongly anomalous concentrations of calcium, molybdenum, titanium, vanadium, magnesium and gallium were detected in samples of metasiltstone and chloritized diorite between Lost Creek and Erickson Creek. No mineralization of obvious significance was found during the current study.

North of Erickson Creek, the bedrock consists of metasiltstone and sill-like bodies of diorite. Locally, the siltstone contains strongly anomalous concentrations of zinc and copper, no sulfide minerals were seen however. Near Hess Creek, samples of altered hornblende diorite contain strongly anomalous concentrations of copper, bismuth, titanium, vanadium and gallium. The copper values are contained in disseminated chalcopyrite and range up to 2800 ppm. Minor molybdenum values were also detected.

North of Hess Creek rocks of the Rampart Group dominate the bedrock geology. The lithic tuffs of the region contain weakly anomalous concentrations of calcium, molybdenum and titanium. The volcanic rocks also contain strongly anomalous concentrations of gallium, magnesium, scandium and yttrium. Locally, argillites that are interbedded with the volcanic rocks contain barium concentrations as high as 4%.

North of the Yukon River, the volcanic sequences seem to be more mafic rich and scattered, strongly anomalous concentrations of nickel and chrome were detected. No mineralization was found during the current study however.

Mining Activity and Economic Geology

Felix Pedro discovered gold in the Fairbanks district on Pedro Creek, north of Fairbanks in 1902 and active mining has been in progress since that time. Gold was discovered in the Tolovana district in 1914 when workable placers were found on Livengood Creek, near the town of Livengood. The placer gold deposit on Livengood Creek is being actively mined and about 1,000,000 ounces of gold may remain in the deposit (B. Thomas, personal communications, 1977).

Placer mining in the Fairbanks district has produced about 7,239,000 ounces of gold from 1903 through 1959, and gold production in the Tolovana district has amounted to about 375,000 ounces of gold up to 1959 (Koschmann and Bergendahl, 1968). Active placer mining continues in both districts.

The source of the placer gold deposits is believed to be lode gold deposits of gold-quartz and gold-quartz-sulfide vein affinities, that are closely associated with small intrusive bodies found throughout the terrane. The placer deposits occur as bench deposits, as abandoned channel deposits, and also as active stream channel deposits. Production from lode gold, antimony, lead, silver and tungsten deposits has occurred in the Fairbanks district. Lode deposits of gold and silver are generally vein deposits believed by some investigators (Forbes et al, 1969) to be associated with small granite, diorite and quartz diorite stocks that occur throughout the Yukon-Tanana Uplands. The veins are of several definite types and include gold-quartz veins, gold-stibnite-quartz veins, sulfide-quartz veins and gold-sulfide-quartz varieties. Podiform deposits of stibnite occur commonly associated with shear zones and some quartz veins. Production of antimony has taken place from these deposits. Tungsten deposits, closely associated with small intrusive bodies found throughout the Yukon-Tanana Uplands, occur near thin, discontinuous beds of limestone or calcium-rich layers within the Birch Creek Schist. Several small tungsten deposits near Gilmore Dome, north of Fairbanks, have produced in the past and one deposit on Gilmore Dome is currently being mined.

The tungsten lodes of the Gilmore Dome area are locallized near the contact with the Gilmore Dome quartz diorite stock. The scheelite mineralization is concentrated in limy layers within the schist-quartzite country-rock and may represent remobilization of sedimentary tungsten (Metz, 1977). Contact metamorphic rocks consist of calcite-epidote skarn and calcite-diopside skarn and are closely associated with the tungsten deposits. Work by the U. S. Bureau of Mines at the Colbert Lode on Gilmore Dome has resulted in the discovery of about

20,000 tons of high grade ore averaging 3.29% WO_3 (U.S.B.M., 1943-1945). There are other tungsten lodes known in the Cleary Summit area, and the probability of finding other such tungsten deposits in the region seems high.

On the north-flank of Murphy Dome and south of the Chatanika River many small quartz veins and shear zones were found during the examinations of the pipeline excavation. The veins and zones of shearing are heavily iron stained locally. No sulfide minerals or visible gold were seen in these rocks, however, analysis of rock samples revealed anomalous concentrations of silver, gold, molybdenum, nickel, lead, tungsten and zinc.

An extensive zone of potassic alteration surrounds the Pedro Dome quartz diorite stock. Combined sodium and potassium concentrations of the rocks north Pedro Dome in the altered zone are as high as 13%. The extensive shearing and quartz veining in the rocks near Murphy Dome is probably spacially and genetically related to the intrusive activity. Sandvik (1967) believes that there were at least four distinct periods of mineralization in the Fairbanks district. The first phase of mineralization is characterized by barren quartz veins. The second phase of mineralization consists of quartz-arsenopyrite-pyrite-gold veins that are post quartz monzonite, of the Cleary area, in age. The third generally high-grade phase of mineralization belongs to the quartz-stibnite-gold-arsenopyrite and antimony sulfosalts veins. The fourth and final phase of mineralization consists of quartz and stibnite with little or no gold.

Several small lode mining operations were in production in the Cleary Summit area in 1977. One vein, known as the Kawalita vein is located near the Keystone Mines property, northeast of Cleary Summit and has been described as a typical Bonanza type vein by Sandvik (1967). The vein system contains abundant free gold and trace sulfosalts. The footwall of the vein is marked by lenses of stibnite that lie along the contact. Forbes et al (1968) reported that vein material from the Kawalita assayed between 10.6 and 238 ppm gold, with a weighted average grade of 74 ppm for the entire width of the vein. Assays as high as 100 ounces of gold per ton are known from this high-grade ore shoot (Rudy Vetter, owner, personal communication, 1977). Forbes et al (1968) have shown that the wall-rock in both the footwall and the hanging wall contain anomalous gold concentrations that extend at least five feet into the country-rock.

Another mineralized zone on Willow Creek, just north of Pedro Dome, is being developed and some ore was shipped in 1977. The zone contains a distinctly different type of mineralization then that of the Kawalita vein. The Willow Creek deposit is a highly mineralized shear(?) that can be traced for almost 0.8 kilometers (0.5 miles). The mineralized material is predominantly quartz, carbonate, clay and sulfide mineralization. The mineralized zone is marked by intense shattering of the schist-quartzite-marble-countryrock. One section of the mineralized zone does not appear to be a vein, rather it appears to be either a replacement deposit in a limy layer in the schist-quartzite countryrock or a metamorphosed syngenetic carbonate-hosted accumulation of sulfides. Similar zones of mineralization are known on Chatham Creek and at one locality northwest of Pedro Dome. The mineralization consists of thinly laminated and rhythmically banded marmatitic sphalerite, galena, stibnite, pyrite and locally massive antimony sulfosalts, that are probably jamesonite and boulangerite. Trace gold, and up to 80 ounces of silver per ton have been reported from high-grade galena samples.

The Cleary Summit-Pedro Dome area has long been recognized as a highly mineralized district. The probability of finding unknown veins and mineralized zones in the region seems high. It is also possible that mining of many of the previously uneconomic deposits in the region may become economically feasible in the future.

North of the Chatanika River, the country-rock is much the same as that south of the Chatanika only with a different structural grain. The rocks south of the Chatanika River exhibit at least two distinct phases of deformation while those to the northwest do not. The schist-quartzite country-rock near Pedro Dome exhibits evidence that the rocks were affected by a late Mesozoic thermal event that may by related to the intrusive activity and mineralization.

No mineralization of significance was found in the pipeline corridor between the Chatanika River and Globe Creek. At Globe Creek an extensive outcrop of Tolovana Limestone is present in the pipeline right of way, as well as on the Elliot Highway. The limestone is characteristically a low magnesian limestone. Quartzite and some dolomitic limestone are present in close proximity to the limestone occurrence. The Tolovana Limestone and associated rocks may represent and important source of raw materials for the production of Portland cement if the feasibility of such an industry should come about in the interior.

Near Globe Creek, medium-grained greenstones are present. The rocks are probably metamorphosed mafic igneous rocks and samples of the greenstone contain anomalous concentrations of silver, gold, tin and tungsten. No anomalous nickel or copper values were detected, and no sulfide minerals were found during this study. The probability of finding significant metal concentrations associated with these metaigneous rocks seems low. North of Globe Creek, the country-rock consists of a Mesozoic sequence of shale, siltstone, quartzite and sandstone. No anomalous metal concentrations were detected during this study although the bedding surfaces of the shale and siltstone members are often coated with subhedral crystals of pyrite or marcasite. Some small quartz and calcite veinlets cut these rocks, however only pyrite was found in the veinlets. Near Wilbur Creek, the Mesozoic rocks become more clastic in character and conglomeratic layers constitute a major portion of the rock sequence. The sedimentary rocks are intruded by dikes and a small intrusive body composed of fine-to medium-grained monzonite and quartz monzonite. The intrusive rocks exhibit varying degrees of alteration and disseminated sulfide mineralization occurs throughout the dikes and intrusive bodies. The sulfides are dominantly pyrite, chalcopyrite, and molybdenite. Copper concentrations as high as .052% and molybdenum concentrations as high as 12 ppm were detected. Minor lead and zinc concentrations were also detected. The intrusive rocks near Wilbur Creek appear to have a rather limited extent and the probability of this occurrence being of economic tenor seems low.

Northeast of the Wilbur Creek occurrence, similar intrusive rocks crop out. The intrusives are heavily ironstained and intensely fractured. No visible sulfides were detected, however the rocks do contain manganese concentrations as high as 1.7%, lead concentrations as high as 397 ppm and zinc concentrations as high as 460 ppm. The high manganese content is probably related to a heavy coating of pyrolusite(?) that occurs locally. The rocks in this area seem to have a moderate potential and further work is needed. The rocks between Wilbur Creek and Shorty Creek are composed of very fine-grained, siliceous metasiltstones that are fractured and sheared. Locally, the metasiltstones are cut by numerous quartz-sulfide veins. The veins cut the metasiltstone oblique to the bedding surfaces and generally strike northeast with a southerly dip. The sulfides that constitute most of the vein material are present as clots and kidney-shaped concentrations as much as 13 centimeters (5 inches) thick. Major arsenopyrite, stibnite, galena, and chalcopyrite constitute the bulk of the vein material and secondary scorodite and malachite are also present. Boron concentrations as high as 300 ppm, bismuth concentrations as high as 610 ppm and cobalt concentrations as high as .43% were detected in vein material. Copper values as high as .21%, nickel values as high as .17% and antimony values as high as .05% were detected in high-grade samples of sulfide-bearing vein material. The veins found during the examination of this area are small, however the potential for finding other such mineralized vein-systems in the area seems high.

A "porphyry" prospect belonging to B.P. Minerals, Co. near the head of Shorty Creek was actively drilled in the early part of the 1970's. A claim block consisting of at least 44 claims was staked, however, the results of the drilling and the present status of the claim group is not known. It is possible that the intense shearing and shattering of the metasiltstones and the mineralized vein systems in the area are somehow related to the intrusive activity.

West of the Tolovana River, the bedrock is different than that east of the Tolovana, and is composed primarily of chert, dolomitic limestone and highly altered volcanics. Northwest of the Livengood-Manley Hot Springs Road, the black chert member of the Livengood Chert unit is intensely shattered. The zone of fracturing can be traced for about 300 meters (1,000 feet) and is of interest because the fractures are coated with tourquoise(?) and faustite, which is essentially a zinc equivalent of tourquoise. Samples from the area have produced somewhat conflicting geochemical responses. Samples collected by the U. S. Bureau of Mines in the area contained anomalous copper values as high as 680 ppm and molybdenum concentrations as high as 41 ppm. Samples collected during this study from the same area contained only minor anomalous concentrations of zinc, silver, tin and phosphorous. The copper and zinc are obviously of a secondary nature and the source of the metals is unknown. Further work is needed in the area to determine if there is a relationship between the secondary copper and zinc mineralization in the cherts, and a sequence of saussuritized dacitic volcanics that are in contact with the cherts to the north. The presence of mineralization in the associated chert and volcanics indicate an area that has a moderate to high probability of containing metal concentrations of unknown size and distribution.

Just south of Lost Creek, an extensive zone of silicified dolomite, dolomitic limestone, chert, siltstone and dacitic volcanics is present. The chert and siltstone members are highly sheared and cut by many small quartz stringers locally. The rocks in the area contain anomalous concentrations of silver, gold, molybdenum, tin, tungsten and lead. No mineralization was visible in these rocks, however, the area does contain the anomalous metal concentrations and needs further work.

North of Lost Creek, the bedrock is composed of interbedded gray, black, green, red, white and brown chert, siltstone, shale and sandstone. The sediments are cut by dikes that range from trachyte to basalt in composition. Locally, coarse-grained intrusive rocks composed of mafic-rich diorite are also present. The intrusive rocks contain minor disseminated sulfides. Minor pyrite and magnetite are present in the mafic-rich phases. None of the sulfide or magnetite accumulations in the area appeared to be of significance.

North of Lost Creek near Erickson Creek, the character of the bedrock changes and rocks of the Permian Rampart Group are present. The rocks generally consist of interbedded tuff, tuff breccia and argillite with minor chert and sedimentary rocks. The Rampart Group also contains a marked intrusive igneous rock component that generally consists of medium-to coarse-grained hornblende diorite. At an occurrence just south of Hess Creek, a sequence of meta-siltstone and shale has been intruded(?) by a sill-like body of hornblende diorite that contains as much as 10% disseminated sulfides. The sulfide mineralization is composed of pyrite and chalcopyrite, and copper values as high as 0.28% were detected in selected samples. The diorite at this locality is a medium-to coarse grained hornblende diorite porphyry that is sausseritizied and sericitized. Secondary quartz veins are abundant and cross-cut the diorite extensively. The diorite contains secondary biotite after hornblende and some of the diorite is highly chloritized. The mineralized intrusive rock near Hess Creek does not appear to be of economic tenor, however the occurrence of the porphyry-type mineralization in rocks of the Rampart Group indicates that the terrane may have good mineral potential and may contain copper porphyry type deposits.

North of Hess Creek, clearly intrusive forms of hornblende diorite crop out. The intrusives contain up to 10% magnetite, and are extremely chloritized. No sulfide minerals were found during the current study. The genetic relationship between the clearly intrusive diorites north of Hess Creek and the sill-like forms that occur throughout the Rampart terrane is not known. The clearly intrusive forms may also have some potential for copper porphyry-type mineralization. North of Hess Creek, argillite beds within the volcano-sedimentary sequence contain up to 4% barium. Samples of tuff and tuff breccia from the area contain anomalous concentrations of chrome, molybdenum, vanadium, tungsten and silver. No mineralization was found during the present study however.

South of Isom Creek, a sequence of rocks that are thought to be Tertiary in age is present and consists of interbedded conglomerate, lithic sandstone, graphite layers, dikes of various compositions and minor siliceous siltstone and sandstone. The sequence is probably correlatable with similar Tertiary rocks that are known along the Yukon River to the west and to the north in the Fort Hamlin Hills. The rocks occupy a graben-like structure outlined by a lineament in Hess Creek and by a similar lineament in the Isom-Rogers Creek valleys. To the west, Tertiary rocks are the host for the coal deposits at the Drew Mine, near the mouth of Hess Creek. If these rocks are correlatable, the Tertiary(?) rocks found in the Pipeline Corridor may contain similar deposits. No above background uranium concentrations were detected, in the Tertiary rocks however further work is needed to fully evaluate the uranium potential of this area.

Just south of Isom Creek a large shear zone(?) about 15 meters (50 feet) wide is present. The material in the shear zone contains sphalerite, pyrite and minor galena. Zinc concentrations as high as .21% and lead concentrations to 300 ppm were detected. Minor nickel and chrome values were also present.

In summary, the rocks of the Livengood quadrangle have good mineral potential and may contain a variety of mineral deposit types. The complex structural and geologic framework of the rocks coupled with the heavy forest cover over most of the region will complicate most exploration programs. However, the probability of finding still undiscovered deposits seems high.

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Tanana Quadrangle

Previous Investigations

Geologic investigations in the Tanana Quadrangle began as early as 1898 when geologists of the U. S. Geological Survey traversed the area. Recent work on the bedrock geology of the region include work by Chapman et al (1972); Detterman (1973); Foster et al (1973); Patton and Miller (1970) and Churkin (1973); all of the U. S. Geological Survey. Regional geophysical surveys in the quadrangle include work by Brosge et al (1970); and two open file reports by the U. S. Geological Survey (1973) on aeromagnetic surveys conducted in the quadrangle. Papers by Detterman (1973) and Patton (1973) are the latest works on the tectonics of the region.

Regional Geology and Petrology

The regional geology of the northeastern portion of the Tanana quadrangle is much the same as that of the northwestern part of the Livengood quadrangle. Interbedded sequences of tuff, tuff breccia, and argillite of the Permian Rampart Group, crop out north and east of the Ray River. North of 5 Mile Camp, a thick sequence of slate, quartzite, schist and phyllite is present. This sequence is believed to be upper Paleozoic in age (Chapman and Yeend, 1972). The phyllites are interbedded with very-fine grained, micaceous metasiltstone, slate, and minor quartzite, and are generally very fine grained, dark-gray to black phyllites that contain pods and irregular veinlets of quartz. Patton and Miller (1970) correlate this unit with similar rocks to the north near the Kanuti River.

The phyllites of the Kanuti River region have been correlated with plutonic and metamorphic rocks of the Kokrines - Hodzana highlands area complex to the west (Patton and Miller, 1970). The phyllite terrane in the Tanana Quadrangle is intruded and altered by granitic intrusives of Mesozoic age (Patton and Miller, 1970).

Structural Geology

The structural geology of the rocks in the Tanana quadrangle is dominated by the Kaltag Fault. This major right-lateral, strike-slip fault has been mapped by Chapman and others (1975) and is believed to follow the structural low occupied by the Yukon River. The fault is a major structural break and can be traced for about 440 kilometers (275 miles) across west-central Alaska. The eastern extension of the fault into the Livengood quadrangle has not been identified. However, several large northeast trending faults and strong lineaments in the Livengood quadrangle at Beaver Creek, Victoria Creek, Hess Creek, Isom-Rogers Creeks, and the Porcupine lineament north of the Yukon Flats may be the eastern extension of the Kaltag Fault (Florence Weber, Personnal Communications, 1977). Evidence of Quaternary movement along traces of the fault west of Tanana have been found.

The phyllite units in the Tanana D-6 quadrangle are highly folded and sheared. A strong foliation is developed and quartz stringers and pods are present along fractures within phyllite sequence. The folding produces a highly variable foliation generally striking between 020° and 115° and dipping 25 to 40 degrees to the southwest. At one locality, small crenulations were found indicating secondary folding at 370° and dipping 22° south.

Geochemistry

Geochemical reconnaissance in the Tanana quadrangle during the current study consisted of the collection of 12 rock samples (see Tables 21 and 22, Appendix A) from the inner pipeline corridor. The sampling was concentrated in an area where the bedrock is dominated by dark gray phyllite. Statistical analysis of the geochemical data has shown that 58% of the samples collected contain weakly anomalous, anomalous and strongly anomalous concentrations of at least one element. Threshold values (see Tables 23 and 24, Appendix A) for each element were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation for the 90%, 95% and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are either the detection level or nearly the same value.

The phyllites that crop out north of 5 Mile Camp contain strongly anomalous concentrations of zinc and copper. No sulfide mineralization was found during the current study, and further work is clearly needed in the area.

Economic Geology and Mining Activity

Gold was first discovered in the Rampart District in about 1882. No significant production occurred until about 1896 when rich gold placer deposits were discovered on Little Minook Creek, south of Rampart. Gold placers of the Rampart district have produced about 86,800 ounces of gold up to 1959 (Koschmann and Bergendahl, 1968) and active placer mining is continuing in the region. Many of the placer deposits in the Rampart District contain accessory tin, cinnabar, pyrite, galena, barite and scheelite (Waters, 1934).

Coal was discovered about 32 kilometers (20 miles) northeast of Rampart in 1897, when Oliver Miller found several coal seams on the Yukon River, opposite the mouth of Hess Creek. This locality, later known as the Drew Mine, produced about 1,200 tons of coal up to 1903. The coal occurs in a thick section of Tertiary sedimentary rocks composed of sandstone, conglomerate, shale and coal, believed to be Pliocene(?) in age. A similar deposit occurs on Lower Minook Creek, south of Rampart.

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Previous Investigations

Geologic investigations along the upper Koyukuk and Chandalar Rivers in north-central Alaska began as early as 1899 when F. C. Schrader of the U. S. Geological Survey conducted reconnaissance geologic investigations. The Kanuti River area in the south-central part of the Bettles quadrangle was first visited by W.C. Mendenhall (1902) of the Geological Survey. The first definitive work in the area was done by A.G. Maddren (1913) of the U. S. Geological Survey, who visited most of the important mining districts north of the Yukon River and reported on the regional geology and mining activities throughout the area. Maddren (1913) recognized the complex geology present in the quadrangle and his work combined with that of other workers served to describe the regional geology of the area. Recent work by Patton and Miller (1973) has resulted in a reconnaissance geologic map of the quadrangle and some regional geochemical data has been collected.

Preliminary geologic investigations by Patton and Miller (1970) in the Kanuti River area have delineated several areas with high mineral potential. Detailed geologic mapping and geochemical sampling by Herreid (1969) near Sithylemenkat Lake in the south-central part of the quadrangle has outlined areas that contain high concentrations of nickel, cobalt, chromium, and iron. Herreid (1969) also produced detailed petrographic descriptions of many of the rocks found throughout the region.

Geophysical investigations by Lathram (1972), Barnes (1967, 1971), Gedney et al (1972), and Packer et al (1975) have resulted in a better understanding of the tectonics of the region and work by Lathram (1973), Detterman (1973), and Patton (1973) has led to a better understanding of the bedrock relationships and the tectonic framework of the region.

Regional Geology and Petrology

The Bettles quadrangle is situated on the eastern extension of the Kokrines - Hodzana Highlands areas of the upper Yukon - Koyukuk province, in north-central Alaska. The region is dominated by a crystalline terrane composed largely of metasedimentary and metaigneous rocks that have been intruded by Mesozoic granitic rocks and mafic and ultramafic bodies of either Paleozoic or Mesozoic age. The metasediments are chiefly pelitic schists and quartzites with subordinate calc-schist, quartzo-feldspathic schist, and phyllite of lower Paleozoic or Precambrian age. Carbonate layers within this sequence of rocks contain fossils that are mid-Paleozoic in age and the metasediments are believed to interfinger locally with Devonian carbonates (Patton and Miller, 1970).

The metasedimentary rocks present in the pipeline corridor are generally quartz-muscovite schist and orthoquartzites that range from the greenschist facies to lower amphibolite facies grade (Patton and Miller, 1973). Locally, near the contact with Mesozoic granitic bodies, the schist and quartzite country rock has been upgraded to the pyroxene hornfels facies. Euhedral andalusite and cordierite grains are present locally (Patton and Miller, 1973).

At several localities in the east-central part of the quadrangle, an ophiolite-like assemblage of altered pillow basalt, diabase, gabbro, serpentinized peridotite and dunite, and bedded chert is present (Patton and Miller, 1970). This assemblage of rocks may reflect a major structural hinge, that marks the southern edge of the Yukon-Koyukuk basin.

Payne (1955) and later workers have long recognized the wedge-like Yukon Geosyncline that is bounded on the south by the Ruby Geanticline and on the north by the Brooks Range Geanticline and the Kobuk Trough. A belt of mafic and ultramafic complexes that parallels the southern margin of the Yukon Geosyncline can be traced from the upper Melozitna River west of the Bettles quadrangle to Caribou Mountain, in the east-central part of the quadrangle, a distance of about 104 kilometers (65 miles) (Patton and Miller, 1970).

Two mafic-ultramafic complexes along the southern margin of the Yukon Geosyncline have received some detailed examinations. One complex, located southwest of the pipeline corridor, near Sithylemenkat Lake, was described by Patton and Miller (1970) as an area with good mineral potential, and as a result, Gordon Herreid (1969) of the Alaska Division of Geological and Geophysical Surveys conducted detailed mapping and geochemical sampling in the area. The Sithylemenkat Lake complex is composed chiefly of gabbro, diabase, basalt, diorite, peridotite, pyroxenite, greenstone, and minor metamorphic rocks of greenschist facies grade. The olivine-bearing rocks are moderately-to highly serpentized and locally sheared. Some cross-fiber asbestos veinlets, about 3 millimeters (0.12 inches) wide are present (Herreid, 1969). No sulfide mineralization or chromite accumulations of significance were found. The mafic-ultramafic complex at Caribou Mountain, just south of Old Man Pipeline Camp, is situated within the Kanuti-Hot Springs granitic batholith. The rocks within the mafic-ultramafic complex consist primarily of harzbergites and dunites. Locally, these rocks are serpentinized. The contact between the Caribou Mountain complex and the surrounding granitic rocks is possibly a fault contact (Patton and Miller, 1970). Herreid (1969), believes that the mafic-ultramafic complexes formed during the Jurassic when steep thrust faults were active on the southern hinge-zone of the Yukon Geosyncline, and the faults tapped deep zones of mafic and ultramafic magmas, that subsequently were intruded and tectonically mixed. Patton and Miller (1966) have mapped similar mafic-ultramfic complexes to the north in the Hughes Quadrangle, and believe that the complexes were emplaced along steep thrust faults along the northern margin of the Yukon Geosyncline.

The Kanuti-Hotsprings plutonic complex is composed mainly of coarse-grained, porphyritic biotite granite and medium-to coarse-grained, porphyritic quartz monzonite. The complex, dated at 106 million years B.P., is believed to have formed penecontemoraneously with the uplift of the margins of the Yukon Geosyncline (Herreid, 1969).

Rocks north of the Kanuti-Hot Springs plutonic complex consist mainly of Paleozoic phyllite and schist, that are probably correlatable with the metamorphic rocks south of the Kanuti complex. The phyllite units are generally dark-gray to black phyllite with subordinate fine-grained metagraywacke. The schist units are dominantly quartz-muscovite schist, chlorite schist, quartz-feldspathic schist and subordinate quartzite, all of greenschist and lower amphibolite facies.

North of Prospect Creek, in the northeastern part of the quadrangle, upper Paleozoic or Mesozoic mafic volcanic and plutonic rocks crop out. This sequence of rocks is composed mainly of basalt, diabase, and gabbro, all of which have been metamorphosed. The metavolcanic and metaplutonic rocks contain well-developed epidote that probably represents a lower greenschist facies metamorphic event.

Locally, throughout the Kanuti terrane bodies of felsic igneous rocks are present. These felsic rocks occur as flows, breccias, and tuffs, and have been dated at 58 ± 7 million years B.P. (Patton and Miller, 1973). The felsic rocks commonly contain disseminated sulfide mineralization and upon weathering, produce prominant gossan zones.

Near the northeast corner of the Bettles quadrangle, Mesozoic sedimentary rocks are present. This sequence of rocks is composed of massive pebble-to cobble-conglomerate and minor sandstone. The conglomeratic units have been broken into two members, one that has igneous pebbles and one that is composed of volcanic graywacke and mudstone. The sequence of rocks was first described by Mendenhall (1902), who assigned it to the Bergman Series of probable Cretaceous age.

Structural Geology

The structural geology of the Bettles quadrangle is dominated by tectonic events associated with development of the Yukon Geosyncline (Lathram, 1973). The Yukon Geosyncline is bounded on the south by the Ruby Geanticline and on the north by the Brooks Range Geanticline and the Kobuk Trough. The convergence of the genanticlinal structures forms the recumbant "V" shaped Yukon Geosynclinal trough, whose apex falls in the Bettles quadrangle.

Lathram (1973) feels that interaction between two continental masses in the Paleozoic and Mesozoic resulted in the down-warping or subsidence of the margins of the continental masses and subsequent eugeosynclinal deposition. Deposition in the Yukon Geosyncline during the Mesozoic was controlled by uplift and erosion of the marginal fold belts and resulted in the deposition of the Mesozoic sedimentary sequence seen in the area today. The Lower Paleozoic or Precambrian schist belt that parallels the south flank of the Brooks Range and the schist terrane in the Kanuti River area may be the remnants of the old marginal fold belts (Lathram, 1973).

Deep-seated faulting associated with the down-warping of the continental margins and intrusion of mafic and ultramafic magmas along the faults is marked by a thin belt of mafic and ultramafic complexes along the south flank of the Brooks Range and also the northern margin of the Kokrines - Hodzana Highlands (Herreid, 1969). Patton and Miller (1973) have mapped thrust fault contacts between several of the ultramafic bodies and associated mafic volcanic assemblages. The thrusts are mapped as over-thrust from the north.

The Mesozoic and Tertiary volcanic and sedimentary rocks found within the Yukon Geosynclinal sequence are folded and faulted and only regional geologic mapping has been done over most of the area.

Geochemistry

Geochemical reconnaissance in the Bettles quadrangle during the current study consisted of the collection of 55 rock and stream sediment samples by M.I.R.L. personnel between the Ray River on the south and the south fork of the Koyukuk River on the north. Seventy-three percent of the samples collected contain weakly anomalous, anomalous and strongly anomalous concentrations of at least one element (see Tables 25 and 26, Appendix A). Threshold values (see Tables 27 and 28, Appendix A) for the 90%, 95% and 98% confidence intervals for each element were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation for the 90%, 95% and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values are either the detection level or nearly the same value.

Rocks of the Caribou Mountain mafic-ultramafic complex contain strongly anomalous concentrations of cobalt, chrome, magnesium, nickel, lead, tin, copper and zinc. The cobalt, copper and magnesium values in rocks of the Caribou Mountain Complex are about average for mafic and ultramafic rocks, and high chrome and nickel values have been detected in chromite-rich harzbergites and dunites.

Samples of biotite granite and quartz monzonite from the Kanuti-Hot Springs plutonic complex contain strongly anomalous concentrations of sodium and strontium which are commonly associated with these rock types.

Samples of quartz muscovite schist and chlorite schist collected near Bonanza Creek contain strongly anomalous concentrations of silver and lead, and weakly anomalous concentrations of zinc and vanadium.

Mining Activity and Economic Geology

Placer gold was first discovered in the Koyukuk district sometime between 1895 and 1900, on the sand bars of the Koyukuk River (Koschmann and Bergendahl, 1968). Total gold production in the district through 1959 has been estimated to be about 278,000 ounces (Koschmann and Bergendahl, 1968). Most of this production, however, is from the Wiseman area. The U. S. Bureau of Mines reports about 5,300 ounces of gold production from the Bettles quadrangle proper. No production from lode gold or base-metal deposits has occurred in the quadrangle.

The mafic-ultramafic complexes along the southern margin of the Yukon-Koyukuk geosyncline are alpine peridotites composed of harzbergites and dunites. The mafic-ultramafic complex at Caribou Mountain, just south of the Kanuti River, is believed to be Jurassic in age (Patton and Miller, 1970) and is situated in the center of the Kanuti-Hot Springs granitic batholith of Cretaceous age. The harzbergites and dunites exhibit varying degrees of serpentinization. The serpentinization may be in response to the intrusion of the granitic complex. This situation is highly favorable for the development of asbestos. Hydrothermal fluids from the granites may have migrated away from the intrusives due to a positive water gradient that usually accompanies this type of intrusion. The fluids would be drawn toward the ultramafics, which usually have negative water gradients, thereby providing an avenue for the migration of fluids and subsequent serpentinization of the olivine-bearing rocks. Cross-fiber asbestos veinlets to 4 millimeters (0.16 inches) in length were found during the current study, however further reconnaissance is needed to evaluate fully the asbestos potential of the area. Chromite and magnetite accumulations in the ultramafic body at Caribou Mountain are generally restricted to very thin, discontinuous layers generally less than 5 millimeters (0.12 inches) thick. The potential for finding economic quantities of chromite in this ultramafic body seems low. Patton and Miller (1970) indicate that the average chromium value was less than .26%. The stream sediment geochemistry of the area indicated that stream sediment sampling may be useful in delineating unknown and undiscovered ultramafic bodies.

Tertiary volcanic rocks that consist of rhyolitic flows, tuffs and breccias are closely associated with the Mesozoic granitic batholith of the eastern extension of the Kokrines - Hodzana Highlands area. The volcanic rocks are the host for disseminated copper, lead and zinc mineralization locally. One such locality near the head of the Kanuti River contains lead concentrations as high as 2%, zinc concentrations as high as 0.3% and silver concentrations as high as 1 ounce per ton. The volcanic rocks are mainly sericitized and silicified rhyolites and rhyolite breccias. The rhyolite breccias generally consist of angular fragments of quartz and felsic rock fragments set in a groundmass of cryptocrystalline quartz and sericite. Galena and sphalerite occur in grains as much as 5 millimeters (0.2 inches) in diameter and are disseminated in a pyritic zone about 100 meters (300 feet) long (Patton and Miller, 1970). The rhyolite rests on and probably intrudes the Cretaceous biotite quartz monzonite of the Kanuti batholith. The rhyolite zone is highly oxidized and heavily iron-stained and is permeated by limonite. Patton and Miller (1970) feel that deposits of this type are favorable targets for exploration in north-central Alaska. Similar deposits are located near Indian River, 120 kilometers (75 miles) southwest of the Kanuti area, where lead, zinc and silver mineralization also occurs.

In the extreme northeastern corner of the Bettles quadrangle, the Jim River pluton is in contact with a sequence of mafic volcanic and intrusive rocks of Mesozoic age. The mafic rocks are altered and are greenstones. Locally, the greenstones contain abundant pyrite. Stream sediment samples collected by the U. S. Geological Survey along the Jim River contain anomalous concentrations of lead and copper. On their regional geologic map of the Bettles quadrangle, Patton and Miller (1973) have mapped the contact between the Jim River granitic pluton and the mafic igneous rocks in the valley of the Jim River. The favorable geologic setting and anomalous stream sediment geochemistry indicate an area that may have potential for base-metal sulfide accumulations.

Rocks of the Bergman Group in the northern part of the Bettles quadrangle exhibit low radiation levels when tested with a scintillometer. The conglomerate at one locality near the Middle Fork of the Koyukuk River, consists of interbedded cobble-to boulder conglomerate and black-to dark-gray, thin-bedded, fissile shale. The shale interbeds contain some carbonaceous material that was probably plant material. The source of the sediments that constitute the bulk of the Bergman Group was probably the fold belts that flank the Yukon Geosynclinal basin. No significant uranium concentrations were found during this study, however there may be moderate potential for the development of secondary uranium concentrations in the Bergman Group rocks.

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Wiseman Quadrangle

Previous Investigations

Geologic investigation of the Wiseman quadrangle began as early as 1899, when Schrader (1900) of the U. S. Geological Survey conducted reconnaissance geologic investigations along the Chandalar and Koyukuk Rivers. Brooks (1904) discussed the early mining activities in the area and described the gold placer deposits found along the Middle Fork of the Koyukuk River at Tramway Bar, about 48 kilometers (30 miles) above Bettles. Smith and Mertie (1930) discussed the mineral resources of northwest Alaska and described the coal deposits and gold placers at Tramway Bar. Smith (1926-1942) compiled information on many of the mining activities and mineral production in Alaska. Brosge (1960) described a sequence of metasedimentary rocks that occurs along the south-flank of the Brooks Range. Payne (1955) defined the major tectonic features of north-central Alaska, including the Brooks Range Geanticline, Kobuk Trough and Yukon Geosyncline, that dominate the tectonic history of northern Alaska. Barnes (1967) conducted regional gravity studies in the area and later work by the U.S.G.S. (1973) resulted in aeromagnetic maps at various scales, for the eastern part of the quadrangle. Recent work by Brosge and Reiser (1971) and Brosge et al (1970) on the bedrock geology in the quadrangle has resulted in a reconnaissance geologic map of the quadrangle and work by Brosge and Reiser (1970) has resulted in regional geochemical investigations throughout the quadrangle. Work by Lathram (1973), Detterman (1973), Brosge and Dutro (1973) and Churkin (1973) has resulted in tectonic reconstructions and a better understanding of the history of the Precambrian (?), Paleozoic and Mesozoic rock sequences present in northern Alaska. Work by the U. S. Geological Surveys is continuing in an effort to evaluate the resource potential of the rocks in the region.

Regional Geology and Petrology

The regional geology of the Wiseman quadrangle is dominated by a Precambrian (?) to Cretaceous sequence of carbonate, shale, conglomerate, chert, schist, phyllite, calc-schist and meta-igneous rocks. The entire sequence has been folded, faulted and metamorphosed in part. Structural thickening of the sequence has occurred as a result of imbricate thrust faulting and isoclinal folding of the rocks along the south-flank of the Brooks Range.

A thick sequence of massive and interbedded, pebble-to cobble conglomerate and shale, crops out in the southernmost part of the Wiseman quadrangle. The conglomerate unit has been broken into two distinct members, one that is composed dominantly of igneous rock clasts and one that is composed of volcanic rock and mudstone clasts. Both members have a wacke matrix and some iron cement. This sequence has been assigned to the Bergman Group of probable Cretaceous age, by Mendenhall (1902). Brosge and Reiser (1964) have mapped similar Bergman Group rocks to the east in the Chandalar quadrangle.

North and east of the Middle Fork of the Koyukuk River, a fairly thick sequence of interbedded meta-igneous rocks (greenstones) and chert of probable Mesozoic age crops out. The greenstones are dominantly metabasalt, metadiabase and metagabbro, and well developed pillow structures are present locally. The greenstones contain clots of chlorite and epidote, and probably represent a lower greenschist facies metamorphic event. The greenstone-chert sequence near the Koyukuk River may be correlatable with similar greenstone sequences to the west along the south-flank of the Brooks Range. A thick sequence of greenstones in the Angayucham Mountains, near Walker Lake, may occupy a similar structural and or stratigraphic position as those at Cathedral Mountain near Coldfoot, in the southern Wiseman quadrangle. Fritts (1970) described the greenstone sequence in the Angayucham Mountains as a weakly-metamorphosed sequence of altered pillow basalts and interbedded phyllite, chert and limestone of probable Devonian age. Recent work by the U. S. Geological Survey on chert samples from the Angayucham Mountains has shown the cherts to be Triassic in age (Donald G. Grybeck, U.S. Geological Survey, personal communication, 1977). The greenstone sequence at Cathedral Mountain is a well-bedded sequence of weakly-to moderately metamorphosed pillow basalt, interbedded with dark gray-to black chert. Clastic rocks of Cretaceous age are in contact with the greenstone sequences in both areas. The contact between the Cretaceous clastic rocks and the greenstones in the Angayucham Mountains has been described as a thrust fault contact, with the Cretaceous clastic sequence thrust over the greenstones from the south (Fritts, 1970). The contact between the Cretaceous clastic sequence (Bergman Group rocks) and the greenstone sequence at Cathedral Mountain is obscurred by overburden, and the contact relationships are uncertain.

On the north-flank of Cathedral Mountain, a sequence of graywacke sandstone and subordinate quartzose sandstone and quartzite is present. This sequence contains isolated bodies of greenstone that may be equivalent to the greenstones to the south. The age of these rocks is uncertain and may be Paleozoic or Mesozoic. North of the Rosie Creek Pass, just north of Cathedral Mountain, a fairly thick sequence of dark-gray to black phyllite and subordinate fine-grained metagraywacke crops out. The structural and stratigraphic relationships between this unit and the graywacke to the south is unknown. The age of these rocks is uncertain, but they are probably Devonian or late Paleozoic (Patton and Miller, 1973).

North of Slate Creek and Twelvemile Creek, in the eastern Wiseman quadrangle, a thick sequence of metamorphic rocks with complex structural and stratigraphic relationships is present. This sequence of rocks, composed of phyllite, quartz-feldspathic schist, marble, calc-schist, micaceous marble, quartzite and slate, is complexly folded and faulted and is cut by large quartz veins at several localities. At one locality, just south of Minnie Creek, a good exposure of graphitic, quartz, muscovite schist is present. The rocks range from a medium-to coarse grained, graphitic, quartz, muscovite schist to a micaceous quartzite. Locally the schist contains as much as 10% sulfide mineralization. Large boudins and lenses of optically-clear smokey quartz to 15 centimeters (6 inches) thick are present. This metamorphic sequence may represent the eastern extension of the "schist belt" of the western Brooks Range.

North of Wiseman, in the area of Vermont Dome and the Hammond River, a sequence of schist, phyllite, quartzite, slate, and grit is present. These rocks are of a lower metamorphic grade than the schists and quartzites to the south. The phyllite units in this sequence are generally dark-gray to black phyllite with abundant quartz stringers. Interlaminated slate sequences are black, thinly laminated slate with locally abundant pyrite. North of the Hammond River, a thick sequence of highly deformed and tectonically thickened limestone, schistose marble, dolomite, micaceous-silty limestone, slate, phyllite and siltstone is present. This package of rocks forms the southern belt of the core of the Brooks Range province. Imbricated thrust faulting coupled with high-angle reverse and normal faulting of the sequence has complicated the stratigraphic relationships betweeen the rock units. The lowest most unit recognized in the central Brooks Range Devonian sequence is the Skajit Limestone of middle Devonian age. The Skajit Limestone unit is composed predominantly of light gray, thin-to massively bedded, locally carbonaceous, dolomitic limestone; and includes minor chlorite schist, muscovite schist and marble (Chipp, 1972). Overlying the Skajit Limestone to the north is an unnamed sequence of limestone, siltstone and sandstone of late Devonian age, that grades upward into a sequence of limestone, quartzite, and conglomerate of latest Devonian age.

Structural Geology

The structural geology of the rocks in the Wiseman quadrangle is dominated by large-scale isoclinal to overturned folds, thrust faults, high-angle faults and small-scale folds.

Miogeosynclinal deposition during the Paleozoic near the core of the present day Brooks Range resulted in the deposition of a thick sequence of limestone, silty limestone, siltstone and shale. Penecontemporaneous volcanic activity deposited basalts, rhyolitic volcanics and tuffs of various compositions within the limestone-shale sequence. Subsequent regional metamorphism of the sequence has transformed the volcanic rocks into quartz muscovite schist, quartz feldspathic schist, meta-rhyolite and greenstone, and has transformed the sedimentary rocks into marbles, metasiltstones, grits and phyllite.

Foreshortening of the entire sequence has resulted from the development of imbricate thrust faulting along the south-flank of the Brooks Range. The thrust faulting has superimposed the rocks in structural rather than depositional sequences.

Oceanic volcanism along the south-flank of the Brooks Range during the Mesozoic produced a fairly thick sequence of pillow basalts and inter-bedded limestone and chert that can be traced intermittantly from the western Brooks Range, near Walker Lake, at least as far as the Middle Fork of the Koyukuk River in the eastern Wiseman quadrangle.

High-angle faulting has been active throughout the Brooks Range province and has added to the complexity of the geology in the region.

Geochemistry

Reconnaissance geochemical investigations in the Wiseman quadrangle during this study consisted of the collection of 69 rock and stream sediment samples. Fifty-nine percent of the samples contained weakly anomalous, anomalous, and strongly anomalous concentrations of at least one element (see Tables 29 and 30, Appendix A). Threshold values for the various elements (see Tables 31, 32, 33, and 34, Appendix A) were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation for the 90%, 95%, and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are the detection level or nearly the same value.

Samples of greenstone and gabbro from the Cathedral Mountain area contain weakly anomalous copper concentrations, anomalous concentrations of iron and titanium and strongly anomalous concentrations of chromium and magnesium. The anomalous values may reflect the normal high background metal content of these mafic igneous rocks.

Sporadic anomalous concentrations of manganese, iron and sodium occur in samples of schist and iron-stained quartz vein material. No base metal anomalies of significance were found in the schist and quartzite countryrock near Wiseman, however the area needs further work.

Mining Activity and Economic Geology

Placer gold was first discovered in the Koyukuk district on the bars of the Koyukuk River, some time between 1895 and 1900. The first major placers were discovered on Myrtle Creek and on the Hammond

River, around 1899 and 1900 respectively (Cobb, 1973). Placer gold production for the district through 1961 amounted to about 270,000 ounces of gold. Most of the production has been restricted to an area within about a 32 kilometer (20 mile) radius of Wiseman.

Lode production in the Koyukuk district has been small, and generally restricted to production of antimony from stibnite-quartz veins that cut the crystalline schist country-rock throughout the region.

Mining activity in the region today consists mainly of small, gold placer operations on many of the old producing creeks. One large operation on Mascot Creek, west of Wiseman, was in operation in 1977. No known lode mining was in progress in 1977.

The metamorphic rock sequence between Wiseman on the north and Twelvemile Creek on the south, in the Pipeline Corridor, has been correlated with a similar sequence of rocks in the western Brooks Range (Grybeck et al, 1977). The metamorphic sequence in the western Brooks Range has been interpreted as resulting from pene-contemporaneous miogeosynclinal sedimentation and volcanic activity sometime in the early Paleozoic (Thomas E. Smith, Univ. of Alaska, personal communication, 1977). The metamorphic rocks in the western Brooks Range are the host for the metamorphosed volcanogenic massive sulfide deposits of the Ambler mining district. This sequence of metamorphic rocks is composed of marble, metasiltstone, grit and phyllite of sedimentary origin and quartz-muscovite schist, quartz-feldspathic schist, meta-rhyolite and greenstone of volcanic origin. The known massive sulfide deposits of the Ambler district are for the most part restricted to the meta-volcanic rocks. Rocks in the Pipeline Corridor that have been correlated with rocks of the Ambler district are composed of a relatively thick sequence of phyllite, marble, calc-schist, quartz-feldspathic schist, quartz-muscovite schist and quartzite with complex structural and stratigraphic relationships. This metamorphic sequence is complexly folded and faulted and north-vergent isoclinal overturned folds dominate the structure of the region. At Minnie Creek, southwest of Wiseman, a sequence of graphitic quartz-muscovite schist and micaceous quartzite is present. These rocks contain disseminated sulfides, that constitutes as much as 10% of the rock. The sulfide mineralization consists of major pyrrhotite with minor chalcopyrite, sphalerite and galena. No massive sulfides were found during this investigation, however, the nature of the disseminated sulfide mineralization and the country-rock in the Wiseman area are similar to the "country-rock schist" of the Ambler district (Thomas E. Smith, Univ. of Alaska, personal comm., 1977). The possibility of finding volcanogenic massive sulfide deposits in the Wiseman area seems good. More work is needed in the Wiseman area and to the west in the Wiseman quadrangle to further understand the stratigraphy and structure of the rocks and their relationships to the volcanogenic massive sulfide deposits of the southern Brooks Range schist belt.

North of Wiseman a schist, phyllite, quartzite, slate and grit sequence contains disseminated sulfide mineralization locally. No significant mineralization was discovered during this study. This metamorphic sequence is similar to the package of rocks south of Wiseman but of a lower metamorphic grade. The disseminated sulfides found in the area consist of well-developed cubes of pyrite on the parting surfaces of a slate unit, and only minor blebs of pyrite in a quartz muscovite schist. At Vermont Dome, a northeast-trending zone of quartz veining is about 100 meters (300 feet) wide and contains at least five veins up to 2.4 meters (8 feet) wide. The U. S. Geological Survey has identified stibnite in the vein material, prior to this study, however, no sulfides other than pyrite were found during the present study. The veins are composed of bull quartz and large euhedral quartz crystals to 7.6 centimeters (3 inches) inches in diameter are present. The vein material also contains large clots of chlorite and muscovite that are generally restricted to the vugs and open-spaces of the veins.

Most of the Creeks in the Wiseman area have been prospected for gold placers in the past and many have produced gold. At several localities above gold-bearing creeks, quartz veins of various sizes have been found. The veins are typical open-space filling type veins that are probably the source of the gold in the creeks. One vein above Confederate Gulch, north of Wiseman, contains euhedral pyrite octahedrens and no other sulfides.

A stibnite-quartz vein is present on Smith Creek, northwest of Wiseman. The vein is composed of stibnite and quartz and little more. About 20 tons of stibnite has been mined from the vein, some of which was recovered by ground sluicing the surface exposure of the vein, in the creek bottom. Several stibnite-quartz veins are known in the Wiseman area and the probability of finding undiscovered antimony resources in the Wiseman area seems high.

South of Wiseman, calc-schist and marble layers in the metamorphic sequence contain scheelite. The extent of the tungsten mineralization is unknown (WGM, Inc., personal comm., 1977).

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Chandalar Quadrangle

Previous Investigations

Geologic investigations and topographic mapping in the Chandalar quadrangle began as early as 1899 when Schrader (1900) traversed the Koyukuk and Chandalar Rivers. Gold production in the Chandalar district began as early as 1906 with the discovery of placer gold deposits on Big Creek and St. Mary's Creek, east of Chandalar Lake. Brooks (1907-1923) described much of the mining activity in the Chandalar region. These reports served as a base from which Mertie (1925) produced the first regional geologic maps of the area. Later work by Mertie (1930) to the east near the Sheenjek River, was the first geologic work done in the eastern part of the quadrangle. Maddren (1913) of the U. S. Geological Survey conducted geologic investigations along the upper Koyukuk and Chandalar Rivers and compiled geologic information obtained by previous investigators in the region. Maddren's work resulted in one of the most complete descriptions of the bedrock geology and mining activity in the Chandalar district. Recent work by Brosge and Reiser (1964) has resulted in a geologic map and structural section of the Chandalar quadrangle. Some regional geochemical investigations have been conducted in conjunction with the mapping programs.

Detailed geologic investigations by Chipp (1970) were conducted in the area near the Mikado Lode, a gold-quartz vein deposit, just east of Chandalar Lake. Chipp (1970) described the bedrock geology and conducted geochemical sampling of the area and presents a structural interpretation of the rock sequences near Chandalar Lake.

Recent work by Lathram (1971) on the tectonics of northern Alaska has provided the basic tectonic framework of the region and has produced the base upon which Churkin (1973) and others have made paleo-tectonic reconstructions and have developed models of the depositional history of northern Alaska from the middle Cambrian through the Cretaceous. The reconstructions are based on litho-environmental interpretations from oil well logs and measured sections throughout the area. Packer et al (1975) present new data on the seismicity of the area. Alaska State Division of Geological and Geophysical Surveys work in the eastern Chandalar quadrangle describes some contact metasomatic "porphyry" deposits near the Mathews River (Wiltse, 1975, unpublished).

Regional Geology and Petrology

The regional geology of the Chandalar quadrangle is dominated by a Precambrian (?) to Tertiary sequence of metasedimentary and metaigneous rocks, clastic sedimentary rocks and intrusive igneous rocks of varying composition. The metamorphic rock sequences are folded, faulted and structurally thickened. Imbricate thrust faulting along the south-flank of the Brooks Range, coupled with questionable stratigraphic relationships between rock units add to the complexity of the geology and to the uncertainty of the stratigraphic position of the various rock units.

Rocks in the southeastern part of the quadrangle are dominantly intrusive rocks that vary from granite to diorite in composition. Several large batholithic complexes are present and the intrusive rocks have a gneissic texture and are sheared and crushed locally (Maddren, 1913). The granitic rocks are generally medium-to coarse-grained, porphyritic biotite granite and gneissic granite that are chloritized. Gneissic quartz monzonite and granodiorite are present locally and contain secondary epidote and calcite. A potassium argon age determination of 101±5 million years B.P. was obtained from the granite of the Hodzana Pluton in the southwestern corner of the quadrangle. The Hodzana Pluton is in contact with a unit composed predominantly of andesite-to dacite flows, pyroclastics and dioritic intrusives believed to be Devonian in age. The volcanics are predominantly pyroxene andesite and hornblende andesite. The intrusive rocks are mainly pyroxene diorite and some gabbroic rocks occur locally. This unit crops out in a thin belt that can be traced from the Mosquito Fork River in the southwest corner of the quadrangle to Caro, near the confluence of Flat Creek and the Chandalar River, in the south-central part of the quadrangle, a distance of about 96 kilometers (60 miles).

Rocks of the Cretaceous Bergman Group have been recognized along the Mosquito Fork River. The Bergman Group in the Chandalar quadrangle is characterized by a sequence of pebble-to cobble-conglomerate and interbedded feldspathic graywacke. The conglomerate is composed of pebbles and cobbles of quartz, quartzite, schist, slate, black and red chert and minor volcanic rock fragments. Fossils found in the Wiseman quadrangle in Bergman Group rocks are Albian in age and plant fossils of late Cretaceous age have also been recognized (Brosge and Reiser, 1964). The conglomerates occur in small, discontinuous outcrops in close proximity to the Devonian volcanics and Cretaceous granitic complexes to the south. The conglomerates strike east-west and dip an average of 30° south.

Just north of the South Fork of the Koyukuk River, small, discontinuous bodies of green, schistose, hornblende diorite and pyroxene diorite of probable Devonian age crop out. The diorite plugs and sills are in contact with black phyllite and slate that are interbedded with fine-grained quartzite. Schistose graywacke and lithic graywacke are present locally. North of the South Fork Flats and south of Slate Creek a sequence of red, black, green, gray and white chert and siliceous argillite is present. The chert is a radiolarian chert locally and is believed to be late Devonian in age (Brosge and Reiser, 1964). Recent work in the Western Brooks

Range by the U.S. Geological Survey has shown that cherts in the Angayucham Mountains may be correlatable with those near the South Fork River, and are Triassic in age.

North of Slate Creek in the western Chandalar quadrangle, a fairly thick sequence of metamorphic rocks is present. The metamorphic rocks consist of quartz muscovite schist, quartz feldspathic schist, calc-schist, micaceous marble, marble, quartzite, slate and phyllite. This sequence is probably equivalent to Chipp's upper plate sequence near Chandalar Lake (Chipp, 1970). Chipp has subdivided his sequence into several mappable units. The lowest most unit is the Mikado Phyllite and is composed of dark-gray, fine-grained phyllite with quartz segregations generally less then 5 millimeters (0.20 inches) thick (Chipp, 1970). Petrographically, the phyllite is composed of about 35% quartz, 40% muscovite, 10% chlorite and 15% opaques. Interlaminated with the phyllite layers are sequences of quartz-muscovite schist and schistose quartzite. The dominant rock type in the schist interlaminations is slightly carbonaceous, quartz, muscovite schist with minor chlorite and rare albite. The upper most unit of Chipp's upper plate sequence is a sequence of interbedded schistose quartzite, quartzite schist and minor phyllite. The schistose quartzite generally consists of about 90% quartz and minor muscovite, chlorite, and trace apatite, sphene, epidote and albite.

Just south of Sukakapak Mountain the character of the schist sequence changes and calcareous schist and marble becomes a prominant member of the rock sequence. The calc-schist is generally a brown-weathering, thin-bedded, calcite-muscovite-quartz-chlorite schist and schistose marble. A few beds of noncalcareous schist and phyllite occur locally. Another prominant rock sequence in the Sukakapak Mountain area is a sequence of schist, phyllite, quartzite, slate and grit. The grit unit is generally a gritty sandstone that locally grades to conglomerate. Minor siltstone is also present.

North of Sukakapak Mountain, the Skajit Limestone unit of upper Devonian age constitutes a major part of the rock sequence. The Skajit Limestone is represented by about 606 meters (2000 feet) of section composed of crystalline and semicrystalline limestone that is dolomitic in part. The limestone ranges in color from white or light-gray to red and brown, where weathering of iron minerals in the limestone has produced the red-brown coloration. The limestones are thin-to massively-bedded and are locally carbonaceous. The limestone sequence contains minor interbeds of calc-schist, muscovite schist, chlorite schist and marble. The sequence may also contain some mafic dikes and volcani-clastics locally. The entire sequence is folded, faulted, metamorphosed and structurally thickened in part by imbricate thrust faulting.

Overlying the Skajit Limestone to the north is an unnamed sequence of slate, phyllite, shale and siltstone with minor schistose sandstone. The contact between this sequence and the underlying

Skajit Limestone is believed to be gradational (Gryc et al, 1976), however, local unconformities may exist. A sequence of calcareous and noncalcareous siltstone, slate, phyllite and calcareous gritty sandstone with minor black limestone interbeds is in unconformable contact with the unnamed slate-phyllite unit overlying the Skajit Limestone.

The plutonic rocks in the central Chandalar quadrangle occur in subparallel northeast-trending belts. An igneous complex north and east of Twin Lakes is composed of gneissic, chloritized, biotite granite, quartz monzonite and granodiorite. Minor hornblende granite with secondary epidote and calcite occurs locally.

A narrow belt of hornblende granodiorite porphyry intrusives east of Mathews River can be traced to the northeast as far as Thru Creek in the north-central part of the quadrangle, a distance of about 48 kilometers (30 miles). The granodiorite bodies are generally composed of fine-to medium-grained hornblende granodiorite, with hornblende phenocrysts to 5 millimeters (0.2 inches) in length. The margins of the intrusives are highly sheared and locally the shearing and pervasive metamorphism has transformed the granodiorite into quartz-chlorite-muscovite schist (Wiltse, unpublished data, 1975). Where the granodiorite intrudes limestone and calc-schist, the calcium-rich rocks have been thermally and hydrothermally altered and calc-silicate hornfels skarns are developed. Well-developed epidote and garnet appear to have selectively replaced the limy country rock (Wiltse, unpublished data, 1975).

A northeast-trending belt of greenstone and greenschist is present in the Mount Snowden area and extends to Your Creek in the north-central part of the quadrangle. The greenstones generally occur in isolated bodies of dark-green, fine-to medium-grained, schistose, hornblende diorite and pyroxene diorite and also as altered andesitic flows. The greenstones contain secondary calcite, epidote and chlorite that probably represent a lower greenschist facies metamorphic event. Similar greenstones in the Christian quadrangle to the east have been dated at 168±8 million years B.P. (Reiser et al, 1965). The greenstones vary in grain size and texture but are generally composed of actinolite, clinozoisite and epidote with minor calcite, chlorite, sphene and quartz. Texturally the greenstones range from aphanitic to granoblastic and blastoporphyritic with actinolite phorphyroblasts to 5 millimeters (0.02 inches) in length. Small segregations of albite with minor calcite, quartz, epidote, clinozoisite, sphene and chlorite occur throughout the greenstones (Chipp, 1970).

Discontinuous sequences of Kanayut Conglomerate of upper Devonian age and Kayak Shale of lower Mississippian age crop out in the northwest corner of the Chandalar quadrangle. Associated with the upper Devonian rocks are the lower members of the Lisburne Group of lower Mississippian age.

Structural Geology

The structure of the rocks in the Chandalar quadrangle is dominated by northeast and east-trending large scale fold belts and imbricate thrust faulting. The thrust faulting has superimposed metasiltstone, marble, black slate, grit and calcareous schists in structural rather then depositional sequences (Wiltse, unpublished data, 1975).

At least two metamorphic events have affected the rocks in the western Chandalar quadrangle. The polymetamorphic character of the rocks is exhibited by isoclinal overturned folding and a smaller pervasive structural event that produced crenulations, quartz boudins and stringers whose strike is oblique to the regional strike of the major structures. Locally, small generally less than 5 centimeters (2 inches) wide premetamorphic quartz veins are enfolded with schist and quartzite and ptygmatic folding is well developed.

Brosge and Reiser (1964) believe that one pulse of metamorphism affected the rocks in the region some time in the early Paleozoic, and have dated samples of schist at 465±14 million years B.P. and 520 million years B.P. This metamorphic event is believed to be related to the isoclinal overturned folding present throughout the terrane. Another event sometime in the Cretaceous is believed to be related to a more pervasive metamorphic pulse that produced small crenulations and a secondary cleavage that strikes obliquely to the regional strike of the country rock. This event has been dated at 103 million years B.P. and 100 million years B.P. (Brosge and Reiser, 1964).

Geochemistry

Approximately 71 rock and stream sediment samples were collected in the Chandalar quadrangle during this study by M.I.R.L. personnel. Sixty-five percent of the samples were weakly anomalous, anomalous and strongly anomalous in at least one element (see Tables 35 and 36, Appendix A).

Threshold values (see Tables 37, 38, 39 and 40, Appendix A) for the 90%, 95% and 98% confidence intervals for each element were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.0 x standard deviation, and 2.33 x standard deviation for the 90%, 95% and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are either the detection level or nearly the same level.

Sporadic base metal anomalies were detected in stream sediment samples in the quadrangle. One stream sediment sample from Nugget Creek in the Chandalar B-6 quadrangle contains strongly anomalous concentrations of zinc in excess of 1,000 ppm. The area has been prospected in the past and gold placers in the area have produced gold. Schrader (1904) reported the discovery of galena near the head of Nugget Creek, however no other lode mineral occurrences have been reported in the area.

Samples of phyllite and metasiltstone from the area south of Mt. Snowden contain weakly anomalous concentrations of copper and strongly anomalous concentrations of copper and zinc. The phyllite contains disseminated pyrite and is heavily iron-stained locally. The bedrock in the area consists of phyllite, metasiltstone, calc-schist and porphyroblastic schist, and further work is clearly needed to fully evaluate the areas mineral resource potential.

Mining Activity and Economic Geology

Placer gold was first discovered in the Chandalar quadrangle in 1899 or 1900, when rich placers were found on Gold Creek, a tributary of the Middle Fork of the Koyukuk River. Gold Creek, and Linda Creek and Magnet Creek which are tributaries of Gold Creek have produced at least 19,600 ounces of gold through 1968 (U. S. Bureau of Mines). The richest ground on Gold Creek occurs where diorite dikes and resistant units in the schist produce constrictions in the valley walls. One such constriction, near the mouth of Magnet Creek is the sight of the richest accumulation of gold in the area. The ground in Gold Creek is fairly shallow, although ground as much as 30 meters (100 feet) deep is known in an abandoned stream channel near Linda Creek. Five miles northeast of Gold Creek, on Emory Creek, minor production from gold placers has occurred. Only about $10,000 in production has been reported from the shallow placers there.

Placer gold was discovered on Big Creek, a tributary of the North Fork of the Chandalar River, in 1906. Big Creek has yielded about 15,000 ounces of gold, of which about 10,000 ounces has been produced from 1950 with the introduction of mechanical equipment. Other creeks in the Chandalar Lake area that have had past production include: Little Squaw Creek; Big Squaw Creek; Tobin Creek; Little McClellan Creek; St. Mary's Gulch and Woodchuck Creek. Bedrock depths in the creeks ranges from 0 to 30 meters (0 to 100 feet) and exceeds 30 meters (100 feet) locally. Total production from the placers in the area has been about 40,000 ounces of gold (Heiner and Wolff, 1968).

About 1908, several gold-bearing quartz veins were discovered near the head of Tobin Creek. By 1913, a shaft 30 meters (100 feet) deep had been sunk and approximately 150 meters (500 feet) of tunnel had been driven on the Mikado Property. One of the tunnels cross cut a 12 meter (40 foot) wide shear zone. The shear zone appears to be a sheeted shear system that contains discontinuous gold values and minor concentrations of arsenopyrite, sphalerite, galena, stibnite and pyrite. A 100 ton per day mill has been erected on site and only sporadic production has taken place to date. Several other gold quartz veins in the area have received some attention but none have produced any ore.

A northeast-trending belt of hornblende granodiorite intrusives and associated copper mineralization is present along a line from Wiehl Mountain to Thru Creek, in the north-central part of the quadrangle. The copper mineralization has received considerable attention since the early 1960's, and no production has occurred. Wiltse (unpublished data, 1975) believes that these deposits are pyrometasomatic skarn deposits that are genetically associated with the hornblende granodiorite bodies. The sulfide mineralization is primarily restricted to pyrite and chalcopyrite that occur as disseminated grains throughout the intrusives and also as enriched zones near the contact with the limy country rock. High-grade pods of massive magnetite and concentrations of chalcopyrite that constitute as much as 15% of the rock are present locally. Since 1960, at least 15 claim groups have been staked on similar deposits and the probability of finding other deposits of this type in the western Chandalar quadrangle seems high.

A shear zone that marks the contact between dark-gray phyllite and a massive limestone unit that constitutes the bulk of the rocks in the Mount Snowden area can be traced for at least 3.2 kilometers (2 miles). The zone of shearing contains discontinuous segragations of pyrite and chalcopyrite. No mineralization of obvious significance was found however.

Just south of Mount Snowden, a fairly large body of greenstone crops out. The greenstone body is gabbroic inpart and contains disseminated pyrite and chalcopyrite. The sulfide mineralization does not appear to be of an economic nature, however, other greenstones in the region may contain similar mineralization.

Phyllitic rocks south of Mount Snowden are polymetamorphosed siltstones and mudstones that contain disseminated pyrite. The pyrite occurs in rudimentary cubes and as blebs that are alligned in layers parallel to the dominant foliation. No other sulfide minerals were recognized in the phyllites, however, further work is needed in the area to fully assess the true mineral potential.

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Previous Investigations

Detailed geologic investigations in the Philip Smith Mountains quadrangle began as early as 1901 when F. C. Schrader of the U. S. Geological Survey traversed the area between Bettles and Barrow. Earlier work by several groups of explorationists along the northern coast of Alaska began as early as 1826 when the Earl of Bathhurst, Sir John Franklin decended the MacKenzie River to its mouth and explored westward to about the 149th degree of longitude (Schrader, 1904). Later work by Dease and Simpson around 1837 surveyed the general geography of the region. Their surveys also described some first geologic observations made during their traversing. Work by Leffingwell (1919) in the Canning River region contributed much to the early geographic and geologic information of the area. Detailed descriptions of permafrost conditions and periglacial processes that are active in the high arctic are included in Leffingwell's work. Geologic investigations in the region continued at a slow pace until about 1940 when the U. S. Geological Survey and the Department of the Navy undertook a program to evaluate the gas and oil potential of Naval Petroleum Reserve #4, now known as National Petroleum Reserve Alaska.

Recent work by Bowsher and Dutro (1957) of the U. S. Geological Survey in the Shainin Lake area has resulted in a better understanding of the stratigraphy and structure of the rock units in the region. Detailed geologic investigations east of Shainin Lake in the Shaviovik and Sagavanirktok Rivers region by Keller et al (1961) has resulted in detailed descriptions of the Mississippian to recent geologic section present in the area. The detailed rock descriptions contained in their report serve as a base for much of the later work in the area. Geologic mapping and sampling by Patton and Tailleur (1964) in the Killik-Itkillik region, east of Shainin Lake has resulted in a regional geologic map and detailed stratigraphic data for the rocks in the area. Brosge et al (1962), produced the first good synthesis of the geologic setting and bedrock geology of the region between Galbraith Lake and the Canadian border. Detailed geologic work by Porter (1965), in the Anaktuvak Pass region contributed much to the understanding of the geologic history and structural evolution of the rock sequences on the north-flank of the Brooks Range. Detailed mapping and structural interpretations by Reed (1968), in an area of the northeast Brooks Range near Peters Lake, resulted in a good treatment of the bedrock geology of the area. Geologic investigations, by Tourtelot and Tailleur (1971), on the Shublik Formation in northern Alaska described the unit, and it's depositional and diagenetic history as well as it's trace and major elemental compositions. Similar work by Wood and Armstrong (1975) on the Lisburne Group limestones resulted in the most complete description of the Lisburne Group, its stratigraphy and its diagenetic history.

Armstrong and Mamet (1975), have studied eight carboniferous stratigraphic sections in north-east Alaska and have described the biostratigraphy of these rocks. Detterman et al (1975) conducted detailed investigations of the post-carboniferous rocks in north-eastern Alaska that resulted in a complete description of these rock units.

Regional Geology and Petrology

The north-central Brooks Range in the Philip Smith Mountains quadrangle is underlain by a thick sequence of highly deformed marine and non-marine detrital sedimentary and marine carbonate rocks of Paleozoic and Mesozoic age (Porter, 1965).

The oldest rocks that crop out in the southern Philip Smith Mountains quadrangle consist of discontinuous outcrops of the middle and upper Devonian Skajit Limestone. The Skajit Limestone is represented by at least 610 meters (2,000 feet) of thin-to massive-bedded, light gray to red-brown, recrystallized limestone and dolomitic limestone. Chert constitutes a major portion of the Skajit Limestone in the Philip Smith Mountains quadrangle, unlike the Skajit Limestone in the Chandalar quadrangle, where chert is lacking and slate and minor sandstone make up a major part of the sequence. Unconformably overlying the Skajit Limestone in the southern part of the quadrangle is a sequence of silty shale, siltstone and sandstone that make up the lowest member of the Hunt Fork Shale. The shale and siltstone are generally dark-gray and weather dark yellow to red. The sandstones are characteristically gray-green, thin-bedded, very fine-grained, calcareous sandstones. Locally, beneath the lower member of the Hunt Fork Shale is an unnamed unit that is composed of brown to orange, gray and black, shale, sandstone, siltstone, conglomerate and limestone that may contain reef structures (Brosge et al, 1977). Minor shaly limestone, conglomeratic limestone, red and green shale, and phyllite are also present. At it's type section on Fire Creek, about 40 kilometers (25 miles) east of the Killik River, the Hunt Fork Shale is about 970 meters (3,200 feet) thick, the lowest 240 meters (800 feet) constitutes the lowest member.

The lowest member of the Hunt Fork Shale grades upward into a sequence of rocks composed of about 300 meters (1,000 feet) of silty shale and siltstone. The shale is generally gray to greenish-gray, dark yellow-red weathering shale with dark-gray silty concretions to 10 centimeters (4 inches) in diameter. Conformably overlying the shale-slate member is a sequence of about 379 meters (1,250 feet) of clay shale, siltstone and silty shale. The lower 76 meters (250 feet) of this member is distinctive because of the nonresistant nature of the clay shale horizons. The clay shales weather easily and usually form areas of lower topographic expression. The soils produced from the weathered clay shale is characteristically bright red, and are easily recognized. A characteristic feature of the Hunt Fork Shale is the relative abundance of anastomozing quartz veins. Pyrite and marcasite crystals are common with small amounts of galena (Chapman et al, 1964). Fossil marine brachiopods, pelecypods, gastropods and fish teeth found in the Hunt Fork Shale are mid Devonian in age (Chapman et al, 1964).

Conformably overlying the Hunt Fork Shale is the Kanayut Conglomerate, a dominantly non-marine sequence of interbedded chert pebble to cobble conglomerate, sandstone and shale. The Kanayut conglomerate has been subdivided into three members at it's type locality near Shainin Lake. The overall extent of the Kanayut conglomerate is not known, however, it has been recognized as far west as Feniak Lake in the western Brooks Range and as far east as the Sheenjek River in the eastern Brooks Range.

The total stratigraphic thickness of the Kanayut probably does not exceed 1,515 meters (5,000 feet). The unit apparently thins to the south, where Kayak Shale of lower Mississippian age lies directly on middle Devonian sandstones and shales possibly of the Hunt Fork Shale. The Kanayut also thins to the north, where it is not recognized in the northern belt of Paleozoic rocks. It may be absent or may be equivalent to a thin conglomerate unit named the Kekiktuk Conglomerate (Brosge et al, 1962). The lowest member of the Kanayut Conglomerate is composed of thin-bedded, fine-grained sandstone and interbedded shale. The sandstone is generally an olive-gray, red-brown weathering, quartzose sandstone that is cross-stratified and occurs in beds less than 0.3 meters (1 foot) thick. The intercalated shale is mainly composed of thin-bedded and cross-bedded, dark-green to black, platy, silty shale and shale. The contact between this lower unit of the Kanayut Conglomerate and the underlying Hunt Fork shale is conformable and appears to be gradational (Chapman et al, 1964). The maximum stratigraphic thickness of this lower unit is about 545 meters (1,800 feet), near Red Rock Mountain, southeast of Anaktuvak Pass (Porter, 1965). The middle member of the Kanayut Conglomerate constitutes the bulk of the unit and is characterized by the presence of conglomerate beds. The middle member exposed at Shainin Lake is composed of about 311 meters (1,026 feet) of conglomerate, sandstone and shale that are interbedded in a possible cyclic pattern throughout the member (Porter, 1965). Porter (1965) describes the cyclic sedimentation as a fining upward sequence of conglomerate to coarse sandstone to shale. Near the top of the conglomerate member (middle member) the amount of conglomerate decreases and is replaced by cross-bedded, platy sandstone. The conglomerate layers do not persist laterally for great distances, and generally are lensoid in shape with thicknesses ranging from 0.3 to 10 meters (1 to 30 feet) (Porter, 1965). Eighty-five percent of the pebbles in the conglomerates are composed of chert ranging to 5 centimeters (0.2 inches) in diameter. The chert varies widely in color with gray, white, black, bluish green, yellowish brown, and red varieties known. White quartz pebbles make up about 5% of the pebbles and the remaining 10% of the pebbles are composed of quartz sandstone, argillite and chert breccia. The pebbles lie in definite layers or are scattered throughout a finer-grained matrix of coarse-grained, quartz sandstone that constitutes between 50 and 80% of the rock. The primary cementing agents are silica and iron oxide. Where silica is the cementing agent, the rock is extremely competent and cross-grain fracturing occurs. The sandstones of the middle member of the Kanayut Conglomerate range from poorly bedded units to well-bedded layers of brownish-gray to light olive-gray, medium-to coarse-grained, thin-bedded to massive, locally ferruginous quartzose sandstone. Locally, thin beds of black pyritic shale containing plant fragments are present (Porter, 1965).

The upper part of the Kanayut Conglomerate, known as the Stuver Member, consists mainly of conglomerate and sandstone. At it's type locality near Shainin Lake, the Stuver Member is composed of between 25 and 50% shale and 50 to 75% fine-grained sandstone and siltstone, and no conglomerate layers are present. The sandstone is usually massive and poorly bedded near the base of the member, and becomes well-bedded near the top of the section. The sandstone is normally a fine-grained, light gray, yellow-weathering sandstone. Shale interbeds are typically brownish-gray-to olive gray or black, platy shale. Raindrop impressions, mudcracks, ripple marks and worm trails are found on the bedding surfaces as well as well preserved plant fossils. The sandstones and shales of the Stuver Member are gradational with the underlying conglomerate member. As much as 300 meters (1,000 feet) of Stuver Member rocks are present in the Anaktuvak Pass area and about 260 meters (860 feet) of section is represented at it's type locality near Shainin Lake, therefore Porter (1965) feels that the Stuver Member thickens to the southwest, which is the case for the entire Kanayut Conglomerate sequence.

Unconformably overlying the Kanayut Conglomerate is the Kayak Shale of lower Mississippian age. Bowsher and Dutro (1957) subdivided the Kayak Shale into five informal members near Shainin Lake. Total thickness of the Kayak Shale is about 290 meters (960 feet). However, due to it's incompetent nature, the shale is extremely deformed. The basal sandstone member consists of about 40 meters (130 feet) of poorly-bedded, grayish-brown siltstone and a more competent medium-gray to brown-gray, very fine-grained quartzose sandstone. The sandstones are ripple marked and worm trails are present locally. The lower black shale member overlying the basal sandstone, is grayish-black, hard, fissile, yellow-weathering shale. The shale contains a strong, well developed axial-plane cleavage (Porter, 1965). The argillaceous limestone member of the Kayak Shale is a bluish-gray, coarsely crystalline, argillaceous, bioclastic limestone. The total thickness of the limestone member is about 30 meters (100 feet). Intercalated shale horizons contain abundant limonite that gives the rock a red-yellow coloration. The upper shale member is composed of dark-gray, calcareous shale and medium-dark gray, slightly argillaceous, bioclastic limestone that weathers dusty red and reddish brown, and is about 43 meters (141 feet) thick. Conformably overlying the upper shale member is a very distinctive, reddish weathering, ferruginous, fine-to medium-grained bioclastic limestone. The limestone layer ranges between 0.3 and 5 meters (1 and 15 feet) thick and is an easily recognized unit marking the upper limit of the Kayak Shale.

Unconformably overlying the Kayak Shale in northern Alaska are rocks of the early and late Mississippian Lisburne Group. The Lisburne Group was first described by Schrader (1904) as the Lisburne Formation, and has since been upgraded to the group status. The Lisburne Group is subdivided into three formations, the Wachsmuth Limestone of early Mississippian age and the Alapah Limestone of late Mississippian age and the Wahoo Limestone of Pennsylvanian and Permian age. The Wachsmuth Limestone has been subdivided into four members at it's type locality near Shainin Lake. The lowest member of the Wachsmuth Limestone at Shainin Lake is a unit that is much the same as the upper part of the underlying Kayak Shale and consists of dark-gray to olive-gray, fine-grained, shaly, argillaceous, nodular limestone and shale. The dominance of the carbonate content of this member is the marked difference between this unit and the underlying Kayak Shale. This sequence of rocks probably represents a continuation of quiet, open-water marine sedimentation that persisted during the deposition of the Kayak Shale (Wood and Armstrong, 1975). The shaly limestone member of the Wachsmuth Limestone is about 6 meters (18 feet) thick at the type locality. Conformably overlying the shaly member of the Wachsmuth Limestone is a richly fossiliferous member that is composed of medium-to dark-gray, medium-to coarse-grained, crinoidal limestone in which the bioclastic content is as high as 20%. The crinoidal limestone member of the Wachsmuth Limestone is about 55 meters (180 feet) thick at its type locality and like the entire Wachsmuth Limestone member, it thins to the northeast and is entirely absent in the Peters Lake section, in the Romanzof Mountains (Reed, 1968).

Conformably overlying the crinoidal limestone member of the Wachsmuth Limestone is a fairly thick sequence of light-gray to white, medium-to coarse-grained, slightly argillaceous, bioclastic, dolomitic limestone, that is about 171 meters (564 feet) thick at the type locality at Shainin Lake. Locally within the member, thin, discontinuous layers of chert are present. The dolomitic phase of the middle member of the Wachsmuth Limestone has been recently interpreted as resulting from sedimentation in a sabkha-type environment near the margin of a semi-restricted marine stable platform, sometime in the early Mississippian (Armstrong et al ,1975 p. 1). The chert of this member is usually present throughout the section, however, the amount of chert appears to decrease toward the top of the section. Locally, in the lower quarter of the middle member, the chert constitutes as much as 40 to 50% of the section. The upper banded chert member of the Wachsmuth Limestone is a 130 meter (429 foot) thick section of thin-banded limestone and chert. The chert is usually a thin-bedded, light-gray to dark-gray, thin laminated to nodular chert. Minor dolomitic limestone layers also occur, interbedded with medium-gray to light-gray, fine-to medium-grained, evenly and irregularly bedded, bioclastic limestone (Patton, 1957). Fossils are fairly common in all of the members of the Wachsmuth Limestone and include crinoids, brachiopods, rugose corals, colonial corals, cephalopods and bryozoans. Total thickness of the unit at the type locality is about 373 meters (1,230 feet), and about 409 meters (1,350 feet) of Wachsmuth Limestone has been measured to the west near Anaktuvak Pass (Porter, 1965). The entire Wachsmuth Limestone is absent to the east near Peters Lake (Reed, 1968). In two measured sections south of Shainin Lake, the banded limestone-chert member may be as much as 90 meters (300 feet) thinner than at Shainin Lake (Brosge et al, 1962). Therefore, the Wachsmuth Limestone unit appears to thin to the east and south.

Conformably overlying the Wachsmuth Limestone is the Alapah Limestone, the late Mississippian component of the Lisburne Group. The Alapah Limestone has been subdivided into nine members at Shainin Lake. Most of the member can be recognized to the east, however, many investigators have lumped the members into three units for ease of geologic mapping. The lower four members of the Alapah Limestone unit at Shainin Lake have been lumped by Porter (1965) and others into a lower Alapah member that is composed of a thick section of limestone and chert. The lower part of this member consists of a basal sequence of dark-gray, fine-grained shaly limestone and minor interbedded black chert, overlain by a thick sequence of dark-gray, fine-grained, argillaceous, massive and thin-bedded, cherty, bioclastic limestone. Next, a sequence of light brown to gray, fine-to medium-grained, fossiliferous limestone is present. The limestones exhibit a coarsening upward habit, with fine-grained limestone grading into medium-grained limestone near the top of individual limestone beds. This sequence is in turn overlain by a member that is composed of brownish-gray, fine-to medium-grained bioclastic limestone. The middle member of the Alapah Limestone is composed of about 76 meters (250 feet) of non-resistant, dark-gray, calcareous shale and grayish-black chert. Minor interbeds of dense, hard, dark-gray, platy limestone that is interbedded with light olive-gray shale and dark-gray argillaceous phosphorite (Porter, 1965). The limestones contain well-developed cross-laminations. The upper lumped unit of the Alapah Limestone consists of the upper four members of the Alapah at its type locality. The upper member is composed of light-gray, fine-grained limestone with interbeds of dark-and light-gray, thin-bedded chert and thick bedded, light gray, fine-grained limestone that contains abundant brachiopods and a coral assemblage including lithostrotionella. This unit is wide-spread and quite distinctive and is invariably found a short distance above the base of the upper member (Porter, 1965). Gigantoproductus, a productid brachiopod, is quite common near the top of the upper limstone member. Specimens of Gigantoproductus to 10 centimeters (4 inches) across have been found in the Galbraith Lake area, in a thin limestone bed believed to be part of the upper limestone member of the Alapah Limestone.

Total thickness of the Alapah Limestone at the type locality near Shainin Lake is about 294 meters (970 feet) (Bowsher and Dutro, 1957), and it is about 704 meters (2,325 feet) thick near Anaktuvak Pass. The unit thins to the east near Galbraith Lake, where about 182 meters (600 feet) of Alapah Limestone is present and then thickens to the east near Wahoo Lake, where 590 meters (1,947 feet) of section is present. The Alapah thins northward along the northeast front of the Brooks Range (Brosge et al, 1962).

Conformably overlying the Alapah Limestone in the northeastern Brooks Range is the Wahoo Limestone of Pennsylvanian and lowest Permian age (Armstrong, 1970). The Wahoo Limestone is absent near Galbraith Lake and thickens to 414 meters (1,367 feet) in the easternmost Brooks Range. Brosge et al (1962) have subdivided the Wahoo into two informal members, the upper member and a lower member. The lower member of the Wahoo limestone is characteristically a medium-gray, fine-to coarse-grained, limestone with minor chert. The upper member of the Wahoo Limestone is similar in composition to the basal crinoidal limestone member of the Wachsmuth Limestone. The rocks commonly consist of coarse-grained crinoidal limestone with minor interbeds of shale and thin-bedded shaly limestone. The upper member is distinguished from the lower member by a zone of black nodular chert that occurs at the base of the upper member. Dolomite is lacking in both members, and coarse-grained limestone constitutes as much as 65% of the upper member. At Galbraith Lake, the upper member of the Wahoo Limestone is missing and rocks of the Permian Siksikpuk Formation rest unconformably on rocks of the lower member. The upper beds of the lower member are pyritic, where they underlie rocks of the Siksikpuk Formation.

Disconformably overlying rocks of the Mississippian Lisburne Group and disconformably underlying rocks of the Triassic Shublik Formation is a Permian sequence of shale, siltstone and minor chert known as the Siksikpuk Formation. At the type locality on Skimo Creek, west of Chandler Lake, the Siksikpuk Formation consists of about 107 meters (354 feet) of variegated green, gray and dark-red, calcareous, cherty, locally ferruginous, shale and siltstone. The shale and siltstone occur in beds that vary from thin and fissile to massive beds as much as 15 centimeters (6 inches) thick. The unit is easily recognizable because it weathers a characteristic red-yellow color. Minor limestone interbeds occur in the section and calcareous cannon-ball concretions are found in and interbedded with the shale and chert. The Siksikpuk Formation in the Galbraith Lake area is at least 181 meters (600 feet) thick and probably as much as 300 to 600 meters (1,000 to 2,000 feet) of section may be present (Brosge et al, 1962). Structural thickening, crumpling, thrust faulting and isoclinal overturned folding in the Atigun Canyon area has obscured the true thickness of the Siksikpuk Formation. The lower part of the Siksikpuk Formation is richly pyritic and thin zones and concretions of pyrite are present. Bladed barite concretions and discontinuous zones of barite are present throughout the Atigun Canyon section. Stratigraphically, the Siksikpuk Formation is equivalent to the Echooka Formation, the lowest formation in the Sadlerochit Group. The Echooka Formation is not recognized in the Galbraith Lake section and the Siksikpuk is considered the lower member of the Sadlerochit Group. The rocks of the Siksikpuk Formation contain an abundant assemblage of fossils including brachipods, corals, and some gastropods, that yield an early Permian age (Brosge et al, 1962).

East of the Sagavanirktok River, the Siksikpuk Formation is not recognized (Yochelson and Dutro, 1960) and the lower member of the Sadlerochit Group that is recognized is the lower part of the Echooka Formation. The Echooka Formation is equivalent in age to the Siksikpuk Formation but differs lithologically. The Echooka Formation has been subdivided into two members; the Joe Creek Member, composed of about 112 meters (371 feet) of thin-bedded, poorly indurated, calcareous, limy siltstone and shale, minor chert interbeds and some quartzose sandstone occurs locally. The sandstones are glauconitic in part and generally consist of detrital quartz and some calcite. The lower 60 meters (200 feet) of the Joe Creek Member is predominantly a dusky-yellow, calcareous mudstone and calcareous siltstone. The rest of the Echooka Member is dominantly quartzose sandstone, quartzite and quartzitic siltstone. The upper member of the Echooka Formation, the Ikiakpaurak Member, is composed predominantly of orthoquartzite, quartzitic sandstone and siltstone. The Ikiakpaurak Member is about 85 meters (280 feet) thick at its type locality and is composed of dark, quartzose sandstones and siltstones that are interbedded with minor orthoquartzites, that are glauconitic in part. The Ikiakpaurak Member is not recognized in the Galbraith Lake section (Detterman et al, 1975).

Conformably and locally unconformably overlying the Echooka Formation is the Ivashak Formation, an early Triassic sequence of silty shale, siltstone, massive sandstone and shale, that is considered the upper formation of the Sadlerochit Group. The Ivashak Formation has been subdivided into three members. The lowest member, the Kavik Member, is composed of thinly laminated to thin bedded, silty shale and siltstone that are composed for the most part of alternating layers of detrital quartz grains and dark bands of sericitic clay. Quartz constitutes as much as 40% of the rock. Conformably overlying the Kavik Member is the middle, Ledge Sandstone Member of the Ivashak Formation. The Ledge Sandstone Member commonly forms prominant hogback ridges and questas, due to its resistant nature. The Ledge Sandstone is composed of 58 meters (190 feet) of medium-grained, massive, quartz arenite. The arenite is composed of 30 to 40% chert fragments and 50 to 60% quartz in subrounded and well-rounded grains. Minor detrital tourmaline, plagioclase feldspar, zircon and pyrite are also present. Locally, the sandstone is conglomeratic and the conglomerates occur in well defined zones in the upper part of the member. The conglomerates are composed of sub-angular to well-rounded granules and pebbles of quartz and chert up to 2.5 centimeters (1 inch) in diameter. A few thin siltstone and silty shale beds are intercalated with the sandstone beds. The upper 33 meters (110 feet) of the Ivashak Formation is composed of thin-bedded to massive, siliceous siltstone and minor silty shale and argillaceous sandstone of the Fire Creek Member (Detterman et al, 1975). The siltstones are predominantly composed of 40 to 80% mineral grains in a siliceous clay matrix. The mineral grains are all well-rounded and are composed of 40 to 60% quartz and as much as 20% chert. Calcite and pyrite occur locally and minor garnet and zircon are present (Detterman et al, 1975).

Recent work by Detterman (1976) on rocks of the Permian and lower Triassic Sadlerochit Group has shown that at least some of the rocks of Permian age in the north eastern Brooks Range are volcanic rocks. At two localities, one on the Ivishak River and the other near Porcupine Lake, Detterman (1976) has identified tuffs, volcanic breccias and flows that exhibit some pillow structures. The tuffs near the Ivishak River are light-to dark-green, fine-grained, amygdaloidal flows. The section near Porcupine Lake is part of a major thrust complex that rests on lower Cretaceous strata (Detterman, 1976). The volcanics are light grayish-green, fine-to medium-grained flows. Dutro et al (1977) have shown that some of the rocks of the upper Devonian sequence in the central Brooks Range include volcanoclastic rocks and flows and include mafic pillow lavas that Dutro believes marks the onset of deeper water deposition in Frasnian (late upper Devonian) time. Sporadic volcanic activity from the Devonian to the Permian in north-central Alaska may have resulted in the deposition of tuffaceous sedimentary rocks as well as still unrecognized volcanic sequences within the predominantly marine sedimentary sequence. Tailleur (personal communication, 1977) believes that much of the shale and siltstone present in the northcentral Brooks Range may in fact be tuffaceous sedimentary rocks.

Conformably overlying the Fire Creek Siltstone Member of the Sadlerochit Group in northeastern Alaska is the Shublik Formation of middle and late Triassic age. The Shublik Formation has been informally subdivided into three members, based on changes in lithology. The basal siltstone member is composed of 21 meters (70 feet) of thin-bedded, organic-rich, phospathic siltstone. Phosphatic concretions and grains with quartz nuclei are fairly common, and detrital grains of plagioclase and sericite are present. The middle member of the Shublik Formation is composed of 100 meters (300 feet) of thin-to thick-bedded, light-gray, silty, fossiliferous limestone and dolomite. The limestone is phosphatic in part and contains small phosphate pebbles and green-gray and black chert grains. Locally, chert layers are interbedded with thin interbeds of silty shale. The remaining 27 meters (90 feet) of the Shublik Formation, at the type locality, is composed of a very soft, incompetent, sequence of fissile, calcareous shale. The shale contains limestone and phosphatic concretions. Locally, the Shublik Formation near Galbraith Lake, in Atigun Canyon, is represented by a sequence of folded and faulted, highly fractured, silty shale, chert and limestone. The contact with the underlying Siksikpuk Formation may be a fault and local disconformable relationships are present.

Conformably and locally unconformably overlying the Shublik Formation in northeastern Alaska is the Kingak Shale of lower to upper Jurassic age (Detterman et al, 1975). The Kingak Shale is not recognized east of the Lupine River, and apparently thickens and thins irregularly over short distances. Near the Canning River, as much as 900 meters (3,000 feet) of section that is most likely Kingak Shale is present (Detterman et al, 1975). However, folding and faulting of the rocks in the area may have resulted in structural thickening of the incompetent shaly horizons. The lower part of the Kingak Shale is represented by at least 181 meters (600 feet) of very fissile paper shale that decomposes into small fragments generally less than 2 centimeters (1 inch) in diameter. Overlying the fissile shale interval is a thin zone of clay shale that is inturn overlain by a section of fissile shale and siltstone about 303 meters (1000 feet) thick. The siltstone is composed of 70 to 80% rounded quartz grains and siderite constitutes as much as 10% of the siltstone. Minor detrital grains of plagioclase, zircon, pyrite, glauconite, and phosphate are present. The matrix of the siltstone is mainly siliceous clay. Rocks believed to be part of the Kingak Shale in the Atigun Canyon area, near Galbraith Lake, are mainly dark gray to black, fissile shale that disconformably overlie the upper limestone member of the Shublik Formation. Fossil fragments were found in rocks believed to be Kingak Shale, however no definitive fossil identifications have been made.

Disconformably overlying rocks of Shublik Formation, Kingak Shale and Ivashak Member of the Sadlerochit Group in northern Alaska is a lower Cretaceous sequence of quartz arenite, clay shale and graywacke sandstone, known as the Kongakut Formation. The contact between the Kongakut Formation and the underlying strata marks a major early Cretaceous unconformity in northern Alaska (Detterman, 1975). The Kongakut Formation has been subdivided into one formal and three informal members. The clay shale member is the lowest member of the Kongakut Formation and is composed of 106 meters (350 feet) of clay shale. Conformably overlying the clay shale member is the Kemik Sandstone Member, a sequence of very fine-grained quartz arenite with minor amounts of glauconite, phosphate, sericite, and zircon. Overlying the Kemik Sandstone Member is the pebble shale member that is 158 meters (520 feet) thick. The pebble shale member contains a section of about 53 meters (175 feet) of highly manganiferous beds of silty shale. The manganese beds are uniformly black with small pellets and thin beds of manganese carbonates (Detterman et al, 1975). Conformably overlying the pebble shale member is the siltstone member composed of a thick sequence, 291 meters (690 feet), of thin-bedded siltstone with minor interbeds of sandstone.

The Okpikruak Formation, named by Gryc et al (1951, p. 159) is exposed along the Okpikruak River in the Chandler River area west of Anaktuvak Pass, and is present in the Atigun Canyon area. The formation was extended to the eastern Brooks Range by Detterman (1963, p. 195), who defined the base of the Okpikruak Formation as the base of the Kemik Sandstone Member of the Kongakut Formation, therefore the two formations are at least in part equivalent correlatable units. In the Atigun Canyon area, the unit is composed of several hundred meters (feet) of clay shale and minor siltstone and fine-grained sandstone.

Unconformably overlying rocks of the Okpikruak Formation and rocks of the Kongakut Formation is a fairly thick sequence of marine sandstone, siltstone, shaly limestone, clay shale and conglomerate of the Fortress Mountain Formation of lower Cretaceous age. The conglomerate and sandstones are typically graywacke-type sedimentary rocks that contain abundant clasts and fragments of black and green chert, feldspar and angular mafic igneous rock fragments, all set in a green mudstone matrix (Keller et al, 1961). At it's type section, the Fortress Mountain Formation is about 3,000 meters (10,000 feet) thick, however, the type locality is probably the thickest section of Fortress Mountain Formation exposed on the north-flank of the Brooks Range, and exposures of 1,500 meters (5,000 feet) of section are common.

The Torok Formation of lower Cretaceous age is believed to be the lateral equivalent of the Fortress Mountain Formation (Keller et al, 1961). The Torok Formation is predominantly dark-gray and dark-bluish-gray, fissile to platy, soft, silty shale and clay shale. Locally, lenticular bodies of sandstone, as much as 242 meters (800 feet) thick, occur in the shale sequence. The base of the Torok Formation is not exposed, however, 1,820 meters (6,000 feet) of section is present at the type locality.

Keller et al (1961) believe that a lateral facies change and major interfingering between the two formations accounts for the lithologic differences between the two units.

Unconformably overlying rocks of the Kongakut Formation, Torok Formation and Fortress Mountain Formation in the northern foothills belt of the Brooks Range are rocks of the Nanushuk Group of early Cretaceous age. The Nanushuk Group contains both marine and non-marine rocks and has been subdivided into two formations. The Tuktu Formation is a marine sequence of interbedded, thin-bedded, fine-grained, greenish-yellow, calcareous sandstone; dark siltstone and shale. The sandstone contains abundant sole markings, mainly flute casts, skip and drag marks, and flame structures, all of which are suggestive of deep water turbidite deposition. The Tuktu Formation may be as thick as 515 meters (1,700 feet), but exposures of about 212 meters (700 feet) thick are common. Conformably overlying the Tuktu Formation are rocks of the non-marine Chandler Formation. The Chandler Formation is composed of 1,447 meters (4,775 feet) of cyclically deposited polymictic conglomerate, salt and pepper sandstone, siltstone and shale. The sequence is entirely non-marine and contains abundant features of fluvial deposition including; cut and fill structures, crossbedding, channel deposits, and fine-grained shaly siltstones containing abundant plant fragments. The shaly siltstones are interpreted as being overbank fluvial deposits. Coal is a fairly common feature in the Chandler Formation.

Structural Geology

The structural geology of the rocks in the Philip Smith Mountains quadrangle is dominated by imbricate thrust faults; high-angle normal faults; anticlines and synclines of various sizes; and large, tight, overturned folds. Thrust faulting throughout the north-flank province of the Brooks Range has juxaposed rock units into structural rather than depositional sequences. Rock units that contain a large percentage of incompetent rock such as shales and siltstones have reacted differently to the regional stresses than the rock units with more competent rocks such as cherts, silicificed limestone and conglomerate. Incompetent rocks make up the bulk of the Kayak Shale, Hunt Fork Shale and Siksikpuk Formation. These units have been compressed into tight folds and are cut by many small faults. The shale horizons also tend to localize faults parallel to their bedding (Porter, 1965). Porter (1965) believes that the shale sequences have acted as lubricating zones that decrease the frictional resistance of faulting. The Kanayut Conglomerate on the other hand is a fairly competent rock unit and has been folded into anticlines and synclines of various sizes. Locally, the folds are overturned, and in the Atigun River valley, spectacular overturned folds about one thousand meters (3,000 feet) in amplitude are present. The Lisburne Group limestones are generally competent rocks that are also folded into large-scale structures. The limestones do exhibit extensive deformation where stresses on the rocks cause them to react plastically.

Locally, rocks of the Lisburne Group have been tightly folded and large north-vergent folds are present. Subsequent thrust-faulting along the axial trace of one such overturned fold, in Atigun Canyon, has thrust older rocks of the Mississippian Lisburne Group over rocks of the Siksikpuk Formation of Permian age. Porter (1965) believes that the Hunt Fork Shale may represent the base of a zone of de'collement involving the late Paleozoic section of north-central Alaska. The predominence of east-west striking structures in the Philip Smith Mountains quadrangle indicates that the major tectonic pressures were directed in a north-south direction. The presence of north vergent structures throughout the region may indicate that most of the tectonic stresses were released to the north (Porter, 1965).

Geochemistry

Geochemical reconnaissance in the Philip Smith Mountains quadrangle during the current study consisted of the colletion of 85 rock and stream sediment samples (see Tables 41 and 42, Appendix A) by M.I.R.L. personnel and collection of 109 stream sediment samples by U.S. Geological Survey personnel as part of an AMRAP study of the quadrangle (see Table 43, Appendix A). Fifty-five percent of the samples collected by M.I.R.L. personnel contain weakly anomalous, anomalous, and strongly anomalous concentrations of at least 1 element and 70% of the stream sediment samples collected by the U.S. Geological Survey contain weakly anomalous, anomalous and strongly anomalous concentrations of at least one element. The geochemical analyses conducted by the U.S. Geological Survey Laboratory on their samples and the analyses conducted by the U.S. Bureau of Mines Laboratory in 1976 and 1977 on the samples collected by M.I.R.L. were found to be incompatable with each other, in that the detection levels for the various elements differ, in some cases, by orders of magnitude. Therefore, each set of data was treated as a seperate sample set for the statistical analysis. Threshold values (see Tables 44, 45, 46, 47, and 48, Appendix A) for the various elements in each data set were derived from a statistical manipulation of the raw geochemical data and the calculation of concentrations of the elements at the arithmetic mean plus; 1.645 x standard deviation, 2.00 x standard deviation, and 2.33 x standard deviation for the 90%, 95% and 98% confidence levels respectively. Where the analytical variability is zero or near zero, the threshold values for the confidence levels are the detection level or nearly the same value. Due to the incompatability of the sample analyses and detection level variability, many samples that would normally be considered weakly anomalous, anomalous or strongly anomalous in one data set, are not weakly anomalous, anomalous or strongly anomalous in the other data sets. The incompatability problem has resulted in an uncertainty as to what elemental concentrations are truely anomalous.

The northern foothills of the Brooks Range are underlain by marine and non-marine clastic sedimentary rocks of various compositions. The rocks contain abundant organic material and relatively high background radioactivity measurements were detected with a hand-held scintillometer. No significant uranium concentrations were found during this study, however the rocks of the northern foothills belt may have some potential for uranium accumulations. Locally, stream sediment samples collected by the U.S. Geological Survey, along the north-flank of the Brooks Range contain greater than 2,000 ppm manganese. The manganese anomalies may represent the presence of thin-bedded manganese or manganese nodules in the pebble shale member of the Kongakut Formation. Detterman et al (1975) have reported manganese concentrations as high as 5% and minor lead and copper values in rocks of the pebble shale member of the Kongakut Formation.

In the Atigun Canyon area, rocks of the Shublik Formation contain strongly anomalous concentrations of barium, phosphorous and strontium. Barium concentrations as high as 3% and strontium concentrations 1,000 ppm are probably related to barite and minor celestite in these rocks. Phosphorous concentrations as high as 2% were also detected.

Rocks of the Siksikpuk Formation are predominantly black shale and carbonaceous chert that contain barite and pyrite concentrations locally. Samples of pyritic shale and mudstone from the Siksikpuk unit contain strongly anomalous concentrations in as many as 23 elements including; silver, arsenic, gold, bismuth, cadmium, cobalt, molybdenum, nickel, lead, vanadium, tin, tungsten and zinc. No obviously significant metallic and non-metallic mineralization is known in rocks of the Siksikpuk Formation. However, the high background of metal values, and the presence of bedded barite in rocks of the Siksikpuk Formation in the Atigun Canyon area, strongly suggest a high probably for the occurrence of significant base metal and barite deposits in these rocks and equivalent formations in northern Alaska.

Rocks of the Lisburne Group contain sporadic anomalous concentrations of barium and magnesium. The barium is associated with barite and the magnesium is thought to result from dolomitic phases in the limestone. No anomalous metal values were detected in rocks of the Lisburne Group during this study.

Stream sediment samples from streams draining rocks of the Kanayut Conglomerate contain anomalous and strongly anomalous concentrations of manganese, nickel, chrome, phosphorous, lead, bismuth, and iron. The bedrock source of the anomalous elemental concentrations is not known.

Mining Activity and Economic Geology

Remoteness and the lack of adequate infrastructure in the past have limited the amount of mineral exploration in the Philip Smith Mountains quadrangle. The only known mineral claims in the quadrangle are located near the head of the Wind River, where massive sulfide float samples were found. The U. S. Geological Survey also reports the presence of mineralized quartz veins in the area between the Middle Fork of the Chandalar River and the Wind River. The vein and stockwork deposits contain chalcopyrite, galena and sphalerite (Grybeck, 1977). Stream sediment samples collected by the U. S. Geological Survey during their AMRAP program in the Wind River area contain anomalous concentrations of lead, zinc, copper, barium and vanadium. The bedrock in the area has been mapped (Brosge et al, 1977) as part of the Hunt Fork Shale unit, of mid and upper Devonian age. Some exposures of Skajit Limestone are also known in the area. Rocks mapped as Hunt Fork Shale in the Pipeline Corridor are mainly shaly siltstones that are phyllitic locally. These rocks contain numerous anastomozing quartz veins and Chapman (1964) has reported the presence of pyrite and marcasite crystals and minor galena in some of these quartz veins. No sulfide minerals were seen in Hunt Fork Shale in the Pipeline Corridor, however, stream sediment samples collected by the U. S. Geological Survey, and by M.I.R.L. personnel during this study, contain anomalous concentrations of zinc, copper, vanadium, barium, lead and silver. The massive sulfide occurrences in the Wind River area, coupled with the anomalous stream sediment geochemistry in areas where the bedrock is known to be Hunt Fork Shale indicate that the Hunt Fork Shale may contain stratabound or stratiform massive sulfide deposits of copper, lead, zinc, vanadium and barium affinities, and may also have some potential for vein type mineral deposits.

Rocks of the Kanayut Conglomerate reflect a change in depositional environment from the open-marine deposition of the Hunt Fork Shale to an environment of deposition characteristic of near shore and deltaic conditions. Most of the Kanayut Conglomerate is considered non-marine and the source of the sediments that constitute the bulk of the unit were derived from a northerly source area. The sediments were introduced into a locally reducing environment in which pyrite and possibly other sulfide minerals were accumulating. Locally, the Kanayut Conglomerate does contain disseminated pyrite and galena and near the top of the unit, black pyritic shales constitute the dominate rock type. Therefore, there may be some potential for black shale hosted base-metal sulfide accumulations in the upper part of the Kanayut Conglomerate. To the east in the Romanzof Mountains, the Kanayut Conglomerate may have some uranium potential. The core of the Romanzof Mountains is dominated by a Precambrian(?) and lower Paleozoic sequence of shales, limestones and conglomerates that are intruded by Devonian(?) granitic intrusives (Sable, 1965). The granites are stanniferous granites and contain a higher than background content of uranium and thorium (Donald Grybeck, U. S. Geological Survey, Personal Communication, 1977), and could be a good source for uranium accumulations in the younger sedimentary rocks. The Kanayut Conglomerate near Atigun Pass, in the Pipeline Corridor is very well indurated. The siliceous cementation of the conglomerate has resulted in a tight rock with low porosity and permeability. No anomalous uranium concentrations were found in these rocks and the potential for finding sedimentary uranium accumulations in the Kanayut Conglomerate near the Pipeline Corridor seems low.

Unlike the rocks of the Kanayut Conglomerate, rocks of the overlying Kayak Shale are dominantly marine shales and limestones that were deposited in a marine stable-shelf environment. Both the shales and carbonaceous limestones of the Kayak unit contain disseminated pyrite, indicating that a reducing, sulfide-producing environment was present locally. Stream sediment samples collected by the U. S. Geological Survey in areas where the dominant rock unit is Kayak Shale, contain anomalous concentrations of copper, lead, zinc, barium and silver. One stream sediment sample from a stream in the Atigun Valley, draining rocks of the Kayak Shale contains at least 500 ppm lead and another sample contained 110 ppm zinc. The potential for finding bedded lead-zinc deposits of stratabound or stratiform lead and zinc affinities seems high for the rocks of the Kayak Shale unit. Near the top of the Kayak Shale, the unit contains a large proportion of anastomozing quartz veins. Porter (1965) reported the presence of quartz veins, near Anaktuvak Pass, that contain chalcopyrite, bornite, azurite and malachite. The probability of finding other such mineralized veins near the top of the Kayak Shale unit seems high.

Rocks of the Lisburne Group, although composed largely of bioclastic limestone, have good potential for base-metal sulfide and barite deposits. The Lisburne Group rocks in the eastern Brooks Range were deposited in part in a sabkha-type environment (Armstrong, 1975). The accumulation of fine-grained sediments and limestone in a restricted, stable-shelf, marine environment that impinges on some sort of deltaic complex in a semi-arid climate, where a high rate of evaporation is present, often results in the deposition of sabkha-like sequences of sediments. The movement of ground waters and ocean waters containing complexed metal ions, through the sabkha interface, which usually contains a large amount of decaying organic material that produces a reducing environment, may result in the precipitation of sulfides in the sabkha. If the interpretation of sabkha-type environment of deposition for some of the rocks in the Lisburne Group is correct, the potential for finding base-metal sulfide deposits of the sabkha-type in the Lisburne Group is high.

At Drenchwater Creek, in the Howard Pass quadrangle, west of the Pipeline Corridor (T10S, R1E Kateel River Meridian) the U. S. Geological Survey has recognized volcanic rocks that are believed to be part of the Lisburne Group. The volcanics are mainly tuffs that may be genetically associated with black shales and chert that are the host of "significant" base-metal sulfide mineralization. The U. S. Geological Survey believes that the base-metal sulfide mineralization may be syngenetic and stratiform. Further work is needed to understand fully the genetic relationship between the volcanic rocks and the fine-grained sediments in the region. The massive sulfide occurrence at Drenchwater Creek indicates that the Lisburne Group contains volcanogenic massive sulfide deposits of stratiform or stratabound lead, zinc and barite affinities.

West of Shainin Lake, the Lisburne Group contains a marked increase in the amount of black shale and chert. A thin, generally continuous zone of black chert and paper shale near the top of the Alapah Limestone contains phosphate concentrations as high as 35.8% P_2O_5 (Patton and Matzko, 1959). The phosphate-bearing horizon in the Alapah Limestone has been traced from the Kiruktagiak River, approximately 64 kilometers (40 miles) northeast of Anaktuvak Pass, to Shainin Lake, about 32 kilometers (20 miles) northeast of Anaktuvak Pass, a distance of about 80 kilometers (50 miles). The black chert and shale member is not recognized east of Shainin Lake, and no phosphate accumulations of significance have been found east of the Shainin Lake locality. At the Skimo Creek locality, about 24 kilometers (15 miles) northwest of Anaktuvak Pass, the entire black chert and shale horizon of the Alapah Limestone is exposed (Patton and Matzko, 1959). The phosphate-bearing zone is 11 meters (36 feet) thick and one zone 1 meter (40 inches) thick contains an average of 21% P_2O_5. The phosphatic beds vary in thickness from 5 to 23 centimeters (2 to 9 inches) and contain up to 35.8% P_2O_5. Trace amounts of vanadium, copper, barium, lead, manganese and uranium have been detected in samples from the black chert and shale members. If an eastern extension of the black chert and shale member can be found east of Shainin Lake, the potential for finding phosphate deposits near the Pipeline Corridor seems high. However, the Alapah Limestone in the Pipeline Corridor apparently contains only minor shale and chert and is composed predominantly of massive bioclastic limestone.

Rocks of the Siksikpuk Formation of Permian age and rocks of the Echooka Formation of mid Permian and lower Triassic age have moderate to high potential for barite and base metal sulfide deposits of stratiform or stratabound lead, zinc and barite affinities. Detterman (1976) has for the first time recognized volcaniclastics in the Permian Echooka Formation of the northeastern Brooks Range. The presence of volcanic rocks indicates that there may be a high probability of finding volcanogenic base-metal sulfide deposits associated with the flows, breccias and tuffs. Stream sediment samples, highly anomalous in base metals and barium, collected by the U. S. Geological Survey along the north-flank of the Brooks Range indicate that the region contains a high background of metal concentrations and may contain base-metal and barite deposits of unknown size and distribution. Barium concentrations as high as 1,000 ppm; zinc concentrations as high as 300 ppm; lead concentrations as high as 70 ppm and vanadium concentrations as high as 200 ppm are not uncommon for stream sediment samples. Rocks of the Siksikpuk Formation in the Pipeline Corridor contain thin to moderately-thick, discontinuous zones of barite and disseminated as well as concretionary forms of pyrite. The rocks are dominantly shale, siltstone and thin-bedded carbonaceous chert. The barite occurs in concordant layers that pinch and swell along strike. Layers as much as 0.3 meters (1 foot) thick are present in the Siksikpuk section in Atigun Canyon. No lead or zinc mineralization has been found in the area, however, stream sediment samples from the area contain anomalous concentrations of lead and zinc. The Atigun Canyon occurrence may or may not be of economic significance, however, the occurrence of bedded barite reinforces the probability of finding stratiform and stratabound base metal and barite deposits in the Permo-Triassic of northern Alaska.

The Shublik Formation contains phosphate concentrations west of the Pipeline Corridor, near Chandler Lake. Minor occurrences of phosphate are known in the Pipeline Corridor, and samples of shale collected in Atigun Canyon contain phosphorous concentrations as high as 2%. The occurrence of phosphate-bearing siltstone and shale to the west indicates that the unit may contain phosphate deposits of unknown size and distribution. Pyrite is commonly found in rocks of the Shublik Formation and occurs as concretions and as rhombs and irregular masses of solid pyrite. The overall mineral potential of these rocks seems high, and further work on the Shublik Formation is clearly needed. Rocks of the Shublik Formation in the Atigun Canyon contain higher than background radioactivity when tested with a hand-held scintillometer. Readings on the order of 200 to 300 counts per second were detected. No deposits of uranium are known in rocks of the Shublik Formation, however the unit may have some uranium potential.

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Sagavanirktok Quadrangle

Previous Investigations

Geologic investigations in the region near the Sagavanirktok quadrangle began as early as 1901 when F. C. Schrader of the U. S. Geological Survey traversed the area between Bettles and Barrow. Although Schrader may not have actually been in the Sagavanirktok quadrangle, his observations of the various rock units west of the quadrangle served as a base for future explorationists. Work by Ernest De K. Leffingwell (1919) has proven to be one of the classic studies of geology in the northeastern Brooks Range. Leffingwell's work centered in the area east of the Sagavanirktok quadrangle, near the Canning River. In 1940, the U. S. Geological Survey initiated a program to evaluate the oil and gas potential in the Naval Petroleum Reserve #4. Several publications have been produced as a result of this work. Keller et al (1961) investigated the geology between the Sagavanirktok River and the Shaviovik River region. Keller outlined the regional geology and structure of the rocks in the area and also commented on the petroleum potential of the region. Recent work by Wood and Armstrong (1975) on the diagenesis and stratigraphy of the Lisburne Group has resulted in a better understanding of the depositional history and diagenesis of rocks in the Lisburne Group in the northeastern Brooks Range. Work by Detterman (1976) in the Ivashak River area has resulted in the recognition of volcanic flows, tuffs and breccias in Permian rocks, probably belonging to the Ivashak Formation of the Sadlerochit Group. Work by the U. S. Geological Survey, as part of their Alaska Mineral Resource Assessment Program (AMRAP), has shown that the rocks in the northern foothills belt of the Brooks Range contain a high background of metal concentrations. Other work by the U. S. Geological Survey to the west has shown that the rocks of the Lisburne Group contain stratiform and stratabound mineral occurrences of lead, zinc and barite affinities. Work by the U. S. Bureau of Mines in the Porcupine Lake area to the southeast has shown that similar mineralization may occur in other parts of the northeastern Brooks Range. In addition to the lead, zinc and barite mineralization, some fluorite concentrations are known. Detailed work by Reed (1968) in the Peter's Lake area has resulted in a good treatment of the bedrock geology of the area. Detailed geologic and geochemical investigations by Tourtelot and Tailleur (1971) have resulted in a better understanding of the nature, deposition history and diagenesis of rocks in the Shublik Formation. Armstrong and Mamet (1975) have studied in detail, eight carboniferous stratigraphic sections in northeastern Alaska, and have described the biostratigraphy of these rocks.

Regional Geology and Petrology

Rocks in the Sagavanirktok quadrangle are part of a thick sequence of marine and nonmarine clastic sedimentary, submarine volcanic and marine carbonate rocks of Mississippian through Tertiary age. Basic to intermediate volcanic flows, tuffs and breccias have been recognized (Detterman, 1976) in the Ivashak River area.

The oldest rocks to crop out in the Sagavanirktok quadrangle consist of light-to dark-gray limestone, dolomitic limestone, siliceous limestone, argillaceous limestone, chert, shale, shaly limestone, and dolomite of the Lisburne Group of lower and upper Missippian age. The Lisburne Group has been subdivided into three formations, the Wachsmuth Limestone of early Mississippian age, the Alapah Limestone of mid-to late Mississippian age, and the Wahoo Limestone of Pennsylvanian age. The Wachsmuth Limestone has been subdivided into four members. The lowest member is composed of interbedded, dark-gray to olive-gray, fine-grained, shaly, argillaceous, nodular limestone and shale. The shaly limestone member is about 5 meters (18 feet) thick at the type locality, and probably represents sedimentation in a quiet water, open-marine environment during the early Mississippian. Conformably overlying the shaly limestone member of the Wachsmuth Limestone is a richly fossiliferous sequence of medium-to dark-gray, medium-to coarse-grained crinoidal limestone. The crinoidal limestone member is about 55 meters (180 feet) thick at the type locality near Shainin Lake and thins to the northeast. Conformably overlying the crinoidal limestone member is a thick sequence of light-gray to white, medium-to coarse-grained, slightly argillaceous, bioclastic, dolomitic limestone. The dolomitic section of the Wachsmuth Limestone is about 170 meters (564 feet) thick at Shainin Lake. The dolomitic limestone is locally interbedded with chert and minor shale. The chert is present throughout the section and appears to increase in abundance toward the top of the section. Chert constitutes as much as 40 to 50% of the section locally. The upper member of the Wachsmuth Limestone is composed of about 130 meters (429 feet) of thin-banded limestone and chert. Minor dolomitic limestone interlaminations occur throughout the section and some interbedded bioclastic limestone is also present. The total thickness of the Wachsmuth Limestone at the type locality is about 375 meters (1,230 feet). The unit appears to thicken to the west, near Anaktuvak Pass, where 410 meters (1,350 feet) of section is present (Porter, 1965). To the east near Peters Lake the entire Wachsmuth unit is not recognized (Reed, 1968).

Conformably overlying the Wachsmuth Limestone is the Alapah Limestone of mid and late Mississippian age. The Alapah Limestone has been subdivided into nine members and is represented by about 295 meters (970 feet) of section at its type locality near Shainin Lake. The Alapah unit thickens to the east and west and thins to the north along the north front of the Brooks Range. About 710 meters

(2,325 feet) of Alapah Limestone is present near Anaktuvak Pass and about 595 meters (1,947 feet) of section, recognized as Alapah Limestone is present near Wahoo Lake. For ease in mapping, the nine members of the Alapah have been lumped into three units. The lowest four members of the Alapah have been lumped by Porter (1965) into a unit consisting of a basal sequence of dark-gray, fine-grained, shaly limestone and minor black chert. The basal sequence is inturn overlain by a thick sequence of dark-gray, fine-grained, argillaceous, thin-bedded to massive, cherty, bioclastic limestone. Next, a sequence of light-brown to gray, fine-to medium-grained, fossiliferous limestone is present. This sequence is overlain by a member composed of brownish-gray, fine-to medium-grained, bioclastic limestone. The middle lumped unit of the Alapah limestone is composed of about 75 meters (250 feet) of non-resistant, dark-gray, calcareous shale and grayish-black chert. Minor interbeds of platy limestone and phosphorite are also present. The upper lumped sequence of Alapah Limestone consists of interbedded light-gray limestone and dark-gray, thin-bedded chert. Minor interbeds of thick-bedded, light-gray limestone are also present. The thick-bedded layers contain a rich fossil assemblage including lithostrotionella corals and Gigantoproductus brachipods.

Recent work by Armstrong (1975) has shown evidence of a great variety of environments of deposition during the time of Lisburne Group sedimentation. The environments of deposition represented by the Lisburne Group rocks include open marine sedimentation, stable-shelf sedimentation, open-platform sedimentation, restricted platform sedimentation and intertidal and supratidal sedimentary environments. The intertidal and suptratidal environments of deposition are characterized by the deposition of irregularly laminated dolomite and dolomitic limy mudstone, anhydrite and pseudomorphs of calcite after anhydrite. Algal mats are common in the sediments of this zone. Armstrong (1975) feels that the intertidal and supratidal environments of deposition may represent deposition in a sabkha-like environment.

In northeastern Alaska, the Wahoo Limestone, of Pennsylvanian and lowest Permian age conformably overlies the Alapah Limestone, and has been recognized as the upper unit of the Lisburne Group. The Wahoo Limestone marks a regional transgression from stable-platform sedimentation, represented by the upper Alapah Limestone, to an open platform-shoal environment of deposition. The Wahoo Limestone has been divided into two informal members. The lower member is characterized by the lack of dark-gray limestone and by the presence of medium-and light-gray, coarse-grained, limestone and lithographic limestone (Reed, 1968). The upper member consists of coarse-grained, crinoidal limestone interbedded with shale and shaly limestone.

Disconformably overlying the rocks of the Lisburne Group in northeastern Alaska are rocks of the Sadlerochit Group of Permian and early Triassic age. The Sadlerochit Group is composed of a variety of rock types including orthoquartzite, chert, limestone, sandstone, siltstone and shale. Detterman (1976) has for the first time recognized volcanic rocks in Permian strata near the Ivashak River and to the south near Porcupine Lake. The Sadlerochit Group has been subdivided into two formations, the Echooka Formation of early and late Permian age and the Ivashak Formation of early Triassic age. The Echooka Formation has been further subdivided into two members; the Joe Creek Member and the Ikiakpaurak Member. The Joe Creek Member is composed of thin-bedded, calcareous siltstone and calcareous mudstone near its base. The siltstone and calcareous mudstone are poorly indurated and weather to a dusky yellow and yellow-brown color. Near the middle of the Joe Creek Member, medium- to massive-bedded chert is the dominant rock type. The chert zone is in turn overlain by a sequence of irregularly-bedded clastic limestone. The Joe Creek Member contains an abundant fossil assemblage including brachiopods, bryozoans, corals, and less commonly trilobites and pelecypods. The trace fossil zoophycos is diagnostic of rocks in the Echooka Formation. Overlying the early Permian Joe Creek Member is the Ikiakpaurak Member of late Permian age. The contact between the Joe Creek Member and the Ikiakpaurak Member is conformable and locally gradational. The Ikiakpaurak Member consists mainly of dark, highly quartzose, sandstone and siltstone with interbeds of silty shale. The sandstones are mainly fine-to very-fine grained quartz arenites. The quartz grains that make up the arenites are generally subrounded to subangular and are commonly cemented by silica although calcite cement is known. Glauconite is a common constituent of the quartz arenite and constitutes as much as 10% of the rock locally. Where the glauconite is a dominant constituent of the sandstone, the rock should be called a glauconitic quartz wacke (Detterman et al, 1975).

The Echooka Formation is recognized as the lower formation of the Sadlerochit Group in the northeastern Brooks Range. However, the Echooka Formation is not recognized west of the Sagavanirktok River and the Siksikpuk Formation of early Permian age is considered the lower formation of the Sadlerochit Group. The Siksikpuk Formation consists of about 110 meters (354 feet) of variegated red and green, cherty, shale and siltstone, at the type locality on Skimo Creek, west of Chandler Lake. The Siksikpuk rocks weather to a characteristic red-yellow color and are often easily recognizable. Rocks of the Siksikpuk Formation have been recognized along the north-flank of the Brooks Range from the Sagavanirktok River, on the east, to the Lisburne Peninsula, in northwest Alaska, a distance of over 640 kilometers (400 miles). The Siksikpuk Formation contains an abundant fossil assemblage including brachiopods, corals and some gastropods. Detterman (1976) has recognized volcanic rocks in the Permian rocks of northeastern Alaska. The volcanic rocks occur as flows, tuffs and tuff breccia near the Ivashak River and also near Porcupine Lake in the Arctic quadrangle. The volcanic rocks occur in a sequence of rusty-weathering silty limestone and tuff that conformably overlie rocks of the Lisburne Group (Detterman, 1976). The limestone contains brachiopods and corals that yield a Permian age.

Unconformably overlying the Echooka Formation is the Ivashak Formation of early Triassic age. The Ivashak Formation has been subdivided into three members and is considered the upper formation of the Sadlerochit Group. The lowest member of the Ivashak Formation is the Kavik Member that consists of thin-bedded, silty shale and siltstone, interlaminated with very-fine grained argillaceous sandstone. Rocks of the Kavik Member contain Ophiceras commune Spath and Claraia stachei Bittner; two diagnostic cephalopods that mark the base of the lower Triassic in northeastern Alaska. Conformably overlying rocks of the Kavik Member are rocks of the Ledge Sandstone Member also of lower Triassic age. The Ledge Sandstone Member consists primarily of massively-bedded, quartz arenite. The quartz arenite is generally a light-gray to dark red-brown, well bedded, quartz arenite in beds ranging from 0.6 to 3 meters (2 to 10 feet) thick. Petrographically, the sandstone is composed of subrounded to well rounded grains of quartz that constitute as much as 60% of the rock. Chert is a dominant constituent and constitutes up to 40% of the rock, while plagioclase feldspar, zircon, tourmaline and pyrite are present as accessory minerals. Conformably overlying rocks of the Ledge Sandstone Member are rocks of the Fire Creek Siltstone Member. The Fire Creek Siltstone Member, as its name implies is composed of thin bedded to massive, dark-gray to black, siliceous siltstone. Petrographically, the siltstone is composed of 40 to 80% well-rounded, quartz and chert grains set in a matrix of siliceous, sericitic clay. Secondary calcite constitutes as much as 15% of the rock locally. Pyrite is the most common accessory mineral, but usually does not exceed more than a few percent of the rock.

Unconformably and locally conformably overlying the Sadlerochit Group in northern Alaska are rocks of the Shublik Formation of mid Triassic age. The Shublik Formation consists of a sequence of siltstone, phosphatic siltstone, and shale and has been subdivided into three members. The basal siltstone member is composed of about 20 meters (70 feet) of thin-bedded, phosphatic siltstone that contains limestone concretions locally. Petrographically, the siltstone is composed primarily of angular to subangular quartz grains 0.02 to 0.05 millimeters (0.001 to 0.002 inches) in diameter. Secondary calcite is a common constituent in the rocks and is often the primary cementing agent and may be as much as 40% of the rock. Phosphate grains with quartz nuclei are common and minor plagioclase and sericite are also present. Conformably overlying the basal siltstone member is a sequence of rock composed of limestone and phosphatized coquinite layers. Detridal quartz is present in subrounded grains and locally constitute as much as 20% of the rock. The clay shale member at the top of the Shublik Formation is very soft and incompetent. A few silty, very fine-grained calcareous sandstone beds are also present.

Conformably overlying the Shublik Formation in northeastern Alaska is a thin unit composed of very-fine grained, massively bedded, dark, siliceous, quartz arenite known as the Karen Creek Sandstone. The Karen Creek Sandstone is of late Triassic age and lies between the Shublik Formation and the overlying Kingak Shale.

The Karen Creek Sandstone has a restricted distribution and is exposed best between the Kavik and Aichilik Rivers, where it forms distinctive hogback ridges. The unit thins rapidly to the west and is not readily recognized west of the Kavik River. The Karen Creek Sandstone also thins to the north and changes character away from the north front of the Brooks Range. The rocks of the northern belt are generally more carbonate-rich and apparently reflect a change in depositional environment to the north in the late Triassic (Detterman et al, 1975).

Unconformably overlying rocks of the Shublik Formation in north central Alaska and rocks of the Karen Creek Sandstone in northeastern Alaska is a thick sequence of siltstone, shale, claystone and clay-ironstone known as the Kingak Shale Formation. The lowest part of the Kingak Shale unit is composed of about 181 meters (600 feet) of black, fissile, paper shale. Large cannonball concretions are present near the center of the paper shale section. Overlying the paper shale section is a sequence between 91 to 300 meters (300 to 1,000 feet) of soft, dark-gray, clayshale and minor claystone. The upper part of the claystone sequence contains nodules of clay-ironstone and weathers to a characteristic brick-red color.

Overlying the clay-shale section is a sequence of thin-bedded siltstone and silty shale. The siltstone is composed of 75 to 80% rounded quartz grains and up to 10% siderite. Accessory plagioclase, zircon and minor phosphate and glauconite are also present. The siltstone and silty shale sequence contains an abundant ammonite and pelecypod assemblage that yield an early Jurassic age.

Unconformably overlying rocks of Shublik Formation, Kingak Shale and Ivashak Member of the Sadlerochit Group in northern Alaska is a lower Cretaceous sequence of quartz arenite, clay shale and graywacke sandstone, known as the Kongakut Formation. The contact between the Kongakut Formation and the underlying strata marks a major early Cretaceous unconformity in northern Alaska (Detterman, 1975). The Kongakut Formation has been subdivided into one formal and three informal members. The lowest member of the Kongakut Formation is composed of 106 meters (350 feet) of clay shale. Conformably overlying the clay shale member is the Kemik Sandstone Member, a sequence of very fine-grained, quartz arenite with minor amounts of glauconite, phosphate, sericite, and zircon. Overlying the Kemik Sandstone Member is a pebble shale member that is 158 meters (520 feet) thick. The pebble shale member contains a section of about 53 meters (175 feet) of highly manganiferous beds of silty shale. The manganese beds are uniformly black with small pellets and thin beds of manganese carbonates (Detterman et al, 1975). Conformably overlying the pebble shale member is a thick sequence, 291 meters (960 feet) of section, composed of thin-bedded siltstone with minor interbeds of sandstone.

The Okpikruak Formation, named by Gryc et al (1951, p. 159) is exposed along the Okpikruak River in the Chandler River area west of

Anaktuvak Pass. The formation was extended to the eastern Brooks Range by Detterman (1961, p. 195), who defined the base of the Okpikruak Formation as the base of the Kemik Sandstone Member of the Kongakuk Formation, therefore the two formations are at least in part equivalent correlatable units.

Unconformably overlying rocks of the Okpikruak Formation and rocks of the Kongakut Formation is a fairly thick sequence of marine sandstone, siltstone, shaly limestone, clay shale and conglomerate of the Fortress Mountain Formation of lower Cretaceous age. The conglomerate and sandstones are typically graywacke-type sedimentary rocks that contain abundant clasts and fragments of black and green chert, feldspar and angular mafic igneous rock fragments, all set in a green mudstone matrix (Keller et al, 1961). At the type section, the Fortress Mountain Formation is about 3,000 meters (10,000 feet) thick, however, the type locality is probably the thickest section of Fortress Mountain Formation exposed on the north-flank of the Brooks Range, and exposures of 1,500 meters (5,000 feet) of section are common.

The Torok Formation of lower Cretaceous age is believed to be the lateral equivalent of the Fortress Mountain Formation (Keller et al, 1961). The Torok Formation is predominantly dark-gray and dark bluish-gray, fissile to platy, soft, silty shale and clay shale. Locally, lenticular bodies of sandstone, as much as 242 meters (800 feet) thick, occur in the shale sequence. The base of the Torok Formation is not exposed, however, 1,818 meters (6,000 feet) of section is present at the type locality. Keller et al (1961) believe that a lateral facies change and major interfingering between the two formations accounts for the lithologic differences between the Torok Formation and Fortress Mountain Formation.

Unconformably overlying rocks of the Kongakut Formation, Torok Formation and Fortress Mountain Formations in the northern foothills belt of the Brooks Range are rocks of the Nanushuk Group of early Cretaceous Age. The Nanushuk Group contains both marine and non-marine rocks and has been subdivided into two formations. The Tuktu Formation is a marine sequence of interbedded, thin-bedded, fine-grained, greenish-yellow, calcareous sandstone, dark siltstone and shale. The sandstone contains abundant sole markings, mainly flute casts, skip and drag marks, and flame structures, all of which are suggestive of deep water turbidite deposition. The Tuktu Formation may be as thick as 515 meters (1,700 feet), but exposures of about 212 meters (700 feet) thick are common. Conformably overlying the Tuktu Formation are rocks of the non-marine Chandler Formation. The Chandler Formation is composed of 1,447 meters (4,775 feet) of cyclically deposited polymictic conglomerate, salt and pepper sandstone, siltstone and shale. The sequence is entirely non-marine and contains abundant features of fluvial deposition including: cut and fill structures; crossbedding; channel deposits; and fine-grained, shaly siltstones containing abundant plant fragments. The shaly siltstones are interpreted as being overbank fluvial deposits and coal is a fairly common feature. The polymictic conglomerate consists mainly of clasts of black and gray chert and limestone. The clast are well rounded and average between 1 and 5 centimeters (0.5 and 2 inches) in diameter. The conglomerate beds tend to be lenticular and cut and fill structures are common. The sandstone beds associated with the conglomerate are generally medium-to coarse-grained, massively bedded, lithic sandstone. Petrographically, the sandstone is composed of 40 to 70% lithic fragments, 10 to 15% quartz, 5 to 10% feldspar and minor accessory minerals.

Unconformably overlying the Kingak Shale and rocks of the Nanushuk Group in northern Alaska are rocks of the Colville Group of upper Cretaceous age. The contact between the Colville Group and the underlying strata marks another major Cretaceous unconformity across northern Alaska. The Colville Group has been subdivided into two formations: the Seabee Formation and the Prince Creek Formation. The Seabee Formation has been further subdivided into the Shale Wall Member and the Ayiyak Member. The Shale Wall Member consists of dark, poorly consolidated, thin bedded, bentonitic clay shale. The bentonite occurs primarily in beds 1.3 to 5 centimeters (0.5 to 2 inches) thick throughout the Shale Wall Member. Near the top of the Shale Wall Member, the rocks are dominantly fissile, paper shale interbedded with bentonite layers generally less then 1 centimeter (0.5 inches) thick. The upper part of the Shale Wall Member consists mainly of bedded, devitrified, welded tuff composed of about 90% glass. The Ayiyak Member of the Seabee Formation is composed of a sequence of interbedded sandstone, shale, and siltstone. Minor interbeds of tuff are present near the top of the sequence. The overlying Prince Creek Formation includes all of the late Cretaceous nonmarine rocks above the Seabee Formation. The Prince Creek Formation consists of interbedded sandstone, conglomerate, siltstone, shale, coal and carbonaceous shale. The sandstone is primarily a subfeldspathic lithic arenite, composed of 30 to 60% chert, quartzite, shale and phyllite clasts, 30 to 40% quartz, up to 8% feldspar and generally less 5% matrix composed of sericitic clay. The siltstone and shale constitute a major part of the Prince Creek Formation, and are carbonaceous locally. The Prince Creek Formation has been subdivided into the stratigraphically lower, Tuluvak Tongue and the upper Kogosukrok Tongue. The sandstones of the Tuluvak Tongue are usually clean and porous and occur in beds 3 to 15 meters (10 to 50 feet) thick. The sandstones of the Kogosukruk Tongue occur mainly in thin beds and are generally dirty sandstones containing pebbles between 0.5 and 5 centimeters (0.25 and 2 inches) in diameter. The sandstones of the Kogosukruk Tongue also contains coal beds ranging up to 1.25 meters (4 feet) thick, no coal beds are known from rocks of the Tuluvak Tongue (Detterman et al, 1975).

The Schrader Bluff Formation occurs across the low foothills of the Brooks Range from the type locality on the lower Anaktuvak River to the Canning River in the northeastern part of the Brooks Range. The stratigraphic relationship between the Schrader Bluff Formation and the Prince Creek Formation is uncertain. The Schrader

Bluff Formation has been subdivided into three members. The lowest member, the Rogers Creek Member, is composed of rusty-weathering bentonitic clay shale with thin interbeds of very fine grained sandstone and siltstone. The siltstone is micaceous and tuffaceous (Detterman et al, 1975). Overlying the Rogers Creek Member is the Barrow Tail Member, that consists mainly of fine-to coarse grained, thin-to massively-bedded, feldspathic wacke that is tuffaceous locally. Tuff and bentonite are common in the Barrow Tail Member, and are generally interbedded with sandstone and siltstone. The overlying Sentinel Hill Member is composed of light-gray to tan, thin-bedded, tuffaceous siltstone and silty shale.

Conformably(?) overlying the Kogosukruk Tongue of the Prince Creek Formation are Tertiary nonmarine and marine sedimentary rocks of the Sagavanirktok Formation. The Sagavanirktok Formation has been subdivided into three members. The lowest member, the Sagwon Member, is the coal-bearing sequence of the Tertiary in northern Alaska. The coal in the Sagwon Member is lignite coal with carbonaceous shale partings. The coal is interbedded with dark-gray to brown, fissile, clay shale and siltstone. Massive, lithic, arenitic sandstone and conglomerate form the upper part of the Sagwon Member near Sagwon. The lithic arenite and conglomerate is composed of 60 to 70% clasts of chert and quartzite. The remainder of the clasts are chiefly quartz, feldspar and carbonaceous material. The Sagwon Member is about 142 meters (470 feet) thick at the type locality and contains coal beds as much as 6 meters (20 feet) thick. Conformably(?) overlying the Sagwon Member is a sequence of cyclically-bedded clay shale and siltstone known as the Franklin Bluffs Member, that were apparently deposited in a subaerial environment. Interbedded with the varve-like sequences of clay-shale and siltstone are layers of massively bedded, pink, tan, orange and yellow, unconsolidated sand and gravel. Large-scale cross-bedding of probable eolin origin are common in the sand and gravel intervals. Beds of volcanic ash are also present. Conformably overlying the Franklin Bluffs Member is the Nuwok Member that apparently reflects a return to nearshore marine deposition. The Nuwok Member is composed of a sequence of cross-bedded sandstone and pebble conglomerate that is overlain by a sequence of pebbly mudstone and silty limestone, believed to have been deposited in a lagoonal environment. The sandstone and conglomerate sequence has been interpreted as being the result of deposition in a barrier beach environment.

Structural Geology

The structural geology of the rocks in the Sagavanirktok quadrangle is dominated by east and west plunging, asymmetric folds, normal faulting, high-angle reverse faulting, and thrust faulting. The northern foothills province of the east-central Brooks Range consists of several distinct structural zones that are sub-parallel to the Brooks Range mountain front. The southern-most structural belt is generally restricted to rocks of the Mississippian Lisburne Group.

The rocks in this zone appear as a regular southerly dipping sequence of marine carbonates and shales that may be as much as 3,000 meters (10,000 feet) thick, and occupies a belt 16 kilometers (10 miles) wide locally. However, upon close examination of the Mississippian sequence, it has been shown that the entire sequence is structurally thickened by isoclinal folding and imbricate thrust faulting and perhaps the true stratigraphic thickness of Lisburne Group rocks does not exceed 910 meters (3,000 feet) (Patton and Tailleur, 1964). To the south, in the Philip Smith Mountains quadrangle, the imbricate thrust faulting appears to have been the result of shearing along the axial trace of north-vergent isoclinal overturned folds. The axial plane shearing and subsequent imbricate stacking of thrust slices has resulted in the structural thickening of the rocks in the entire Lisburne Group. The northward directed overthrusting has juxaposed rocks of the Lisburne Group over rocks of the younger Siksikpuk Formation, Echooka Formation, and Shublik Formation.

Rocks that are found within upper Paleozoic and Mesozoic sequence of the northern foothills province in the central Brooks Range, have complex structural relationships that are characterized by tightly compressed north-vergent isoclinal overturned folds. The folded strata are commonly cut by south-dipping high-angle reverse faults and less commonly by normal faults and transverse faults (Patton and Tailleur, 1964). The high-angle reverse faults have thrust slices of the underlying Paleozoic rocks over rocks of the Mesozoic sedimentary sequence. Cretaceous rocks of the northern foothills province are folded into large-scale, east trending, open anticlines and synclines that generally have steepened northern limbs. Locally, rocks of the Fortress Mountain Formation are tightly compressed and isoclinally folded. This intense deformation is accompanied by high-angle faulting and some thrust faulting.

Mining Activity and Economic Geology

Remoteness of the Sagavanirktok quadrangle has limited the amount of mineral exploration within the quadrangle. Although no known mineral claims are present in the region, the overall mineral potential of the rocks seems high.

Rocks of the Lisburne Group in the Sagavanirktok quadrangle are largely bioclastic limestone with minor shale and siltstone. The carbonates, shale and siltstone were deposited in a variety of depositional environments ranging from open marine to carbonate reef and sabkha environments. Penecontemporaneous volcanic activity, is evidenced by felsic-to intermediate-flows, tuffs and breccias in Lisburne Group rocks near Drenchwater Creek in the north-central Brooks Range (Nockleberg, 1978), and by basic flows in the Iktillik River area, west of Galbraith Lake. The felsic-to intermediate-volcanics are the host of "significant" concentrations of galena, sphalerite and minor barite. The sulfides occur in tuff and in chert and dark shales adjacent to the tuff units. Nockleberg (1978) believes the mineralization at Drenchwater Creek, formed from volcanic exhalations, is stratiform, and may represent a piece or fragment of a larger dismembered stratiform body. Although the occurrence of lead and zinc mineralization at Drenchwater Creek is more than 150 kilometers (100 miles) west of the Pipeline Corridor, the similarity and continuity of the rocks in the Lisburne Group across northern Alaska, strongly suggest that the Lisburne Group rocks near the Pipeline Corridor may have moderate to high mineral potential and may indeed contain stratiform lead, zinc and barite mineralization. Armstrong (1975) has shown that the rocks that constitute the Lisburne Group in the eastern Brooks Range were at least in part deposited in a sabkha-type environment. The deposition of fine-grained sediments and limestone in a restricted stable shelf marine environment that impinges on some sort of deltaic complex often results in the deposition of sabkha-like sediments, in an arid climate. The sabkha interface usually contains a large amount of organic material, mainly algal mats, that upon decay result in a reducing environment. The movement of ground waters and seawaters containing complexed metal ions through the sabkha may result in the precipitation of sulfide minerals at the reductive interface. If the interpretation of sabkha-type environments of deposition for some of the rocks in the Lisburne Group is correct, the potential for finding base-metal sulfide deposits of the sabkha-type in rocks of the Lisburne Group seems high. West of Shainin Lake, the Lisburne Group contains a marked phospathic shale component. The phosphatic zone occupies a thin, generally continuous zone of black shale and chert near the top of the Alapah Limestone, and contains phosphate concentrations as high as 35.8% P_2O_5 (Patton and Matzko, 1959). The phosphate-bearing horizon in the Alapah Limestone has been traced for a distance of about 80 kilometers (50 miles) across northern Alaska. The black chert and shale member is not recognized east of Shainin Lake, and no phosphate accumulations of significance are known east of the Shainin Lake locality. On Skimo Creek, northwest of Anaktuvak Pass, the entire phosphate-bearing zone of the Alapah Limestone is exposed. The zone is about 10 meters (36 feet) thick and one section, 1 meter (40 inches) thick contains an average of 21% P_2O_5. Trace amounts of vanadium, copper, barium, lead, manganese and uranium have been detected in samples from the black shale and chert member. The potential for finding phosphate accumulations in the Alapah Limestone in the Pipeline Corridor seems low, because the rocks of the Alapah Limestone in the Pipeline Corridor are composed mainly of bioclastic limestone and little if any shale and chert. However, if an extension of the phosphate-bearing black shale and chert zone can be found east of Shainin Lake, there is good potential for finding other phosphate deposits.

West of the Sagavanirktok River, rocks of the Siksikpuk Formation have a moderate to high potential for barite and base metal sulfide deposits of stratiform lead, zinc and barite affinities. East of the Sagavanirktok River, the Echooka Formation of the Sadlerochit Group is equivalent to the Siksikpuk Formation, and Detterman (1976) has recognized volcanoclastic rocks in the Echooka Formation. The volcanic rocks occur as flows, tuffs and breccias and are intercalated with limestones that contain Permian fossils. To the south near Porcupine Lake, volcanic rocks that may be part of the Sadlerochit Group contain fluorite, lead and zinc mineralization (U. S. Bureau of Mines, 1978). No lead or zinc mineralization has been identified in the Ivashak River sequence. However, the favorable geology coupled with highly anomalous stream sediment geochemistry in the area, indicate an area in which there exists a high potential for lead, zinc, barite and fluorite mineralization.

The Shublik Formation contains phosphate concentrations and anomalous metal concentrations locally. No obviously economic phosphate deposits are known, near the Pipeline Corridor, however, the occurrences of phosphate-bearing siltstone and shale near the base of the Shublik Formation indicate that the unit may contain phosphate deposits of unknown size and distribution. The phosphate occurs primarily as concretions and as oolites within the siltstone and shale sequence. Pyrite is the most common sulfide mineral found in the Shublik Formation. The pyrite occurs in concretions and as rhombs and irregular lenses of nearly solid pyrite. Samples of siltstone and siderite collected by the U. S. Geological Survey contained chromium values as high as 1,500 ppm and vanadium concentrations as high as 3 percent. No sulfides other than pyrite were found in these rocks, however. Even though only minor phosphates and barite concentrations were found in rocks of the Shublik Formation, in the Pipeline Corridor, the overall mineral potential of these rocks seems high. Further work on rocks of the Shublik Formation is clearly needed.

The lower Cretaceous Kongakut Formation contains a zone of manganiferous shale. The paper shale member contains a section 53 meters (175 feet) thick, of black, thin-bedded, pebble shale. The pebble shale contains pellets and thin beds of manganese carbonates. Manganese concentrations as high as 5 percent were detected by the U. S. Geological Survey (Detterman et al, 1975). The presence of manganese concentrations in the pebble shale member of the Kangakut Formation is interesting and clearly needs further work.

The Mesozoic rocks of the north slope province represent a wide range of depositional environments. The rocks may have some potential for sedimentary uranium deposits. Locally, the Mesozoic sediments south of Happy Valley Pipeline Camp contain a higher than background response when tested with a scintillometer. Readings as high as 180 counts per second were recorded near a fairly thick sequence of quartzose sandstone and dark-gray shale. No obvious uranium mineralization was found however.

North of Happy Valley Pipeline Camp near Sagwon, the rocks of the Sagwon Member of the Sagavanirktok Formation contain lignite and sub-bituminous coal seams as much as 6 meters (20 feet) thick. Several seams are exposed at the Sagwon bluffs locality and one 2 meter (6 foot) seam was sampled for analysis.

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APPENDIX A

Rock and Stream Sediment Sample Trace Element Concentrations and Threshold Values

TABLE 1

VALDEZ QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76Z150	Graywacke		Sr	Bi,Mg
151	Graywacke with quartz veining	Cu		
152	Metagraywacke with 1 meter wide quartz vein			
153	Metagraywacke with quartz veining			
154	Graphitic slate			
155	Graywacke			Bi,P,Sb
157	Graywacke			
160	Graywacke with quartz veining	Bi,V		K,P,Sb,Y,Zr
161	Graywacke and slate with pyrite			
164	Graywacke			
166	Graywacke			
168	Graywacke			
169	Graywacke		Zr	
171	Graywacke			Ca
172	Graywacke and slate with pyrite			Ag,Ba,Fe,Ga,Pb,Ti,V
174	Graywacke with quartz veining			
175	Graywacke with quartz veining	Cr,Ni,Ta	Ca,Pb	Ba,Ga,Mo,Ti
177	Graywacke		Ni	Ag,Pb,Zn
178	Graywacke	Cu		Mo,Pb
179	Graywacke with quartz veining and pyrite			
180	Graywacke			
181	Graywacke with quartz veining			
182	Graywacke with quartz veining			
183	Graywacke with quartz veining			
185	Graywacke with quartz veining			

TABLE 1

VALDEZ QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76Z186	Graywacke		Y	
187	Graywacke and mudstone	Cu,Ni		Ca,Cr,Cu,Fe,Mn,Ni,Sc
189	Graywacke		Sc,Y	Zr
191	Graywacke			
192	Meta-argillite and graywacke			
194	Graywacke and argillite			
197	Graywacke			Ag
199	Slate and graywacke	Ni		Sn
200	Graywacke			
201	Graywacke	Bi		
202	Graywacke and slate with pyrite			
204	Chlorite schist			
205	Graywacke	Bi		Mg,V,Y
207	Graywacke			Bi,P
210	Graywacke		Mg	
211	Graywacke			
212	Graywacke with quartz veining			K
215	Graywacke			
216	Graywacke			
217	Meta-volcanic	Cr		
218	Greenstone with pyrite and (?)chalcopyrite	Mg,Y		
219	Chert and volcanics with pyrite and (?)chalcopyrite	K,Y,Zr	K,La,Y,Zn	Ba,Bi,Ga,P,Sb,Sn,Zn, Zr

TABLE 2

VALDEZ QUADRANGLE

Stream Sediment Sample Trace Element Concentrations

Sample Number	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76Z156	Bi		
158		Sr	Bi,P,Sb
159	Mn		
162		K,Zn	
163	Mg		
165			
167	Ga,Mg	Cr	Ca
170		Zr	
173	Cr,Ga	Ni	Ag,Ba,Cu,Fe,Mn,Pb,Zn
176	Ga,Mn	Cr,Fe,Ni	Mg,Pb,Zn
184	Ga		
188			
190			
193			
195			
196			
198	Ga		Ag
203			
206	K		
208			
209	Mg		
213	Sb,Sr	Bi,P	
214	Bi		

TABLE 3

MIRL Rock Samples, Chugach Terrane, 1976
(based on 47 samples)
Values in PPM or Percent (as noted)

		Minimum or Threshold Values to give indicated confidence level		
Element	Level of Detection	Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	32	34	36
Al		12.16%	12.70%	13.16%
As	800	800	801	801
Au	20	20	20	20
B	100	100	100	100
Ba	700	779	793	807
Be	10	10	10	10
Bi	200	443	484	522
Ca	40	5.81%	6.65%	7.44%
Cd	400	400	400	400
Co	40	40	40	40
Cr	20	145	161	175
Cu	40	91	100	109
Fe		6.97%	7.53%	8.05%
Ga	20	31	33	35
K	1.1%	4.59%	5.01%	5.40%
La	200	200	200	200
Li	1.0%	1.0%	1.0%	1.0%
Mg		3.11%	3.42%	3.71%
Mn	60	1420	1558	1686
Mo	10	26	29	31
Na	1%	1.11%	1.13%	1.16%
Nb	800	800	801	801
Ni	20	85	94	102
P	800	1045	1088	1128
Pb	80	298	338	374
Pd	20	20	20	20
Pt	20	20	20	20
Sb	500	519	523	526
Sc	10	33	37	41
Se	300	300	300	300
Si		10.0%	10.0%	10.0%
Sn	60	71	74	76
Sr	10	125	135	144
Ta	300	366	381	396
Te	200	291	318	343
Ti	500	2843	3023	3190
V	40	104	111	118
W	200	200	200	200
Y	70	122	129	136
Zn	10	518	609	693
Zr	20	71	78	84

TABLE 4

MIRL Stream Sediment Samples, Chugach Terrane, 1976
(based on 23 samples)
Values in PPM or Percent (as noted)

Element	Level of Detection	Minimum or Threshold Values to give indicated confidence level		
		Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	34	36	39
Al		12.52%	13.14%	13.72%
As	800	800	800	800
Au	20	20	20	20
B	100	100	100	100
Ba	700	712	714	716
Be	10	10	10	10
Bi	200	421	460	496
Ca	40	1.66%	1.88%	2.08%
Cd	400	400	400	400
Co	40	40	40	40
Cr	20	128	138	147
Cu	40	108	120	132
Fe		7.45%	8.09%	8.68%
Ga	20	29	31	32
K	1.1%	4.21%	4.5%	4.76%
La	200	200	200	200
Li	1.0%	1.0%	1.0%	1.0%
Mg		2.77%	3.02%	3.25%
Mn	60	1285	1382	1472
Mo	10	23	25	25
Na	1%	1.0%	1.0%	1.0%
Nb	800	800	800	800
Ni	20	72	78	83
P	800	1125	1180	1231
Pb	80	376	429	479
Pd	20	20	20	20
Pt	20	20	20	20
Sb	500	509	510	512
Sc	10	31	34	36
Se	300	300	300	300
Si		10.0%	10.0%	10.0%
Sn	60	60	60	60
Sr	10	97	105	112
Ta	300	416	447	475
Te	200	295	325	353
Ti	500	2896	3085	3262
V	40	124	132	141
W	200	200	200	200
Y	70	131	138	145
Zn	10	359	418	474
Zr	20	81	89	96

TABLE 5

GULKANA QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR378	Altered andesite with epidote			Cr,Ni
379	Green basalt with epidote			
380	Dark green basalt with epidote	Co,Cr,Ni,V	Ti	
381	Sheared greenstone with quartz veining	Sc,V		Ga,Sr
382	Coarse-grained gabbro			Sc
383	Greenstone with pyrite			P
384	Biotite granite with pyrite			
385	Biotite granite with pyrite			
386	Gneissic granite with pyrite			
387	Gneissic biotite granite			
388	Gneissic biotite granite with epidote			Sr
389	Gneissic granite with pyrite and chalcopyrite			Ga,Sr
390	Granite and gneissic granite			Ga,Sr
391	Greenstone with pyrite			
392	Greenstone with calcite veining	Cr		Ni
393	Greenstone			

TABLE 5

GULKANA QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR394	Greenstone	Ti		
395	Greenstone with malachite and azurite			
396	Greenstone with pyrite and malachite	V		Co,Cu,Sc
397	Greenstone with pyrite and quartz veining	Co,Sc		Al,Co,Cu,Ga,La,Mo,Sc, Se,Sn,Ti,W,Zn,Zr,Au
76Z220	Greenstone with quartz veining, pyrite and chalcopyrite	Cd,Cr,K,Mg,Ni,Sc, Te,V	Cu,K,Mg,Ti,Y,Zn	Ag,Co,Cu,La,Mg,Mn,Ni, Y

TABLE 6

MIRL Rock Samples, Amphitheater Terrane, 1976
(based on 85 samples)
Values in PPM or Percent (as noted)

Element	Level of Detection	Minimum or Threshold Values to give indicated confidence level		
		Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	33	35	37
Al		12.37	13.61	14.29
As	800	800	800	800
Au	20	22	22	22
B	100	100	100	100
Ba	700	1098	1174	1245
Be	10	10	10	10
Bi	200	435	478	518
Ca	40	11.22%	12.71%	14.09%
Cd	400	400	400	400
Co	40	49	51	52
Cr	20	164	184	203
Cu	40	201	228	254
Fe		12.19%	13.50%	14.73%
Ga	20	26	27	28
K	1.1%	8.46%	9.45%	10.37%
La	200	237	244	251
Li	1.0%	1.0%	1.0%	1.0%
Mg		7.21%	8.11%	8.95%
Mn	60	2113	2334	2540
Mo	10	44	49	54
Na	1%	1.20%	1.26%	1.31%
Nb	800	800	800	800
Ni	20	90	100	110
P	800	1015	1054	1090
Pb	80	96	99	102
Pd	20	23	24	25
Pt	20	26	28	29
Sb	500	506	507	508
Sc	10	58	64	70
Se	300	382	398	413
Si		10.0%	10.0%	10.0%
Sn	60	65	67	68
Sr	10	173	198	221
Ta	300	417	448	477
Te	200	271	289	306
Ti	500	5285	5906	6484
V	40	234	260	285
W	200	237	244	251
Y	70	184	199	231
Zn	10	77	87	96
Zr	20	102	114	125

TABLE 7

MT. HAYES QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR325	Iron-stained quartz muscovite schist		Mg	
327	Chlorite schist	Ca,Fe	Cr	
328	Quartz muscovite schist with pyrite			
329	Quartz muscovite schist and micaceous quartzite	Bi		
330	Quartz muscovite schist with quartz veining			
331	Quartz muscovite schist and micaceous quartzite with pyrite		Ca	
332	Quartz mica schist with quartz veining		Ca	
333	Quartz mica schist			
338	Altered granoblastic amphibolite		Mn,Mo	Ca,Cr,Fe,Mg,Mn,Ti,V,Zn
339	Micaceous quartzite and quartz muscovite schist			
340	Quartz mica schist with pyrite and (?)arsenopyrite		Zr	
341	Sheared basalt with pyrite			Fe,Mg,Mn,Mo,Ti,V
342	Graphitic schist and micaceous quartzite			
343	Iron-stained quartz mica schist and micaceous quartzite		Zr	
344	Quartz muscovite schist			
345	Sheared gabbro(?)			

TABLE 7

MT. HAYES QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR346	Quartz muscovite schist with calcite veining		Mo	
348	Iron-stained quartz mica albite schist			
349	Quartz muscovite schist			
350	Quartz muscovite schist			
351	Amphibolite with pyrite and chalcopyrite	Cu	Mn,Mo	Co,Fe,Sc,Ti,V,W
352	Quartz muscovite schist		Mo	Sc
353	Chlorite schist			Ag,Mg,Mn,Pb,Sn,Y
354	Quartz muscovite schist and micaceous quartzite		Mo	Sc
356	Sheared basalt with calcite veining			
357	Silicified, altered, igneous rock with pyrite and chalcopyrite			Sr
358	Chloritized diorite with pyrite			Ba
359	Gneissic quartzite with chalcopyrite			Cu,Zn
360	Altered intrusive rock			Ag
361	Altered felsite with pyrite			
362	Diabase			Bi,P,Pb,Sb,Zn
363	Quartz monzonite porphyry			
364	Altered quartz monzonite porphyry with chalcopyrite			Bi
365	Prophlitized intrusive rock			Bi,P,Pb
366	Altered diabase with pyrite	Bi		Ni,P,Pb,Zn
367	Lithic tuff with calcite veining			

TABLE 7

MT. HAYES QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR368	Propylitized intrusive rock			
369	Lithic tuff with calcite veining			
370	Altered diorite with pyrite			
371	Lithic tuff	Cr,Ni		
372	Hornblende diorite with quartz and calcite veining			
373	Altered lithic tuff			

TABLE 8

MT. HAYES QUADRANGLE

Stream Sediment Sample Trace Element Concentrations

Sample Number	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR325			
333			Bi,P
334	Ni	V,K	Ag,Y
335			
336			
337			
342c		Zr	
343c			
344c		Fe	
345c		K,Mn	Mg,Ni
346c		V	Ti
347	Zr	V	
348c			
351c			
352b		V	Mo,Sc
353c	Fe,Mg	Mn	Bi,P,Zn
355		Sc	
374			
375			
376			

TABLE 9

MIRL Rock Samples, Birch Creek Terrane, 1976
(based on 155 samples)
Values in PPM or Percent (as noted)

Element	Level of Detection	Minimum or Threshold Values to give indicated confidence level		
		Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	26	27	28
Al		11.58%	12.67%	13.69%
As	800	855	867	877
Au	20	21	22	22
B	100	108	110	112
Ba	700	881	918	953
Be	10	10	10	10
Bi	200	385	412	436
Ca	40	4.20%	4.95%	5.64%
Cd	400	400	401	401
Co	40	47	49	50
Cr	20	141	159	176
Cu	40	238	278	314
Fe		7.14%	7.94%	8.69%
Ga	20	24	25	25
K	1.1%	7.44%	8.31%	9.11%
La	200	200	200	200
Li	1.0%	1.0%	1.0%	1.0%
Mg		2.48%	2.81%	3.13%
Mn	60	1572	1776	1966
Mo	10	18	19	20
Na	1.0%	1.97%	2.24%	2.49%
Nb	800	801	801	801
Ni	20	82	92	101
P	800	956	986	1013
Pb	80	122	130	137
Pd	20	20	20	20
Pt	20	20	20	20
Sb	500	512	515	517
Sc	10	25	27	29
Se	300	523	566	607
Si		11.23%	11.50%	11.76%
Sn	60	66	67	69
Sr	10	105	121	135
Ta	300	406	433	459
Te	200	300	328	354
Ti	500	2877	3240	3577
V	40	90	99	107
W	200	228	234	239
Y	20	93	98	101
Zn	10	81	90	98
Zr	20	163	184	204

TABLE 10

MIRL Stream Sediment Samples, Birch Creek Terrane, 1976
(based on 31 samples)
Values in PPM or Percent (as noted)

Element	Level of Detection	Minimum or Threshold Values to give indicated confidence level: Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	23	24	25
Al		10.68%	11.28%	11.83%
As	800	800	800	800
Au	20	20	20	20
B	100	100	100	100
Ba	700	700	700	700
Be	10	10	10	10
Bi	200	344	371	396
Ca	40	6010	6642	7229
Cd	400	400	400	400
Co	40	40	40	40
Cr	20	87	95	102
Cu	40	40	40	40
Fe		4.84%	5.15%	5.44%
Ga	20	20	20	20
K	1.1%	4.67%	5.16%	5.61%
La	200	200	200	200
Li	1.0%	1.0%	1.0%	1.0%
Mg		1.86%	2.03%	2.19%
Mn	60	1016	1081	1142
Mo	10	13	14	15
Na	1%	1.14%	1.19%	1.24%
Nb	800	800	800	800
Ni	20	48	51	55
P	800	873	886	898
Pb	80	161	177	191
Pd	20	20	20	20
Pt	20	20	20	20
Sb	500	500	500	500
Sc	10	17	19	20
Se	300	300	300	300
Si		10.0%	10.0%	10.0%
Sn	60	60	60	60
Sr	10	73	80	87
Ta	300	300	300	300
Te	200	295	325	353
Ti	500	2070	2209	2337
V	40	57	60	62
W	200	200	200	200
Y	20	87	90	93
Zn	10	60	67	73
Zr	20	92	102	111

TABLE 11

MIRL Rock Samples, Amphitheater Terrane, 1976
(based on 85 samples)
Values in PPM or Percent (as noted)

		Minimum or Threshold Values to give indicated confidence level		
Element	Level of Detection	Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	33	35	37
Al		12.87	13.61	14.29
As	800	800	800	800
Au	20	22	22	22
B	100	100	100	100
Ba	700	1098	1174	1245
Be	10	10	10	10
Bi	200	435	478	518
Ca	40	11.22%	12.71%	14.09%
Cd	400	400	400	400
Co	40	49	51	52
Cr	20	164	184	203
Cu	40	201	228	254
Fe		12.19%	13.50%	14.73%
Ga	20	26	27	28
K	1.1%	8.46%	9.45%	10.37%
La	200	237	244	251
Li	1.0%	1.0%	1.0%	1.0%
Mg		7.21%	8.11%	8.95%
Mn	60	2113	2334	2540
Mo	10	44	49	54
Na	1%	1.20%	1.26%	1.31%
Nb	800	800	800	800
Ni	20	90	100	110
P	800	1015	1054	1090
Pb	80	96	99	102
Pd	20	23	24	25
Pt	20	26	28	29
Sb	500	506	507	508
Sc	10	58	64	70
Se	300	382	398	413
Si		10.0%	10.0%	10.0%
Sn	60	65	67	68
Sr	10	173	198	221
Ta	300	417	448	477
Te	200	271	289	306
Ti	500	5285	5906	6484
V	40	234	260	285
W	200	237	244	251
Y	70	184	199	231
Zn	10	77	87	96
Zr	20	102	114	125

TABLE 12

BIG DELTA QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR304	Quartz muscovite schist			
306	Garnetiferous quartz, muscovite schist			
307	Micaceous metasiltstone			
308	Quartz biotite schist			
309	Quartz muscovite schist			Sc,Y
323	Quartz biotite schist			Bi
324	Calcic amphibolite	Mn	V	Ca,Sr,Ti

TABLE 13

BIG DELTA QUADRANGLE

Stream Sediment Sample Trace Element Concentrations

Sample Number	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR305			P
310			
311			
312			Pb
313			
314			
315			
316			
317			
318			
319			
320	Cr		
321		Sr	Ca
322		Ca,Sr,V	Cr

TABLE 14

MIRL Rock Samples, Birch Creek Terrane, 1976
(based on 155 samples)
Values in PPM or Percent (as noted)

Element	Level of Detection	Minimum or Threshold Values to give indicated confidence level		
		Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	26	27	28
Al		11.58%	12.67%	13.69%
As	800	855	867	877
Au	20	21	22	22
B	100	108	110	112
Ba	700	881	918	953
Be	10	10	10	10
Bi	200	385	412	436
Ca	40	4.20%	4.95%	5.64%
Cd	400	400	401	401
Co	40	47	49	50
Cr	20	141	159	176
Cu	40	238	278	314
Fe		7.14%	7.94%	8.69%
Ga	20	24	25	25
K	1.1%	7.44%	8.31%	9.11%
La	200	200	200	200
Li	1.0%	1.0%	1.0%	1.0%
Mg		2.48%	2.81%	3.13%
Mn	60	1572	1776	1966
Mo	10	18	19	20
Na	1%	1.97%	2.24%	2.49%
Nb	800	801	801	801
Ni	20	82	92	101
P	800	956	986	1013
Pb	80	122	130	137
Pd	20	20	20	20
Pt	20	20	20	20
Sb	500	512	515	517
Sc	10	25	27	29
Se	300	523	566	607
Si		11.23%	11.50%	11.76%
Sn	60	66	67	69
Sr	10	105	121	135
Ta	300	406	433	439
Te	200	300	328	354
Ti	500	2877	3440	3577
V	40	90	99	107
W	200	228	234	239
Y	20	93	98	101
Zn	10	81	90	98
Zr	20	163	184	204

TABLE 15

MIRL Stream Sediment Samples, Birch Creek Terrane, 1976
(based on 31 samples)
Values in PPM or Percent (as noted)

		Minimum or Threshold Values to give indicated confidence level		
Element	Level of Detection	Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	23	24	25
Al		10.68%	11.28%	11.83%
As	800	800	800	800
Au	20	20	20	20
B	100	100	100	100
Ba	700	700	700	701
Be	10	10	10	10
Bi	200	344	371	396
Ca	40	6010	6642	7229
Cd	400	400	400	400
Co	40	40	40	40
Cr	20	87	95	102
Cu	40	40	40	40
Fe		4.84%	5.15%	5.44%
Ga	20	20	20	20
K	1.1%	4.67%	5.16%	5.61%
La	200	200	200	200
Li	1.0%	1.0%	1.0%	1.0%
Mg		1.86%	2.03%	2.19%
Mn	60	1016	1081	1142
Mo	10	13	14	15
Na	1%	1.14%	1.19%	1.24%
Nb	800	800	800	800
Ni	20	48	51	55
P	800	873	886	898
Pb	80	161	177	191
Pd	20	20	20	20
Pt	20	20	20	20
Sb	500	500	500	500
Sc	10	17	19	20
Se	300	300	300	300
Si		10.0%	10.0%	10.0%
Sn	60	60	60	60
Sr	10	73	80	87
Ta	300	300	300	300
Te	200	295	325	353
Ti	500	2070	2209	2337
V	40	57	60	62
W	200	200	200	200
Y	20	87	90	93
Zn	10	60	67	73
Zr	20	92	102	111

TABLE 16

FAIRBANKS QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR300	Garnetiferous quartz muscovite schist	Zr		
301	Muscovite schist			Ba,Ca,Mn,Zr
302	Quartz muscovite schist and micaceous quartzite	Mg		Ba,Ca
303	Porphyroblastic schist			
76AJB 1	?			
2	?			
3	?			
4	?			
5	?			
6	Quartz vein material			
7	Quartz vein material			
8	Altered rock			
9	?			
10	Altered rock			
11	Gouge			
12	?			
13	Granite			
14	Quartz monzonite			
15	?			
18	?			
20	?			
21	?			
22	?			
23	?			

TABLE 16

FAIRBANKS QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AJB 25	?			
26	?			
27	?			
28	?			
29	?			
701	Quartz muscovite schist		Na	
702	Quartz mica schist	K		Ga,Na
703	Quartz mica schist			Na
704	Quartzite			Ag,Na,P,Sn
705	Quartz mica schist		P	Na,Sn
706	Quartzite and amphibolite	Ca,Mn,Mo,Zn		Cr,Fe,Mg,Na,Ni
901	Quartz mica schist			
902	Quartzite			
903	Quartz mica schist			V
904	Quartz mica schist			Sb
905	Quartzite		Fe	

TABLE 17

MIRL Rock Samples, Birch Creek Terrane, 1976
(based on 155 samples)
Values in PPM or Percent (as noted)

		Minimum or Threshold Values to give indicated confidence level		
Element	Level of Detection	Weakly Anomalous at 90%confidence level	Anomalous at 95%confidence level	Strongly Anomalous at 98%confidence level
Ag	20	26	27	28
Al		11.58%	12.67%	13.69%
As	800	855	867	877
Au	20	21	22	22
B	100	108	110	112
Ba	700	881	918	953
Be	10	10	10	10
Bi	200	385	412	436
Ca	40	4.20%	4.95%	5.64%
Cd	400	400	401	401
Co	40	47	49	50
Cr	20	141	159	176
Cu	40	238	278	314
Fe		7.14%	7.94%	8.69%
Ga	20	24	25	25
K	1.1%	7.44%	8.31%	9.11%
La	200	200	200	200
Li	1.0%	1.0%	1.0%	1.0%
Mg		2.48%	2.81%	3.13%
Mn	60	1572	1776	1966
Mo	10	18	19	20
Na	1%	1.97%	2.24%	2.49%
Nb	800	801	801	801
Ni	20	82	92	101
P	800	956	986	1013
Pb	80	122	130	137
Pd	20	20	20	20
Pt	20	20	20	20
Sb	500	512	515	517
Sc	10	25	27	29
Se	300	523	566	607
Si		11.23%	11.50%	11.76%
Sn	60	66	67	69
Sr	10	105	121	135
Ta	300	406	433	459
Te	200	300	328	354
Ti	500	2877	3240	3577
V	40	90	99	107
W	200	28	234	239
Y	20	93	98	101
Zn	10	81	90	98
Zr	20	163	184	204

TABLE 18

LIVENGOOD QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR001	Metagraywacke			
002	Rhyolite porphyry			Zn
003	Quartz porphyry with epidote and chlorite	Cu		
004	Quartz porphyry with epidote, chlorite and biotite	Sr		
005	Metasiltstone			
007	Siltstone with quartz veining and iron-staining	Bi		Zn
008	Coarse-grained conglomerate	Bi		
009	Meta-siltstone and meta-conglomerate			
010	Siltstone			
011	Siltstone			
012	Quartz monzonite porphyry with pyrite		K	
013	Siltstone			
017	Meta-siltstone			
018	Meta-siltstone			Ga
019	Siltstone			
020	Siltstone			
021	Siltstone			
022	Siltstone			
023	Siltstone			
024	Siltstone with limonite staining			

TABLE 18

LIVENGOOD QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR025	Altered dike rock with galena, pyrite and chalcopyrite			As,B,Bi,Co,Cu,Ni,P,Sb
026	Siltstone			
027	Altered siltstone			Y
028	Vein material with stibnite, arsenopyrite and galena	Cu		As,B,Co,Ni,P
029	Altered siltstone			B,Be
030	Altered siltstone			B,Be
031	Siltstone with quartz veining			
032	Interlaminated siltstone and sandstone			
033	Siltstone			Ga,K
034	Interlaminated siltstone and sandstone			
035	Siltstone with calcite veining			K,Mn,Y
036	Siltstone with quartz veining			
037	Siltstone			
038	Siltstone		Bi	Ga,P
039	Siltstone with iron staining			
040	Interbedded chert and siltstone	Mo	Y	Au,Ga,V
041	Gouge from fault			
042	Siliceous dolomite	Ca		Mg
043	Siltstone with heavy limonite staining			V
044	Siliceous dolomite with quartz veining	Ca		Mg,Sn

TABLE 18

LIVENGOOD QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR045	Black chert with quartz stringers			
046	Chert			
047	Chert			
048	Chert			
049	Chert		Bi	P
050	Chert with limonite staining			
051	Vesicular basalt	Bi,Ca		
052	Chert		Zn	
053	Chert			
054	Chert	Bi		
055	Meta diorite(?) with galena(?)	Mg,Mo	Ti	Ga
056	Diabase			Bi,P
057	Siltstone and sandstone	P		
058	Chert with limonite staining	Mo		Au,La,Sn
059	Chert	Bi		Ga
060	Chert		Bi,Zr	Au,Ga,La,Mo,Sc,Sn,W
061	Chert	Mo		Au,Bi,La,P,Sc,Sn
062	Chert	Bi		Sn
063	Chert			P
064	Chert	La		Au,Bi,P,Sn
065	Chert with heavy limonite staining	Mo		Ga,La,Mo,Sn,W
066	Chert			
067	Chert			La
068	Chert			
069	Amygdaloidal basalt	Ca,Mo		Ti
070	Chert			
071	Chert			

TABLE 18

LIVENGOOD QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR072	Chert			
073	Chert			
074	Interbedded chert and carbonaceous siltstone	Mo		La,W
075	Chert with manganese staining and quartz veining	Ca,Mn,Mo		Au,Ga,La,Sc,Si,W
076	Trachyte with calcite veining	Mo		Ga,Ti,V
077	Chloritized hornblende diorite			
078	Interbedded siltstone and sandstone			
079	Sandstone and shale			
080	Sandstone with calcite and quartz veining			
081	Trachyte	V		Ti
082	Siltstone			
083	Chloritized hornblende diorite with biotite			
084	Siltstone with limonite staining	Ca		
085	Chloritized diorite			
086	Siltstone with heavy iron staining			
087	Chloritized diorite with pyrite	Ca,Mo,Ti,V		Ga
088	Chloritized diorite	Ca		
089	Chert and siltstone			
090	Coarse sandstone with iron staining	Ca,Mo,Ti		Ga,Mg,V,Y
091	Silicified siltstone with limonite staining			
092	Silicified sandstone	Ca		

TABLE 18

LIVENGOOD QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR093	Chloritized diorite			P
094	Siltstone	Bi,V		Ga
095	Chloritized diorite			Bi
096	Silicified siltstone			
097	Silicified siltstone			
098	Silicified siltstone			
099	Silicified siltstone at contact with diorite sill (?)			Cu
100	Chloritized diorite			
101	Siliceous siltstone			Zn
102	Chert			
103	Hornblende diorite with chalcopyrite and pyrite	P		Bi,Ga
104	Chloritized granodiorite with pyrite			Bi,P
105	Hornblende granodiorite with pyrite, chalcopyrite,malachite	Mo	Bi,Y	Ga,Sc,Zr
106	Chloritized granodiorite		Bi,Sr	
107	Granodiorite with pyrite and chalcopyrite	Mo,Y		Bi,Cu,Ga
108	Chloritized diorite with pyrite	Ca,Mo		Ga,Ti,V
109	Silicified metasiltstone with pyrite			
110	Chloritized, biotite diorite with pyrite	Ca		
111	Siltstone			

TABLE 18

LIVENGOOD QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR112	Biotite diorite with pyrite	Ca		Ti,V
113	Chert	Bi		
114	Biotite diorite			
115	Greenstone	Mg		Sc
116	Hornblende diorite			Ga
117	Chert			
118	Chert			
119	Chert			
120	Volcanics and argillite	Ca,Mg	K	Ga,Mo,Sc,V,Y
121	Lithic tuff			Mn,V
122	Siltstone	P	Y	
123	Argillite in contact with volcanics			Ga
124	Sheared volcanics with calcite veining	Y		
125	Volcanics and argillite	Mo		Ga
126	Altered volcanics	Mo		Sc
127	Sandy siltstone			Sc
128	Lithic tuff with calcite and quartz veining	Ca		Mn
129	Silicified tuff with pyrite and quartz veinlets	Ca,Mo,Ti		
130	Well-indurated sandstone	Ca		Mg
131	Diorite	Ca,Mo		Ga,Mg,Sc,V,Y
132	Basalt with calcite veining	Ca		Ga,Mo,Y
133	Greenstone with calcite veining	Ca,Mo		Sc,V

TABLE 18

LIVENGOOD QUADRANGLE

Rock Sample Descriptions and Trace Element Concentrations (continued)

Sample Number	Sample Description	Weakly Anomalous Elements 90%C.L.	Anomalous Elements 95%C.L.	Strongly Anomalous Elements 98%C.L.
76AMR134	Andesite with calcite veining	Ca		
135	Tuff		Mg	Ga,La,Mo,Sc,Ti,V,W,Y, Zr
136	Lithic tuff with calcite veining		Mg	
137	Argillite with manganese staining			Ba,K,Y
138	Argillite with manganese staining and quartz stringers	Cd		Ba,Mn
139	Tuff with limonite staining and calcite stringers			Mg
140	Lithic tuff with calcite and quartz stringers			
141	Argillite			
142	Shale with limonite staining			
143	Argillite			
144	Lithic tuff with calcite veinlets			Mg
145	Lithic tuff			
146	Argillite			
147	Tuff	V		
148	Lithic tuff with manganese staining			
150	Greenstone with calcite stringers	Ca		Sr
151	Lithic tuff with calcite stringers and manganese staining			Sr
152	Micaceous argillite			
153	Argillite with manganese staining			