Geology of the McCarthy B-4 Quadrangle, Alaska

By E. M. MACKEVETT, JR.

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Describes a 30,000-foot sequence of sedimentary and volcanic rocks which range in age from Permian and possibly older to Quaternary, several small plutons, and numerous small copper deposits

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GEOLOGY OF THE McCARTHY B-4 QUADRANGLE, ALASKA

By E. M. MACKEVETT, JR.

ABSTRACT

This report supplements the geologic quadrangle map of the McCarthy B-4 quadrangle by providing additional and more detailed geologic information, particularly on stratigraphy and lithology. The McCarthy B-4 quadrangle, on the rugged southern flank of the Wrangell Mountains, contains a sequence of layered consolidated rocks more than 30,000 feet thick, scattered small plutons, and widespread surficial deposits. These rocks range in age from Permian(?) and Permian to Quarternary.

The oldest rocks in the quadrangle, a thick sequence of Permian(?) submarine lavas and their derivative volcaniclastic rocks, are overlain by Permian marine sedimentary rocks practically devoid of volcanic material. Gabbro plutons cut both the Permian(?) and Permian rocks. Middle Triassic marine sedimentary rocks locally unconformably overlie the Permian rocks. The Nikolai Greenstone, extensive continental basaltic lavas of late Middle and(or) early Late Triassic age, is well exposed in the quadrangle. The Nikolai and most of the older rocks, particularly those with volcanic affinities, show the effects of low-grade regional metamorphism. The Nikolai is disconformably overlain by Late Triassic carbonate rocks, the Chitistone and Nizina Limestones. The carbonate rocks grade upward into carbonaceous shale, impure limestone, and chert of the McCarthy Formation of Late Triassic and Early Jurassic age. A major regional orogeny, near the close of the Jurassic or in the pre-Albian Cretaceous, produced the dominant structural features of the quadrangle. Marine Cretaceous sediments that are mainly represented by fine-grained clastic rocks were deposited unconformably on the older rocks, partly in restricted basins. The Cretaceous and older rocks were uplifted, mildly deformed, and eroded prior to the initial phase of Wrangell Lava volcanism in the Teritary. The subaerial Wrangell Lava and intercalated continental sedimentary rocks of the Frederika Formation are locally preserved in the northeastern part of the quadrangle. Other Tertiary rocks include small plutons of felsic hypabyssal rocks or intermediate to mafic intrusives, chiefly granodiorite, and a few andesite dikes and sills. The quadrangle's Quaternary surficial deposits are largely related to glacial processes, which have been important in developing the present physiography.

The B-4 quadrangle contains numerous copper deposits, including a few that have been small producers, local gold placers, and a few lodes or occurrences that contain gold, antimony, arsenic, or molybdenum. Silver is a minor constituent of most of the copper deposits.

INTRODUCTION

This report supplements the McCarthy B-4 geologic quadrangle map (MacKevett and Smith, 1970) by providing additional stratigraphic and lithologic descriptions of the map units and short summaries of the structural and economic geology. (For optimum benefit, this report should be used with the geologic quadrangle map which shows graphically the discrete geologic units and structural features described in this report.) The McCarthy B-4 15-minute quadrangle is about 260 miles east of Anchorage on the southern flank of the Wrangell Mountains (fig. 1). Altitudes in the quadrangle range from about 2,000 to 9,875 feet. To a large extent the quadrangle's physiography reflects glaciation and glacier-related erosion. Valley glaciers occupy the upper reaches of Glacier Creek, Toby Creek, and a few other stream valleys. Alpine glaciers and remnants of snow and ice fields are widely distributed throughout the higher terrain. Broad U-shaped valleys characterize the lower extents of the Chitistone River and a few other glacial streams, but most streams in the quadrangle are actively downcutting and occupy narrow V-shaped valleys.

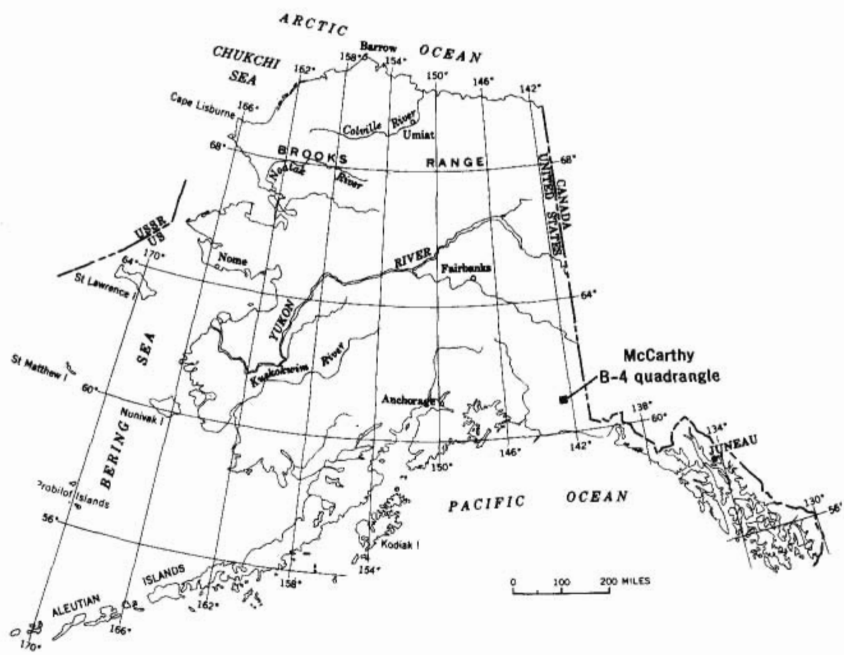

FIGURE 1.—Index map showing location of the McCarthy B-4 quadrangle, Alaska.

The smaller streams in the quadrangle discharge largely through the Nizina River into the Chitina River, which is a major tributary of the Copper River. During 1967 only one person lived in the quadrangle during most of the year, although in the summer and early fall the quadrangle generally is visited by a few prospectors, miners, and hunters. The Glacier Greek landing strip is suitable for small aircraft, and occasionally small fixed-wing aircraft have used gravel bars along the Chitistone River as landing sites. Most travel within the quadrangle is by foot or by helicopter. Bedrock outcrops are good throughout most of the quadrangle, but locally bedrock is masked by surficial deposits, snow, ice, or vegetation.

The mapping was helicopter supported and used 1:48,000 scale cronoflex base maps. Supplementary laboratory studies consisted mainly of petrographic and mineralogic investigations. Grateful acknowledgement is given to several persons who made valuable contributions to the geologic studies. They include D. L. Jones, who was mainly responsible for the stratigraphic and paleontologic studies of the Cretaceous rocks; R. E. Grant, N. J. Silberling, and R. W. Imlay, who respectively studied the Permian, Triassic, and Jurassic fossils; G. R. Winkler and J. G. Smith who participated in the geologic mapping; the late Walter L. Holmes and his wife who shared their knowledge of the region and provided hospitality; and Jean O'Neill, who contributed information on current mining activities.

The geology of the B–4 quadrangle was described previously by Moffit and Capps (1911) and by Moffit (1938). Reports pertinent to the quadrangle's economic geology include Miller (1946), Berg and Cobb (1967), Bateman (1932), Sainsbury (1951), and MacKevett and Smith (1968). Recent detailed geologic studies of nearby regions have resulted in geologic quadrangle maps (MacKevett, 1970a, b) and other reports that contain geologic data relevant to the B–4 quadrangle (MacKevett, 1970c).

GEOLOGIC SETTING AND STRUCTURE

The B–4 quadrangle contains a sequence of layered consolidated rocks more than 30,000 feet thick that ranges in age from Permian(?) and Permian to Tertiary, scattered intrusive rocks, and varied Quaternary surficial deposits (table 1 and fig. 2).

Figure 2 is a generalized version of the geologic quadrangle map (MacKevett and Smith, 1970). Several of the geologic units shown on the geologic map and described in this report have been combined and except for the main faults, structural features are not shown in the figure.

TABLE 1.—*Summary of rocks in the McCarthy B-4 quadrangle, Alaska*

Formation or unit	System	Series	Estimated maximum thickness (feet)	Dominant lithology
Surficial deposits	Quaternary			
Andesitic dikes	Tertiary and Quaternary(?)			Andesite.
Felsic hypabyssal rocks.	Tertiary			Dacite.
Intermediate to mafic intrusive rocks.	do			Granodiorite.
Frederika Formation and lower part of Wrangell Lava.	do	Miocene	2,000	Varied continental sedimentary rocks and andesitic lava.
MacColl Ridge Formation.	Cretaceous	Upper Cretaceous	2,000	Sandstone and conglomerate.
Chititu Formation	do	Lower(?) and Upper Cretaceous	5,000+	Mudstone and shale.
Moonshine Creek Formation.	do	Lower and Upper Cretaceous	250	Siltstone.
Schulze Formation	do	Lower(?) and Upper Cretaceous	150	Siliceous sandstone and siltstone.
Kennicott Formation.	do	Lower Cretaceous	475	Sandstone, siltstone, and conglomerate.
Upper member of McCarthy Formation.	Triassic(?) and Jurassic.	Upper Traisic (?) and Lower Jurassic.		Impure limestone.
Lower member of McCarthy Formation.	Triassic and Jurassic(?)	Upper Triassic and Lower Jurassic(?)	600+	Impure limestone and carbonaceous shale.
Nizina Limestone	Triassic	Upper Triassic	1,000	Limestone with some chert.
Chitistone Limestone.	do	do	1,800	Limestone and dolomite.
Nikolai Greenstone.	do	Middle and(or) Upper Triassic	13,000	Basalt.
Unnamed marine sedimentary rocks.	do	Middle Triassic	150	Chert, siltstone, and shale.
Gabbro	Permian or Triassic.			Gabbro.
Hasen Creek Formation.	Permian	Lower Permian	900	Varied sedimentary rocks.
Station Creek Formation.	Permian(?)	Lower Permian(?)	4,600	Basalt and basaltic andesite and their derivative volcaniclastic rocks.

The pre-Cretaceous rocks are part of a large northwest-trending belt that extends along the southern flank of the Wrangell Mountains. Rocks in this belt are overlapped from the north by the Wrangell Lava and by Tertiary continental sedimentary rocks and from the south by Cretaceous marine sedimentary rocks or by Quaternary fluvioglacial deposits.

Three crudely distinctive geologic terranes of near-equal area extend diagonally southeastward across the quadrangle (fig. 2). The northernmost terrane is characterized by a thick southwest-dipping homoclinal sequence of Nikolai Greenstone and older rocks. The middle terrane is structurally complex and is composed of Nikolai Greenstone and younger Triassic rocks that are strongly faulted, and the southernmost terrane is dominated by gently folded Cretaceous sedimentary rocks.

There are many steep faults in the quadrangle and one major and several subordinate thrust faults. Only the largest faults are shown in figure 2. The steep faults form a well-developed northeast-striking set, a complementary northwest-striking set, and other fault sets that strike nearly north or nearly west. Dip-slip components of displacement predominate on most of these faults, but a few of the steep faults, particularly some with near-west strikes, have dominant strike-slip displacement components. Faults of the northeast-striking set can be traced for 8 miles and are exemplified by a fault that extends from near the southern boundary of the quadrangle to the Glacier Creek Glacier, by a fault that is well exposed near the head of Radovan Gulch, and by a fault along Grotto Creek in the northwest part of the quadrangle. The northwest- and north-striking faults are not as well developed. The west-striking faults are probably younger than most other faults and are best exemplified by the faults along Copper and Dan Creeks that splay into a plexus of subsidiary faults near their eastern ends.

The well-exposed major thrust fault in the northwest part of the quadrangle has been traced for many miles to the northwest in the McCarthy B–5 and C–5 quadrangles (MacKevett, 1965b, and 1970b) and is well illustrated by Moffit (1938, pls. 8A and 9B). This fault cannot be mapped confidently south of the Nelson prospect, but its southeastward trace may be represented by altered zones parallel to Nikolai Greenstone flows. The maximum displacement on this thrust fault is probably not more than a few thousand feet. The other thrust faults have small outcrop traces and displacements.

Most of the faults probably formed during the major regional

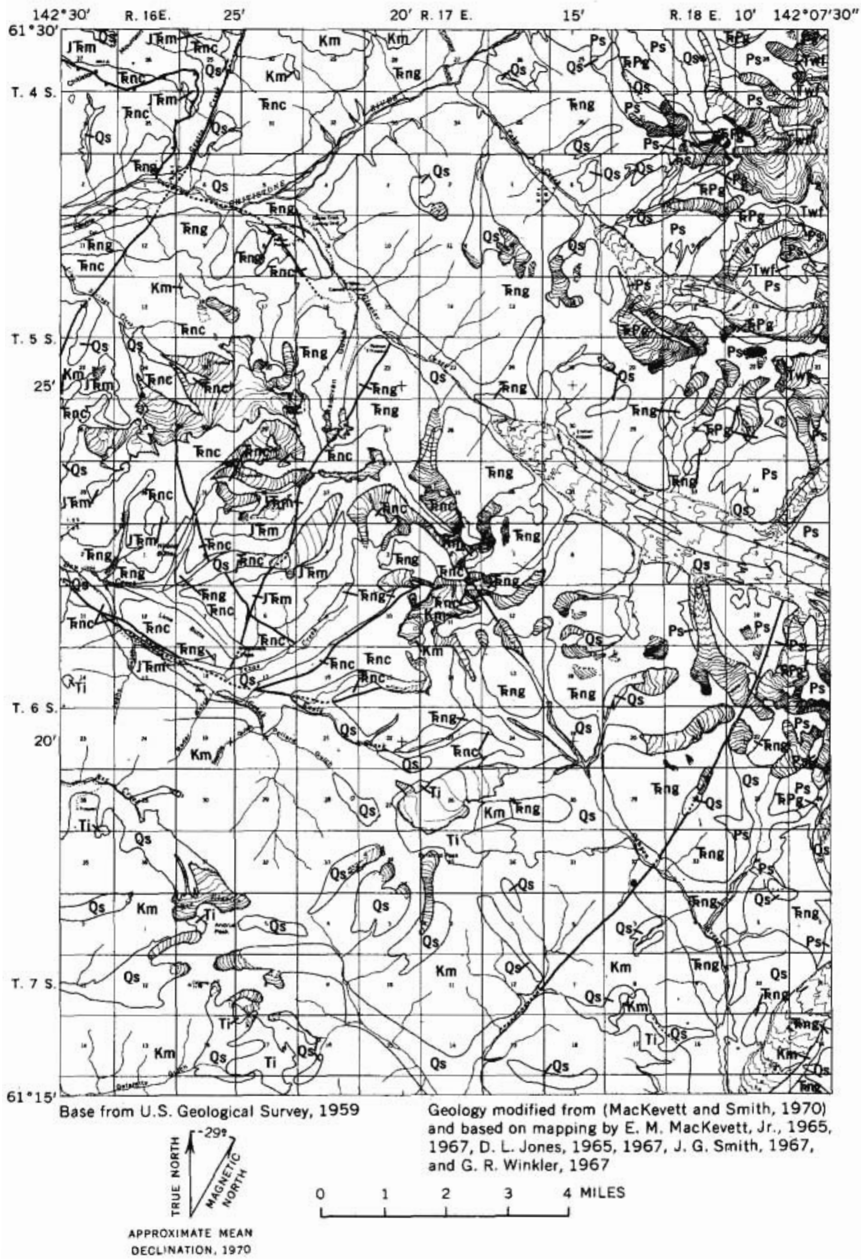

FIGURE 2.—Generalized geologic map of the McCarthy B–4 quadrangle, Alaska.

EXPLANATION

	Qs	**Surficial deposits** *Include alluvium, older alluvium, talus, rock glaciers, moraines, landslides, and fluvioglacial deposits*	QUATERNARY
	Ti	**Intrusive rocks** *Chiefly dacite and granodiorite*	TERTIARY
Miocene	Twf	**Lower part of Wrangell Lava and Frederika Formation** *Diverse continental sedimentary rocks of the Frederika Formation and subaerial andesitic lava and pyroclastic rocks of the Wrangell Lava*	TERTIARY
Lower and Upper Cretaceous	Km	**Marine sedimentary rocks** *Include, in ascending order, Kennicott, Schulze, Moonshine Creek, Chititu, and MacColl Ridge Formations*	CRETACEOUS
Upper Triassic and Lower Jurassic	JTRm	**McCarthy Formation** *Almost entirely rocks of lower member*	TRIASSIC AND JURASSIC
Upper Triassic	TRnc	**Nizina and Chitistone Limestones**	TRIASSIC
Middle and (or) Upper Triassic	TRng	**Nikolai Greenstone**	TRIASSIC
Middle Triassic	TRs	**Unnamed marine sedimentary rocks**	TRIASSIC
	TRPg	**Gabbro**	PERMIAN OR TRIASSIC
	Ps	**Skolai Group** *Includes Station Creek and overlying Hasen Creek Formations*	PERMIAN(?) AND PERMIAN

Contact
Dotted where concealed; includes depositional and intrusive contacts and some fault contacts

Steep fault
Approximately located; dotted where concealed

Thrust fault
Approximately located; dotted where concealed; sawteeth on upper plate

FIGURE 2.—Continued.

orogeny at or near the close of Jurassic or in Early Cretaceous time. However, since some of the steep faults cut Cretaceous rocks, they probably originated or were reactivated during Tertiary time.

The dominant folds in the quadrangle trend northwestward and include moderately open to tight and overturned folds, mainly related to the Late Jurassic and(or) Early Cretaceous orogeny, and broad, gentle to moderately open post-Cretaceous folds.

The major unconformity in the quadrangle separates Cretaceous from older rocks. Lesser unconformities separate Permian and Triassic rocks, Cretaceous and Tertiary rocks, and Quaternary surficial deposits from older rocks. Several disconformities are recognized in the quadrangle's stratigraphic succession.

STRATIGRAPHY AND LITHOLOGY

Layered consolidated rocks in the B-4 quadrangle include submarine and subaerial volcanic rocks, abundant marine sedimentary rocks, and some continental sedimentary rocks (table 1 and fig. 2). Intrusive rocks ranging in composition from gabbro to granodiorite and dacite form small stocks, dikes, and sills that cut many of the layered rocks. Except for the Nikolai Greenstone and older rocks, which have undergone low-grade regional metamorphism, and small contact-metamorphosed zones contiguous to some plutons, metamorphic effects are lacking in the quadrangle. A variety of Quaternary surficial deposits locally mantles the bedrock.

SKOLAI GROUP

The Skolai Group and its subdivisions, the Station Creek and Hasen Creek Formations, were named and described by Smith and MacKevett (1970). The Skolai Group is well exposed in the east-central and northeastern parts of the quadrangle. It is weakly metamorphosed regionally and consists of submarine lavas and their derivative volcaniclastic rocks, the Station Creek Formation, and an overlying sequence of marine sedimentary rocks, the Hasen Creek Formation.

STATION CREEK FORMATION

The Station Creek Formation of 4500 feet maximum thickness is divided into a submarine volcanic flow unit and an overlying volcaniclastic unit which constitutes more than half the formation. Both units form moderately rugged outcrops. The base of the formation is not exposed, and its upper contact is gradational with the Hasen Creek Formation. Contacts between the volcanic and volcaniclastic units are broadly gradational. The formation is cut by gabbro plutons and by a few andesitic dikes.

The volcanic unit contains basalt and basaltic andesite flows, subordinate coarse volcaniclastic rocks, chiefly pillow breccias and tuff breccias, and less abundant fine-grained volcaniclastic rocks and dacite or andesite flows. The lava flows are as much as 100 feet thick, and some are marked by pillow structures. Low-grade metamorphic minerals widespread throughout the volcanic rocks have obliterated many primary textural features. Many of the lavas are amygdaloidal and porphyritic. More detailed petrographic descriptions of the Station Creek are given by Smith and MacKevett (1970).

The upper, volcaniclastic unit contains beds between a few and about 100 feet thick that consist of rocks ranging from coarse volcanic breccias to finely laminated volcanilutites with volcanic graywacke predominating. A few lava flows are intercalated with the stratigraphically lower volcaniclastic rocks. Many beds are graded, and some show load casts. The volcaniclastic rocks contain abundant fragments of Station Creek volcanic rocks and assemblage of secondary minerals, such as albite, pumpellyite, chlorite, epidote, and calcite, which reflect low-grade regional metamorphism.

No fossils have been found in the Station Creek Formation. Because it gradationally underlies fossiliferous Lower Permian rocks, the Station Creek Formation is considered to be Early Permian(?) in age.

HASEN CREEK FORMATION

The Hasen Creek Formation is about 900 feet thick and typically forms moderately smooth or subdued outcrops. It gradationally overlies Station Creek volcaniclastic rocks and generally underlies the Nikolai Greenstone with slight angular unconformity. Locally it is apparently unconformably overlain by unnamed marine sedimentary rocks of Middle Triassic age. It is cut by numerous gabbro bodies, mainly sills, and by a few felsic Tertiary plutons.

The formation is lithologically diverse and includes impure chert, shale, sandstone, conglomerate, siltstone, and limestone. These rocks range from light gray to grayish black and are typically thin bedded. The impure cherts consist largely of chalcedony and quartz and also contain argillaceous dust, scattered crystals of mica, chlorite, quartz, plagioclase, and fairly abundant microfossils, chiefly radiolarian tests and spicules. Quartz veinlets that cut the cherts are fringed locally by clinozoisite and pumpellyite.

The shale is mainly fissile, carbonaceous or siliceous. Generally it contains abundant clay minerals, illite, and quartz, along with carbonaceous debris and scattered microfossils. The sandstone ranges from fine to coarse grained and in places shows cross or graded bedding. Most of the sandstone is impure lithic arkose and subgraywacke. These rocks contain abundant clasts, including lithic fragments chiefly of nonvolcanic origin, quartz, plagioclase, K-feldspar, and micas, chiefly biotite. The clasts are embedded in a microcrystalline matrix composed largely of secondary minerals.

The coarse sandstone locally grades into granule and pebble conglomerates. Subrounded lithic clasts are conspicuous in the conglomerates and generally are composed of rocks derived from subjacent beds. The siltstones are mineralogically similar to the sandstones but are finer grained and contain better sorted and more rounded clasts and less abundant K–feldspar and lithic fragments.

Limestones of the Hasen Creek Formation are dominantly fossiliferous wackestones (terminology of Dunham, 1962) consisting of worn disarticulated fossil fragments as much as 1 cm (centimeter) long in a matrix of carbonate mud that generally constitutes more than half of the rock's volume. The carbonate mud is mainly calcite, but it is locally dolomitic and generally contains some clay minerals and carbonaceous material. Calcite veinlets cut some of the limestones.

Fossils are abundant in the Hasen Creek limestones and occur sparsely in some other rocks of the formation. They are dominantly crinoids, but they also include brachiopods, bryozoans, and corals. Numerous fossil collections from the formation in the McCarthy C–4 quadrangle were studied by R. E. Grant and indicate an Early Permian age (Smith and MacKevett, 1970). Some of the recently studied Hasen Creek fossil collections from the B–4 quadrangle contain brachiopods indicating the Guadalupe stage (Early and Late Permian) (R. E. Grant, 1969, written commun.). These brachiopods are not definitely Late Permian indicators and, in the absence of more conclusive evidence, the formation is still considered Early Permian in age.

UNNAMED MARINE SEDIMENTARY ROCKS

Unnamed marine sedimentary rocks underlie a small area near the northeast corner of the quadrangle. They disconformably underlie the Nikolai Greenstone and probably unconformably overlie the Hasen Creek Formation, but their basal contact is poorly exposed. The sedimentary rocks, a sequence about 150 feet thick, form moderately smooth to subdued outcrops. These rocks consist of thin-bedded chert, siltstone, and fissile shale and are dark gray or grayish black and locally carbonaceous.

Two fossil collections from the sedimentary rocks were studied by N. J. Silberling (written commun., 1968) who reports: "These two collections, from beds beneath the Nikolai Greenstone, are somewhat alike. Both contain poorly preserved impressions of ornate ammonites and traces of halobiid pelecypod ribbing. On this basis they are no older than upper Arisian (mid Middle Triassic). Moreover, the ammonites resemble trachyceratids in which case they are Ladinian (late Middle Triassic) or younger. Also represented are indeterminate cylindrical or conical objects (possibly coleoids, i.e., 'belemnites') and fragments of bone."

The unnamed marine sedimentary rocks are therefore assigned a Middle Triassic age.

NIKOLAI GREENSTONE

The Nikolai Greenstone is widespread and very well exposed in the quadrangle where it forms moderately rugged outcrops. The greenstone disconformably underlies the Chitistone Limestone and unconformably overlies Permian rocks of the Hasen Creek Formation or, rarely, the intervening unnamed marine sedimentary rocks. Angular discordances at the base of the greenstone are generally less than 10 degrees. The regionally widespread Nikolai Greenstone consists of a sequence of subaerial basaltic lava flows and a basal conglomerate. The formation reaches its maximum known thickness of about 13,000 feet in this quadrangle but is typically about 10,000 feet thick. Nikolai lava flows are generally 1 to 12 feet thick and conspicuously amygdaloidal. The basal conglomerate is about 250 feet in maximum thickness and is composed of beds 2 to 15 feet thick. Typically the contacts between the conglomerate and the overlying lava are sharp, but locally they are gradational and marked by intercalated beds and flows.

Basal conglomerates of the Nikolai are poorly sorted dark-greenish-gray rocks that consist of abundant subrounded pebbles in a fine-grained matrix that generally constitutes 10 to 25 percent of the rock. Many of the conglomerates have been sheared and extensively altered. The pebbles, which are largely derivatives of the Skolai Group, include volcanic and volcaniclastic rocks, chert, limestone, gabbro, and quartzite. Matrices of the conglomerates are graywackelike assemblages dominated by secondary minerals such as chlorite, pumpellyite, albite, quartz, opaque dust, calcite, locally abundant hematite, and rare prehnite, clinozoisite, and disseminated pyrite.

The Nikolai lavas are altered basalts that are dark greenish gray and weather to shades of brown. They are fine-grained slightly porphyritic lavas with intergranular and, uncommonly, subophitic textures and contain scattered phenocrysts between 1 and 5 mm (millimeter) long. Amygdules from 1-5 mm long and exceptionally a few centimeters long are generally rather uniformly distributed throughout most of the flows and include spherical, ellipsoidal, and irregular dumbbell-shaped forms. Some of the greenstones are cut by calcite veinlets.

The Nikolai basalts consist of plagioclase, chiefly labradorite, abundant clinopyroxene, less abundant relict olivine, minor to abundant opaque minerals, and an array of alteration products. The phenocrysts are chiefly plagioclase but include some corroded clinopyroxene. The clinopyroxene is mainly augite but some is probably pigeonite. Opaque minerals in the greenstone are magnetite and ilmente, subordinate hematite and pyrite, and rare flecks of native copper and unidentified sulfides. The alteration products are chlorite, including antigorite and ferrugginous serpentine minerals, clay minerals, sericite, and less common calcite, epidote, sphene, and leucoxene. The greenstone's alteration products and amygdule constituents indicate low-grade regional metamorphism. Most Nikolai amygdules contain chlorite and calcite. Chlorite is generally dominant and is locally represented by more than one variety. Some amygdules are characterized by quartz or chalcedony and epidote or by prehnite or natrolite. Less abundant to rare constituents of amygdules are pumpellyite, thomsonite, heulandite, native copper, tenorite, and copper carbonates.

Except for relicts of Permian fossils in limestone clasts of the conglomerate, the Nikolai Greenstone is unfossiliferous. On the basis of its stratigraphic position, it is considered to be late Middle and(or) early Late Triassic in age.

CHITISTONE LIMESTONE

The Chitistone Limestone, which is well exposed in the west-central and northwest parts of the quadrangle, forms rugged, bold outcrops that include some spectacular cliffs. Solution cavities and channels, including a few large caverns, are conspicuous in some Chitistone outcrops. Most Chitistone strata are 5 to 20 feet thick, although thinner beds locally intervene between the thicker beds and in places are dominant in zones as much as 150 feet thick. Thickness of the formation ranges from about 500 to 1,800 feet. The marked contrasts in thickness indicate nonuniform deposition throughout Chitistone time and possibly that the subjacent Nikolai Greenstone was locally emergent during early stages of Chitistone deposition. The Chitistone Limestone disconformably overlies Nikolai Greenstone and gradationally underlies Nizina Limestone.

The Chitistone Limestone consists of lime mudstone and lesser amounts of wackestone, crystalline limestone, and dolomite (terminology of Dunham, 1962). Some beds contain scattered generally spherical chert nodules less than 6 inches in diameter. Calcite veinlets and veins as much as 6 inches thick cut many of the Chitistone rocks and are locally abundant in strongly fractured rocks. Many Chitistone and Nizina limestones emit a fetid odor when broken. The formation's carbonate rocks range from light to dark greenish gray and weather light yellowish or grayish brown. Generally the lime mudstones and wackestones are medium or dark shades of gray and the crystalline carbonates light gray.

The dominant carbonate mudstones range from relatively pure calcite-rich rocks to dolomitic rocks, which are confined to lower parts of the formation. Typically the mudstones contain widely scattered bioclastic debris, pellets and clots of lime mud, rare calcite oolites, and blebs of limpid calcite, in a matrix of lime mud. The bioclasts include echinoid plates and less abundant spherical, rodlike, and arcuate microfossils. Dolomite is a primary constituent of some of the carbonate mud, and many of the mudstones are neomorphic, partly or largely recrystallized. Most of the mud contains sparsely distributed minute opaque minerals, chiefly pyrite, and rare quartz and clay minerals. Thin stylolites cut a few of the mudstones. The wackestones are mineralogically and texturally similar to the mudstones, but they contain more than 10 percent clastic constituents.

The crystalline carbonates consist of crystalline phases of limestone, dolomitic limestone, and dolomite, with crystals between 0.1 and 0.5 mm in diameter forming interlocking mosaics. Most of the crystalline carbonates contain small quantities of quartz, pyrite, and hematite. These rocks probably represent recrystallized lime mudstone and wackestone. The dolomite-rich types are in lower parts of the formation.

The formation's cherts, which are dark gray to black chalcedony with minor amounts of calcite, fracture subconchoidally.

The Chitistone Limestone was probably deposited in shallow seas partly under intertidal and supratidal conditions on a carbonate shelf that overlaid a platform of epeirogenetically submerged Nikolai Greenstone (Armstrong and others, 1970). Its most diagnostic fossils are sparsely distributed ammonites of the genus *Tropites* that indicate the late Karnian Stage of the Late Triassic (N. J. Silberling, written commun., 1968).

NIZINA LIMESTONE

The Nizina Limestone, mapped with the Chitistone in figure 2, is widely distributed in the west-central and northwest parts of the quadrangle where it forms moderately rugged outcrops. Its approximate thickness ranges from 700 to 1,700 feet within the quadrangle. The 1,700-foot estimate may be too large because of unrecognized structural complications; probably a more valid maximum thickness is about 1,000 feet. Most Nizina strata are between ½ and 2 feet thick, but some are as much as 10 feet thick. Thin shaly limestone partings intervene between a few of the limestone beds. The Nizina Limestone conformably overlies the Chitistone Limestone along broadly gradational contacts and conformably underlies the lower member of the McCarthy Formation.

The Nizina Limestone consists of limestone with subordinate local chert lenses and nodules. The limestones include abundant lime mudstone, fairly abundant wackestone, and rare grainstone (terminology of Dunham, 1962). These carbonate rocks are dark greenish gray or less commonly shades of medium or dark gray where fresh. They are yellowish brown or light brown or, rarely, darker shades of brown, light gray, or olive gray where weathered. Calcite veinlets and veins as much as 6 inches thick are abundant.

The typical Nizina lime mudstones are composed largely of cloudy calcite particles 20 to 30 microns across that generally enclose widely scattered pellets and irregular clots of lime mud, bioclastic debris, chiefly echinoid plates and spicules, blebs of clear calcite, and flecks of pyrite and hematite. Some of the lime mudstones are neomorphic or incipiently neomorphic and contain crystals of clear calcite about 0.05 mm in length that have replaced lime mud particles. Fine stylolites have developed in some of the lime mudstones. Besides their dominant calcite, some lime muds contain minor amounts of quartz, dolomite, clay minerals, and carbonaceous material.

The wackestones differ from the lime mudstones by containing more abundant clastic constituents, chiefly pellets of lime mud and bioclastic detritus enclosed in a matrix of lime mud. Some of the wackestones are partly recrystallized.

The rare grainstones in the formation contain abundant oolites about 0.3 mm in diameter cemented by finely-crystalline calcite. The grainstones also contain a few nonoolitic calcite grains and other clasts, chiefly chert.

The chert forms irregular nodules, usually a few inches in maximum dimension but occasionally as much as 2 feet long, a foot wide, and 6 inches thick, which locally coalesce to form layers of chert or lenses 2 to 6 inches thick. The chert is grayish-black to black with dull subvitreous surfaces and subconchoidal fractures and consists of chalcedony with sparse veinlets of calcite.

The Nizina limestones are generally purer than similar rocks in the lower member of the McCarthy Formation. The Nizina Limestone differs from the underlying Chitistone Limestone in its prevalent thin beds, lack of bedded dolomite, more abundant chert, and typically darker colors.

According to Armstrong, MacKevett, and Silberling (1970) the Nizina Limestone probably formed on the basinward slope of a drowned carbonate shelf platform of Chitistone Limestone. Some older Nizina Limestone is probably locally contemporaneous with some younger parts of the Chitistone Limestone. A similar contemporaneity is indicated between younger parts of the Nizina and older strata of the lower member of the McCarthy Formation. The characteristic Nizina fossils are pelecypods of the genus *Halobia*. In the B–4 quadrangle, lower parts of the Nizina Limestone locally contain faunal elements generally found in the Chitistone Limestone. Paleontologic studies by N. J. Silberling indicate that the Nizina Limestone is Late Triassic, with an age span from late Karnian to middle Norian.

McCARTHY FORMATION

LOWER MEMBER

The lower member of the McCarthy Formation is widely distributed in the northwestern part of the quadrangle where it is more than 600 feet thick. It conformably overlies the Nizina Limestone and gradationally underlies the upper member. The lower member is characterized by incompetent thin-bedded, strongly deformed strata that generally form subdued outcrops.

The lower member is impure limestone with minor amounts of shale and impure chert. It contains more limestone in this quadrangle than do the McCarthy lower member rocks in the McCarthy C–4 and C–5 quadrangles (MacKevett, 1970a, b, c). Spherical chert nodules, 1 to 2 inches in diameter, are localized in some of its lower strata, and narrow gash veins and veinlets of quartz or of quartz and calcite occupy crestal zones of some of the folds.

The impure limestones consist of wackestone and lime mudstone and rare grainstone and crystalline limestone (terminology of Dunham, 1962). These rocks are dark greenish gray or, exceptionally, dark gray where fresh, and light or grayish brown where weathered. Typically the wackestones are very fine grained, thinly laminated rocks that contain scattered clasts in a microcrystalline matrix. Most of them contain dispersed carbonaceous material and fairly abundant bioclasts and qualify as carbonaceous bioclastic wackestone. The bioclasts are dominantly calcareous and include spherical and rodlike forms and spicules. Other clasts in the wackestone include grains of calcite and less abundant quartz and pyrite and a few clots of lime mud. The matrix is chiefly locally recrystallized lime mud consisting of calcite and minor dolomite and chalcedony.

The lime mudstones are dense aggregates and coalesced pellets of lime mud and a few scattered clasts of calcareous microfosssils and rarely grains of calcite, quartz, and pyrite. Limpid neomorphic calcite has partly replaced the lime mud in some of the mudstones. The lime mud is dominantly calcite with lesser amounts of chalcedony, carbonaceous material, and dolomite.

The crystalline limestone is probably a neomorphic lime mudstone. It contains scattered calcareous spherical and rodlike microfossil remains in a mosaic of calcite crystals about 0.1 mm long. The rare grainstone is subrounded calcite grains from 0.1 to 0.15 mm in diameter and minor interstitial very fine grained calcite and wispy carbonaceous material. The grainstone contains widely dispersed opaque minerals, chiefly pyrite, and a few spicules replaced by chalcedony and chlorite.

The shales are calcareous and carbonaceous rocks that are dark gray to black and weather dark brown. They are thinly laminated, very fine grained, and consist of quartz, calcite, clay minerals, carbonaceous material, and minor amounts of plagioclase, dolomite, and widely dispersed opaque minerals, chiefly pyrite. Most of the shales contain scattered relicts of microfossils. The impure cherts are dark-gray chalcedony-rich rocks that contain subordinate calcite, carbonaceous material, opaque minerals, and scattered microfossils.

The lower member of the McCarthy Formation contains widespread pelecypods of the genus *Monotis*, which according to N. J. Silberling (written commun., 1968) indicate the late Norian Stage of the Late Triassic. In the B-4 quadrangle, lower parts of the member contain a faunal assemblage that includes pelecypods of the genus *Halobia* and other fossils generally found in the Nizina Limestone that are indicators of the early(?) and mid Norian Stages (N. J. Silberling, written commun., 1968). This faunal distribution substantiates the interpretation that the lower part of the lower member is locally a deep water temporal equivalent of the upper part of the Nizina Limestone. No diagnostic fossils were found in the uppermost 200 feet of the member, and the rocks of this stratigraphic sequence may be as young as earliest Jurassic.

UPPER MEMBER

The upper member of the McCarthy Formation is not differentiated from the lower member in figure 2. Exposures of the upper member are confined to the northwest part of the quadrangle and consist of approximately 850 feet of stratigraphically lower parts of the member. These exposures represent the southeasternmost known outcrops of the member, which is well developed in the McCarthy C–4 and C–5 quadranges (MacKevett, 1970a, b). The upper member gradationally overlies the lower member. The upper contact of the member is not exposed in the B–4 quadrangle. Most strata in the member are ½ to 2 feet thick and form ribby outcrops due to differential erosion of the beds.

Upper member rocks, which are dark gray and generally weather yellowish brown, consist of impure limestone and lesser quantities of chert and spiculite. Gradations between the member's calcareous and siliceous rocks are common. The dominant impure limestones are bioclastic wackestones (terminology of Dunham, 1962) that in places are partly recrystallized. These wackestones consist of fine clasts, generally less than 0.1 mm long, in an extremely fine-grained matrix that is largely composed of crystalline calcite. The clasts include abundant bioclastic remains, chiefly calcareous or siliceous spheres and spicules, grains of calcite, subordinate quartz, plagioclase, and opaque minerals, mainly pyrite. The minor matrix constituents include carbonaceous material, chlorite, dolomite, and secondary iron oxides.

The upper member is probably entirely Early Jurassic in age, although its basal strata may be Late Triassic. Fossils collected from near the base of the member include ammonites that according to R. W. Imlay almost certainly belong to the genus *Psiloceras*, indicative of the Jurassic Hettangian Stage. Stratigraphically higher fossil collections contain *Arietites* and other ammonites indicative of the Jurassic lower Sinemurian Stage (R. W. Imlay, written commun., 1968).

KENNICOTT FORMATION

The Kennicott Formation, the lowest of the five Cretaceous units in the quadrangle (which are combined in figure 2), is best exposed throughout a belt that extends from south of Dan Creek to near the southeastern corner of the quadrangle. It also forms scattered outcrops elsewhere in the quadrangle. The formation has been described and redefined by Jones and MacKevett (1969, p. K6–K11).

A strong angular unconformity separates the Kennicott Formation from subjacent Triassic rocks, and it is overlain by the Schulze Formation with disconformity or possible unconformity, by the Moonshine Creek Formation with disconformity, or by the Chititu Formation with apparent conformity or minor disconformity. It is cut by a few felsic dikes and sills and by rare sandstone dikes. The formation ranges in thickness from a few tens to about 475 feet, and its strata are thin bedded to massive.

The Kennicott Formation consists of a basal conglomerate as much as 75 feet thick grading upward into a sequence of sandstone, siltstone, and shale and containing scattered calcareous concretions and erratically distributed wood and plant debris. The conglomerates generally form bold outcrops; other Kennicott rocks form moderate to subdued outcrops.

Most of the basal conglomerate beds are 5 to 20 feet thick and consist of granule or pebble conglomerate, rarely of cobble or boulder conglomerate. The conglomerates are well indurated and medium dark gray, dark greenish gray, or light gray where fresh and diverse shades of brown where weathered. Their clasts are subrounded to rounded and reflect local provenances with most clasts being derivatives of Nikolai Greenstones or Triassic carbonate rocks. Most of the conglomerates have coarse- or medium-grained wacke or calcite-cemeted arenite matrices which contain quartz, plagioclase, calcite, chlorite, chalcedony, clay minerals, and subordinate glauconite, carbonaceous debris, and pyrite and other opaque minerals.

Sandstones of the formation include several types of wacke and arenite (terminology of Williams and others, 1954, p. 290–294). These rocks are well indurated, typically thin bedded, and locally flaggy or platy. They are light to dark greenish gray where fresh and light brown or yellowish brown where weathered. Most of the sandstones are fine or medium grained. The wackes include feldspathic, lithic, and arkosic varieties consisting of subangular clasts in microcrystalline matrices that constitute 10 to 35 percent of the rock. Their clasts include quartz and slightly less abundant plagioclase and lithic fragments, chiefly chert, minor to locally abundant K-feldspar and calcite, minor leucoxene, ilmenite, pyrite, and rare zircon, epidote, and barite. Matrices of the wacke consist of chalcedony, chlorite, and clay minerals including kaolinite, with subordinate calcite, brown carbonates, sericite, carbonaceous material and secondary iron oxides.

The arenites are mainly feldspathic or lithic calcite-cemented arenites which contain subangular or subrounded clasts of abundant quartz, plagioclase, and lithic fragments, chiefly chert, and minor to rare calcite, glauconite, K-feldspar, biotite, pyrite, ilmenite, and magnetite. In addition to calcite, matrices of some arenites contain minor chlorite, clay minerals, sericite, dolomite, chalcedony, hematite. Alteration products of some of the clasts include leucoxene, hematite, sericite, chlorite, and clay minerals.

The siltstones and shales are thin-bedded to fissile rocks that locally are finely laminated. Generally they are medium gray and weather yellowish or reddish brown. Most of the siltstone and shales consists of small clasts, chiefly quartz and subordinately hematite, calcite, biotite, and plagioclase, in microcrystalline matrices that contain abundant kaolinite and illite and lesser amounts of chalcedony, calcite, chlorite, and secondary iron oxides.

Only the younger part of the regionally bipartite Kennicott Formation is represented in the B–4 quadrangle. This part of the formation contains a variety of fossils, mainly in concretions, that include diagnostic ammonites of the late early Albian (Early Cretaceous) zone of *Brewericeras hulenense* (Jones and MacKevett, 1969, p. K10, K11).

SCHULZE FORMATION

The Schulze Formation, Jones and MacKevett, 1969, p. K13–K15) forms small outcrops in the upland north of Boulder Creek near the western border of the quadrangle. These outcrops are probably isolated remnants of fairly extensive rocks that underlie uplands in the central part of the McCarthy B–5 quadrangle (MacKevett, 1965b). The Schulze Formation overlies the Kennicott Formation with disconformity or possibly with slight angular discordance. Its top is eroded, and its maximum thickness is about 150 feet.

The formation is characterized by thin-bedded light-colored erosion-resistant siliceous rocks. It consists of fine and very fine grained sandstone, siltstone, and platy porcellanite. These rocks are typically light gray and weather buff or yellowish brown. The siliceous rocks of the formation contain abundant microfossils, but no megafossils were found. Megafossils from the formation in the B–5 quadrangle indicate a probable age range from late Albian (?) to Cenomanian (Early(?) to late Cretaceous) (Jones and MacKevett, 1969, p. K14, K15).

MOONSHINE CREEK FORMATION

The Moonshine Creek Formation (Jones and MacKevett, 1969, p. K11–K13) is poorly exposed and sparsely distributed in the B–4 quadrangle. It forms small outcrops that are mainly erosional outliers in the north-central and southeastern parts of the quadrangle. The incomplete Moonshine Creek stratigraphic sections in the B–4 quadrangle are 250 feet in maximum thickness, in marked contrast with the formation's 3,500 foot thickness at its type locality in the McCarthy C-4 quadrangle (MacKevett, 1970a). The Moonshine Creek Formation disconformably overlies the Kennicott Formation or unconformably overlies Nikolai Greenstone. South of Canyon Creek, the Moonshine Creek apparently disconformably underlies the Chititu Formation. Elsewhere its upper surfaces are being subaerially eroded. Rocks of the formation are mainly thin bedded and generally form moderate slopes.

The Moonshine Creek Formation consists of fine-grained sandstone and siltstone with minor coarse-grained sandstone and conglomerate. Generally its basal unit is a pebble or granule conglomerate a few feet thick. Most of the Moonshine Creek is medium or dark gray and weathers light brown or orange brown.

Siltstones of the formation are moderately well sorted and contain fine clasts, chiefly of quartz and plagioclase in microcrystalline clay-rich matrices. The sandstones are feldspathic or lithic wacke and arenite. These rocks are moderately indurated and sorted, and their dominant clastic constituents, quartz, plagioclase, and lithic fragments, are embedded in microcrystalline matrices or are cemented by calcite.

More detailed descriptions of the formation, based largely on geologic studies in the McCarthy C-4 and C-5 quadrangles, are given by Jones and MacKevett (1969, p. K11-K13) and by MacKevett (1970a, c).

The Moonshine Creek Formation contains *Inoceramus* and ammonites of the genus *Desmoceras* (*Pseudouhligella*) that indicate an age span from late Albian to late Cenomanian (Early and Late Cretaceous) (Jones and MacKevett, 1969, p. K13). Part of the formation is contemporaneous with the Schulze Formation and probably with some older parts of the Chititu Formation.

CHITITU FORMATION

The Chititu Formation, named by Jones and MacKevett (1969, p. K15), is the dominant rock unit throughout the southern part of the quadrangle. The formation erodes to smooth rounded slopes locally breached by more resistant strata or by dikes and sills. The Chititu Formation is from 5,000 to 9,000 feet approximately, but accurate estimates of its thickness are precluded by folds and by the lack of persistent marker beds. It overlies the Kennicott Formation with apparent conformity or minor disconformity. At one locality south of Canyon Creek, the Chititu apparently disconformably overlies the Moonshine Creek Formation along a poorly exposed contact. At a few other places marked by obscure contacts it apparently unconformably overlies pre-Cretaceous rocks. The Chititu Formation is overlain conformably by the MacColl

Ridge Formation and locally is cut by Tertiary plutons, chiefly felsic dikes and sills. Chititu rocks have been converted to hornfels in irregular metamorphic aureoles near some of the larger plutons.

The Chititu Formation contains abundant pelitic rocks, chiefly mudstone with subordinate shale, and lesser amounts of porcellanite, sandstone, limestone, and limy concretions. Its thermally metamorphosed variants are hornfels and silicified mudstone. Sandstone dikes locally cut the formation, generally at high angles to the bedding. Most of these dikes are less than 2 feet thick and are resistant. The concretions, which are best developed in the pelites, range from about 2 inches to 2 feet in maximum dimension. They are commonly spherical, but a few have irregular discoidal configurations. Most of the mudstone and shale is dark greenish gray or dark gray on both fresh and weathered surfaces. The mudstones are fairly massive, moderately to well-indurated rocks with a hackly fracture. The shales are finely laminated and typically fissile. The mudstones and shales are similar in mineral content, being silica rich and containing scattered finely comminuted detrital grains, chiefly quartz, embedded in aggregates of clay minerals, illite, sericite, chlorite, secondary iron oxides, and chalcedony. Their less abundant detrital constituents include plagioclase, chert fragments, biotite, and rare K–feldspar, zircon, and magnetite. Many of the mudstones and shales contain disseminated pyrite, and a few are characterized by fairly abundant calcite. Quartz or calcite veinlets cut some of the pelites. Some of the shales and mudstones contain poorly preserved remains of microfossils.

The porcellanites are medium- to dark-gray siliceous rocks that are extremely fine grained and fracture subconchoidally. They consist mainly of chalcedony flecked with scattered grains of quartz, carbonates including calcite, dolomite, and ankerite, and pyrite. Most of the porcellanites contain minor amounts of carbonaceous material, chlorite, clay minerals, and secondary iron oxides. Some are cut by quartz or calcite veinlets. Spherical microfossil tests as much as 0.02 mm in diameter are common in the porcellanite. The tests are mainly siliceous, but a few are calcareous.

The sandstones include feldspathic wacke and subordinate arkosic wacke and lithic arenite (terminology of Williams and others, 1954, p. 290–294). Typically the sandstones are fine to medium grained, poorly sorted, and well indurated. They are medium to dark gray and weather brownish gray. The feldspathic wackes consist of subangular grains, chiefly of quartz and plagioclase, embedded in a microcrystalline matrix that constitutes less than 25 percent of the rock's volume. The matrix consists of clay minerals, chalcedony, chlorite, carbonaceous material, sericite, and minor amounts of calcite, dolomite, leucoxene, and secondary iron oxides. Less common grains in the feldspathic wackes are calcite, K–feldspar, pyrite, magnetite, ilmenite, apatite, biotite, epidote, and lithic fragments, chiefly chert.

The arkosic wacke is mineralogically and texturally similar to the feldspathic wacke but contains more abundant plagioclase and K–feldspar relative to quartz. All of the sandstone dikes studied are either lithic or arkosic wacke.

The lithic arenite contains abundant calcite-cemented subangular to subrounded clasts including lithic fragments that resemble cherty rocks of the McCarthy Formation and less abundant calcite, quartz, plagioclase, and opaque minerals, chiefly leucoxene. The lithic arenites also contain rare clay minerals and chlorite.

The limestone occurs as a few discrete beds and numerous lenses. It is light or medium gray with mottled gray-brown weathered surfaces. The limestone is impure, very fine grained, and contains diverse amounts of non-carbonate minerals mainly as detritus. Most of the limestone is closely fractured and veined by limpid calcite and is composed mainly of turbid microcrystalline calcite, and qualifies as lime mudstone in Dunham's (1962) classification. Some of the lime mudstone has been converted into neomorphic calcite. Besides the dominant lime mud the limestone contains sparsely distributed chalcedony, quartz, sericite, chlorite, calcite grains, plagioclase, pyrite, hematite, ilmenite, leucoxene, and rod-like remains of microfossils.

The metamorphosed Chititu Formation rocks are dark gray weathering to a distinctive medium dark brown that distinguishes them in the field from the typical rocks of the formation. These metamorphic rocks mostly form irregular aureoles surrounding some of the plutons and grade from hornfels to dense silicified rocks and then into normal pelitic rocks outward from the pluton. All appear fine grained with hackly fractures, and most are tough, dense, well-indurated rocks. The hornfels are aggregates of clinopyroxene, epidote, calcite, chlorite, and sphene, suggesting metamorphic grade as high as the hornblende hornfels facies. The less metamorphosed rocks have been pervaded by quartz or calcite but have not been generally recrystallized. Some of the metamorphic rocks contain disseminated pyrite.

The Chititu Formation contains widely distributed *Inoceramus* and less abundant ammonites, both of which substantiate its Late Cretaceous age. The Formation is from Cenomanian to late

Campanian, and in places its basal rocks may be as old as latest Albian (Jones and MacKevett, 1969, p. K17).

MacCOLL RIDGE FORMATION

The MacColl Ridge Formation underlies a few upland areas in the southern part of the quadrangle where its erosion-resistant strata form bold outcrops or cliffs. Its excellent exposures near Pyramid Peak have been illustrated by Jones and Berg (1964, fig. 4). The formation is about 2,000 feet thick in the B–4 quadrangle, but its top is not exposed. It overlies the Chititu Formation with apparent conformity and is cut by Tertiary plutons. Its strata are generally 1 to 3 feet thick and locally flaggy.

The MacColl Ridge Formation was named and described in some detail by Jones and MacKevett (1969, p. K17–K19). The formation consists of coarse- and medium-grained sandstone that in places grades into granule conglomerate, fine-grained sandstone, or, rarely, siltstone. Most rocks of the formation are light or medium gray and weather light brown. The dominant sandstones are arkosic, lithic, and feldspathic wacke in decreasing order of abundance (terminology of Williams and others, 1954). They are well-indurated rocks of diverse subangular clasts in chalcedony-chlorite-clay matrices constituting 15 to 30 percent of the rock. The sandstones are distinguished by the relative abundance of their major clasts: plagioclase, quartz, and lithic fragments, chiefly chert. Their less abundant clasts include K–feldspar, biotite, scattered opaque minerals, mainly magnetite and pyrite, and rare clinopyroxene and apatite. Less abundant matrix constituents and alteration products in the sandstones are actinolitic amphibole, sericite, hematite, limonite, and calcite. Some matrices contain small amounts of carbonaceous material. Near some plutons the sandstones have been baked and slightly recrystallized.

The granule conglomerate is compositionally similar to the coarse-grained lithic wacke. The siltstones generally contain better sorted and more rounded clasts, chiefly quartz, and more carbonaceous material than the wackes.

Diagnostic fossils have not been found in the formation, but the field relations indicate a Late Cretaceous (Late Campanian or Maestrichtian) age (Jones and MacKevett, 1969, p. K18–K19).

FREDERIKA FORMATION AND WRANGELL LAVA

Continental sedimentary rocks of the Frederika Formation are intercalated with the Wrangell Lava and underlie summit regions in the northeastern part of the quadrangle. These rocks which unconformably overlie rocks of the Skolai Group and locally nonconformably overlie gabbro are cut by a few andesitic dikes and sills probably related to the Wrangell Lava. The Frederika-Wrangell sequence is almost 2,000 feet thick in the quadrangle. Lithologically diverse continental sedimentary rocks of the Frederika Formation are dominant throughout the lower part of the sequence and andesites of the Wrangell Lava are dominant throughout the upper part.

The Frederika Formation is conglomerate, sandstone, siltstone, shale, and low-rank coal. Similar rocks from nearby quadrangles have been described in some detail (MacKevett, 1970a, c). These sedimentary rocks are characterized by a wide range in lithology and by strongly contrasting colors and include some rocks rich in tuffaceous material. The few coal seams in the B-4 quadrangle are less than 18 inches thick and do not appear to be extensive. The pelitic rocks of the Frederika Formation contain scattered carbonaceous plant remains, and leaves collected from the formation in the C-4 and C-5 quadrangles have been dated as Miocene (MacKavett, 1970a, b, c).

The Wrangell Lava consists of lava flows, chiefly andesite and basaltic andesite, and subordinate pyroclastic rocks. The lava, which is more extensive in the McCarthy C-4 and C-5 quadrangles, has been described by MacKevett (1970a, c). Only the lower part of the Wrangell Lava is preserved in the B-4 quadrangle where it contains several flows of olivine basalt and a few pyroclastic layers of well-indurated lapilli and crystal tuffs or, rarely, buff-colored ash considered to be of Miocene age. Regionally, Wrangell volcanism extended from the Miocene well into Holocene time.

SURFICIAL DEPOSITS

Quaternary surficial deposits in the quadrangle are alluvium and older alluvium, talus, rock glaciers, several kinds of moraines, landslides, fluvioglacial deposits, and thin veneers of soil, slope wash, or colluvium that were not mapped. Except for the fluvioglacial deposits, the mapped surficial deposits are similar to those described from the nearby McCarthy C-4 and C-5 quadrangles (MacKevett, 1970a, b, c.). Rock glaciers and a variety of moraines are especially well developed in the B-4 quadrangle.

Fluvioglacial deposits as much as 200 feet thick are exposed along the valley walls of the Chitistone River and the tributaries of Young Creek near the southern boundary of the quadrangle. They unconformably overlie older consolidated rocks and locally are overlain by other surficial deposits. The fluvioglacial deposits are poorly consolidated and generally well stratified. They form layers as much as 12 feet thick that are composed of moderately well-sorted sand and silt and lesser amounts of clay, granules, pebbles, and boulders. Typically the larger clasts are subangular and the smaller ones subrounded. Fluvioglacial deposits in the B–4 quadrangle represent the northeasternmost extent of vast deposits underlying large parts of the Chitina Valley west and southwest of the quadrangle. The fluvioglacial deposits probably originated in a periglacial lacustrine environment where overloaded proglacial streams discharged large quantities of sediments into a Pleistocene lake.

INTRUSIVE ROCKS

Intrusive rocks in the quadrangle include gabbro of Permian or Triassic age and intermediate to mafic, felsic hypabyssal, and andesitic rocks of Cenozoic age.

GABBRO

Gabbro forms sills and discordant plutons in the northeastern part of the quadrangle where it intrudes rocks of the Skolai Group. Its outcrops range from masses several miles long and about a half mile wide to narrow sills and dikes a few feet thick. Locally gabbro is nonconformably overlain by the Frederika Formation or cut by felsic dikes.

The gabbros are medium- to coarse-grained rocks composed of minerals 2 to 7 mm long. They are bluish-gray or greenish-gray rocks, weathering to rusty brown or greenish black, and have been altered in various degrees. The gabbros are hypidiomorphic granular or subophitic with rare, generally finer-grained, intergranular phases. Their dominant primary minerals, plagioclase (labradorite) and clinopyroxene, probably augite, generally occur in near-equal amounts and constitute as much as 90 percent of the rock's volume. Other primary minerals include opaque minerals, mainly magnetite and ilmenite, and rare quartz and apatite. Alteration products, abundant in some of the gabbros, include diverse ferruginous serpentine minerals and related chlorites, biotite, uralitic hornblende, sericite, quartz, sphene, pumpellyite, clay minerals, clinozoisite, epidote, and secondary iron oxides. A few of the gabbros contain sparsely disseminated pyrite and pyrrhotite(?).

Although the precise age of the gabbro is not known, it is considered to be Permian or Triassic because it cuts the fossiliferous Lower Permian Hasen Creek Formation and because gabbro pebbles are local components of the basal conglomerate of the Triassic Nikolai Greenstone.

D. H. Richter (written commun., 1969) states that gabbro cuts the lower part of the Triassic Nikolai Greenstone in the Nabesna quadrangle, which borders the McCarthy quadrangle on the north. Richter's observations, along with field evidence in the McCarthy B–4 and C–4 quadrangles, suggest that the gabbro may have formed during more than one intrusive stage in the Triassic and possibly Late Permian, but conclusive evidence for multiple episodes of gabbro intrusion is lacking in the B–4 quadrangle.

INTERMEDIATE AND MAFIC INTRUSIVE ROCKS

A few stocks and small satellite cupolas of Tertiary intermediate and mafic intrusive rocks cut the Cretaceous Chititu and MacColl Ridge Formations in the southern part of the quadrangle. Pelites of the invaded Chititu Formation have been metamorphosed near some intrusive masses forming aureoles as much as several thousand feet wide. In a few places the intermediate and mafic rocks are cut by felsic hypabyssal plutons. The stocks and related smaller intrusive masses form bold outcrops underlying rugged terrain.

The intermediate and mafic intrusive rocks are largely medium-grained hypidiomorphic granular rocks, granodiorite, quartz diorite, and subordinate diorite and gabbro, that weather dark gray or dark greenish gray. The stock near Pyramid Peak is crudely zoned with a border zone of gabbro a few hundred feet wide, a dioritic intermediate zone of similar width, and a central zone of quartz diorite and granodiorite. The other intrusive masses consist of granodiorite and quartz diorite without apparent zoning.

The quartz diorite contains abundant plagioclase, mainly calcic andesine, fairly abundant quartz, clinopyroxene (augite), biotite, and hornblende, and minor to trace amounts of sphene, zircon, apatite, K-feldspar, and opaque minerals, chiefly magnetite. Its secondary minerals include uralitic hornblende, chlorite, sericite, calcite, and clay minerals. The granodiorite differs from the quartz diorite in containing sodic andesine, more abundant K-feldspar, and only trace amounts of clinopyroxene.

Diorite in the intermediate zone of the stock near Pyramid Peak is composed of abundant plagioclase, chiefly normally zoned sodic labradorite-calcic andesine, and abundant brown hornblende formed partly at the expense of clinopyroxene, which is present as scattered frayed relict crystals. Its minor to rare constituents are quartz, biotite, sphene, and magnetite, and its alteration products include uralitic hornblende, sericite, chlorite, and clay minerals.

The border zone gabbro is locally xenomorphic granular in texture. It is composed of abundant normally zoned labradorite, augite, hypersthene, and olivine, and minor to trace amounts of apatite, sphene, K-feldspar, quartz, ilmenite, and magnetite. Its alteration products are biotite, uralitic hornblende, chlorite and related ferruginous serpentine minerals, sericite, and clay minerals.

Th intermediate and mafic intrusive rocks are late Tertiary in age. In the McCarthy C–6 and C–5 quadrangles similar intermediate intrusive rocks cut the lower (Tertiary) part of the Wrangell Lava (MacKevett, 1965a, 1970b, c). Granodiorite from a stock near the western border of the adjacent McCarthy B–3 quadrangle north of Glacier Creek Glacier that is probably coeval with the intermediate intrusive rocks in the B–4 quadrangle yielded concordant potassium-argon ages of 8.4 ± 0.25 m.y. (million years) on both hornblende and biotite. This radiometric age, indicative of the Pliocene, is surprisingly young for a plutonic rock and implies substantial and probably rapid Quaternary uplift and erosion.

Data pertinent to the age determinations follow. Potassium analyses were done by Lois Schlocker on a Baird Flame photometer using a lithium internal standard. Argon analyses were made by Jarel Von Essen using standard techniques of isotope dilution. Ages were calculated using the following constants:

K^{40} decay constants:

$\lambda_e = 0.585 \times 10^{-10}$ year^{-1}

$\lambda_\beta = 4.72 \times 10^{-10}$ year^{-1}.

Abundance ratio:

$K^{40}/K = 1.19 \times 10^{-4}$ atom per atom.

Argon analyses and age calculation:

Mineral	Percent K_2O		A^{40} rad (moles/gm)	A^{40} rad / A^{40} total	Apparent age (millions of years ±2.0)
Hornblende	0.534 0.535	0.534	6.657×10^{-12}	0.18	8.4 ± 0.25
Biotite	8.53 8.64	8.58	1.064×10^{-10}	0.20	8.4 ± 0.25

FELSIC HYPABYSSAL ROCKS

Felsic hypabyssal rocks are widespread in the Cretaceous terrane in the southern part of the quadrangle and cut the Chititu Formation and, less commonly, other Cretaceous rocks and Tertiary intermediate to mafic intrusive rocks. Elsewhere in the quadrangle a few felsic dikes cut pre-Cretaceous rocks. The felsic hypabyssal rocks generally form bold outcrops accented by the subdued slopes of their main host rock, the Chititu Formation. Locally their outcrops are highly fragmented and masked by aggregates of chips and slabs. The felsic hypabyssal rocks form dikes and sills and a few small stocks. Most of the dikes and sills are 2 to 10 feet thick; a few of the sills are as much as 150 feet thick. The felsic hypabyssal rocks have locally baked and welded the invaded Cretaceous rocks, and less commonly they contain partly digested inclusions of hornfelsed Cretaceous pelites.

The felsic rocks are mostly dacite but include rare quartz diorite and felsite. They are light gray to pinkish gray and weather light gray to brown. The rocks are typically porphyritic, or locally glomeroporphyritic in some of the dacites, with abundant phenocrysts in a very fine grained intersertal or felty groundmass. The phenocrysts in the porphyritic dacite are 1 to 2 mm long and consist chiefly of plagioclase, mainly oscillatory zoned andesine and calcic oligoclase and less commonly quartz or partly resorbed mafic minerals including clinopyroxene, amphibole, and biotite. The groundmass of the dacites is dominated by plagioclase microlites and alteration products including chlorite, calcite, sericite, epidote, clay minerals, chalcedony, leucoxene, and secondary hydrous iron oxides. The groundmass may also contain quartz and minor to rare K-feldspar, sphene, apatite, and opaque minerals, chiefly pyrite and ilmenite. Most of the dacite contains sparsely disseminated pyrite and is cut locally by calcite or quartz veinlets. The quartz diorite and felsite are mineralogically similar to the dacite but differ in texture.

Field relationships indicate that the felsic hypabyssal rocks are probably late Tertiary, although their upper age limit is equivocal. Their lower age limit is documented by the fact that felsic hypabyssal rocks cut through leaf-bearing Miocene strata in the McCarthy C-4 quadrangle (MacKevett, 1970a) and by the indicated Pliocene age of intermediate intrusive rocks cut by the felsic plutons.

ANDESITIC DIKES

Sparsely distributed andesitic dikes, which are not shown in figure 2, crop out in the northeastern part of the quadrangle where they cut the Frederika Formation and older rocks. The dikes dip steeply and are between 2 and 10 feet thick. They are altered porphyritic andesites characterized by plagioclase and less abundant clinopyroxene phenocrysts in fine-grained, generally intersertal groundmasses rich in plagioclase. The andesitic dikes are similar to those described from the McCarthy C-4 and C-5 quadrangles (MacKevett, 1970a, c). They are probably genetically related to Wrangell Lava volcanism, which extended from late Tertiary well into Quaternary time.

SUMMARY OF ECONOMIC GEOLOGY

The general region is best known for the massive copper sulfide lodes in the lower part of the Chitistone Limestone at the Kennecott mines (mainly in the McCarthy C–5 quadrangle). The B–4 quadrangle contains numerous copper deposits, including a few in geologic settings similar to those of the Kennecott deposits, local gold placers, and a few lodes or occurrences of gold, antimony, arsenic, or molybdenum. Silver is a minor constituent of most of the copper deposits, but except for the rare native silver associated with some of the native copper, no discrete silver minerals have been found. The only significant mineral production in the quadrangle has been from gold placers, which probably is less than a third of the Nizina District's placer gold production of about 143,440 ounces (Koschmann and Bergendahl, 1968, p. 14).

A report by MacKevett and Smith (1968) summarizes the quadrangle's economic geology and gives analytical data for samples collected throughout the quadrangle. Other reports describing the quadrangle's mineral deposits are by Moffit and Capps (1911), Bateman (1932), Miller (1946), and Sainsbury (1951).

The copper lodes are widely distributed in the Nikolai Greenstone and in places are localized in the lower, mainly dolomitic, parts of the Chitistone Limestone; they are rare in the other rocks of the quadrangle. The deposits in the greenstone form veins, altered zones, and uncommon mineralized amygdules and interflow lenses. The veins, which generally are narrow and discontinuous, typically contain chalcopyrite, bornite, or chalcocite as their chief copper minerals and quartz as their dominant gangue. Most of the altered zones are less than 20 feet wide and are characterized by splotchy, scattered surficial coatings of secondary copper minerals, chiefly malachite. Mineralized amygdules in the greenstone contain native copper and generally smaller quantities of other copper minerals. At the Erickson mine, native copper and tenorite form a few slabby interflow lenses in the greenstone. Small masses of native copper are also localized in fractures in the Nikolai Greenstone near the Erickson mine. In the Chitistone Limestone, copper deposits form veins and small lenticular masses. The dominant copper mineral is chalcocite or, exceptionally, as at the Westover prospect, bornite.

Copper-bearing altered zones in the Station Creek Formation are similar to those in the Nikolai Greenstone. Minor amounts of chalcopyrite are associated with a few quartz veinlets that cut Tertiary plutons and hornfelsed Chititu Formation. Nuggets of native copper are found locally in the gold placers.

The gold placers, which have been worked intermittently since 1903, are along Dan and Copper Creeks and their northward-flowing tributaries that drain terrane largely underlain by the

Chititu Formation. Except for a few bench placers that extend into the quadrangle along Dan Creek, the placers are shallow and are the products of modern erosion. Gold is a minor constituent of quartz veinlets at the Taylor prospect, and it probably occurs elsewhere in similar veinlets genetically related to the Tertiary plutons.

Stibnite, which is a constituent of quartz veins and altered zones cutting the Nizina Limestone north of the head of Eagle Creek, is sporadically distributed in a few other veins and altered zones in the quadrangle. Samples from the deposits north of the head of Eagle Creek also contain minor amounts of tungsten.

Molybdenite-bearing quartz float, derived from lodes in the McCarthy B-3 quadrangle, was found on the moraines of Canyon Creek Glacier. Molybdenite is an uncommon mineral in a few quartz veinlets associated with Tertiary plutons in the southern part of the quadrangle.

Realgar and subordinate orpiment are minor constituents of the mineralized fault zone at the Radovan Low-Contact prospect. Arsenic, generally in small amounts, was detected in samples from many of the copper deposits.

Carbonate rocks of the Chitistone and Nizina Limestones may warrant economic interest in the future. The few coal seams in the Frederika Formation are too small, lean, and remotely situated for exploitation.

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