Stratigraphy, Structure, and Economic Geology of the Iliamna Quadrangle, Alaska

GEOLOGICAL SURVEY BULLETIN 1368-B

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By ROBERT L. DETTERMAN *and* BRUCE L. REED

GEOLOGY OF THE ILIAMNA QUADRANGLE, ALASKA

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A comprehensive study of Mesozoic to Holocene sedimentary, volcanic, and plutonic rocks of the Iliamna quadrangle

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STRATIGRAPHY, STRUCTURE, AND ECONOMIC GEOLOGY OF THE ILIAMNA QUADRANGLE, ALASKA

By ROBERT L. DETTERMAN and BRUCE L. REED

ABSTRACT

The Iliamna quadrangle, located near the north end of the Alaska Peninsula, is part of the magmatic arc that characterizes the peninsula. Bedrock in the quadrangle consists of sedimentary, metamorphic, and intrusive and extrusive igneous rocks of Permian(?) to Holocene age. The named rock units include one group, 11 formations, and one complex; some are newly named, others revised.

The oldest rocks are part of the Kakhonak Complex (new), a metamorphic rock preserved mainly as roof pendants in the Alaska-Aleutian Range batholith. The complex contains chloritic greenschist, quartz-mica-garnet schist, gneiss, quartzite, marble, and amphibolite. Metamorphism is mainly of greenschist and low amphibolite facies; unmetamorphosed equivalent rocks are included in the Cottonwood Bay Greenstone (new), Kamishak Formation (revised) of Late Triassic age, and Talkeetna Formation of Early Jurassic age.

A basin east of the early Mesozoic magmatic arc received at least 6,000 m of highly fossiliferous marine clastic sediments during the late Mesozoic. During Middle Jurassic time, volcanogenic graywacke and conglomerate with thick interbeds of siltstone and shale were deposited. These rocks are divided into the Red Glacier Formation, Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, Twist Creek Siltstone, and Bowser Formation of the Tuxedni Group and the overlying Chinitna Formation, subdivided into the Tonnie and Paveloff Siltstone Members. By Late Jurassic time, the Alaska-Aleutian Range batholith had been emplaced as the core of a volcano-plutonic complex that supplied most of the detritus to the flanking basin on the southeast. The conglomerate, siltstone and shale, and arkosic sandstone of this basin are mapped as the Chisik Conglomerate, Snug Harbor Siltstone, Pomeroy Arkose, and upper sandstone members of the Naknek Formation. Deposition into this basin continued throughout the Cretaceous, but within the quadrangle, Lower Cretaceous rocks were eroded before deposition of the sediments forming the Kaguyak Formation in Late Cretaceous time.

A Tertiary basin, developed in what is now Cook Inlet, received about 6,500 m of nonmarine clastic rock. A small part of the basal sequence is preserved as the Copper Lake Formation (new). The greater part of the nonmarine Tertiary sequence underlies Cook Inlet.

Three periods of intrusive activity are recorded. The oldest began in late Early Jurassic time, about 180 m.y. ago, and continued for about 20 m.y. Rocks formed are chiefly diorite, quartz diorite, and granodiorite with lesser amounts of hormblendite and quartz monzonite, part of a 1,300-km-long magmatic arc in southern Alaska. A

second period, between 83 and 55 m.y. ago, produced small plutons, chiefly of quartz monzonite and granodiorite, along the west flank of the batholith. The last intrusive event occurred about 35 m.y. ago, producing small quartz diorite and granodiorite plutons.

Magma generation during the intrusive episodes locally vented to the surface, forming numerous volcanic centers in the quadrangle. The oldest vents produced mainly breccia, agglomerate, and tuff in Late Triassic and Early Jurassic time. Volcanism that began in early Tertiary time has continued intermittently, the latest activity being the eruption of Augustine Volcano in January 1976. Numerous vents produced andesitic to basaltic flows and associated pyroclastic rock. The Gibraltar Lake Tuff (new), Intricate Basalt (new), and Augustine Volcanics are the only units named. Most of the volcanic rocks are assigned to unnamed units.

The magmatic arc and arc-trench gap of N. 40° E. structural trend are the main structural features of the quadrangle. The main fault feature is the Bruin Bay fault, a major high-angle reverse fault along the west side of the Cook Inlet basin that separates early Mesozoic igneous rocks and associated deposits from late Mesozoic sedimentary deposits. It extends from near Mount Susitna, northwest of Anchorage, to Becharof Lake on the Alaska Peninsula, a distance of about 482 km. Movement along the fault is mainly vertical but may have a sinistral component. No Holocene movement is recorded along the fault; it probably has not been active since the Miocene.

The mineral resources of the Iliamna quadrangle are not used at this time; potential resources include petroleum, iron, copper, gold, silver, pumice, and limestone. Further exploration work is warranted for many parts of the quadrangle.

INTRODUCTION

The Iliamna quadrangle (1:250,000) is near the north end of the Alaska Peninsula, about 200 km southwest of Anchorage and across Cook Inlet from Homer (fig. 1). An area of a few square kilometers along the southeast edge is part of the Katmai National Monument. The Valley of Ten Thousand Smokes is 80 km to the south.

Iliamna Lake, the second largest natural freshwater lake entirely within the confines of the United States, occupies the central part of the quadrangle. The lake is 130 km long and averages about 20 km wide, has 1,660 km^2 of surface area, 420 km of shoreline, and a maximum depth of 363 m near the mouth of Iliamna River. Other large lakes in the quadrangle include Kukaklek, Nonvianuk, Battle, Gibraltar, Kakhonak, Meadow, Lower Tazimina, and Sixmile. There are hundreds of small lakes and ponds.

The quadrangle is readily accessible by both air and water transportation. A scheduled airline makes regular stops at Iliamna, and there are seven other widely separated landing strips for small planes on wheels. Numerous lakes and rivers can be used by small planes on floats. Fishing boats regularly travel from Iliamna Lake to Bristol Bay. There are two gravel roads within the quadrangle. The longest one is part of the Alaska State highway system and connects Pile Bay Village and Williamsport. The other runs north up the Newhalen River from the Iliamna airport. Both roads are open to travel only during summer months.

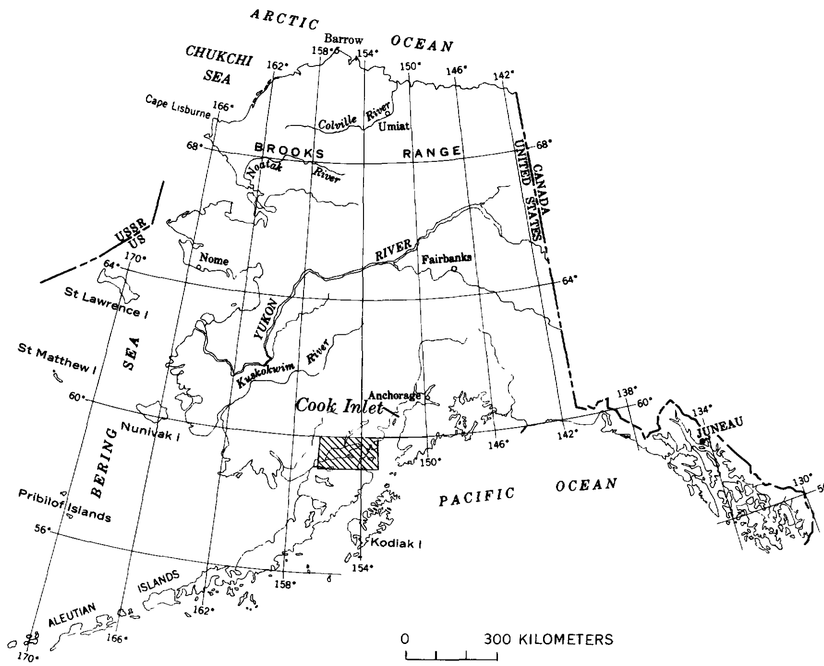


FIGURE 1.—Location of Iliamna quadrangle (cross-hatched area), Alaska.

PREVIOUS WORK

Part of the Iliamna quadrangle was prospected for gold, silver, copper, and petroleum during the period 1893 to 1910. A number of claims and leases were issued, but most activity had stopped by 1915. The first geologic report was written by Martin (1905), who visited Oil Bay in 1903 while drilling for petroleum was in progress. The following year Stanton and Martin (1905) measured some of the many well-exposed sections of Jurassic sedimentary rocks exposed at Iniskin, Oil, and Chinitna Bays. The report of a reconnaissance (the 1909) survey by Martin and Katz (1912) contains the most complete and detailed account of the Iliamna region prior to the present investigation. Their map covers the northeast third of the quadrangle and includes all the areas in which claims or leases for gold, silver, copper, or petroleum had been issued. The 1912 report supplements their earlier rather brief account of the survey (Martin and Katz, 1909).

Insofar as is known, there were no investigations in the area between 1909 and 1921, when Moffit (1922, 1927), A. A. Baker, and Gerald Fitzgerald mapped the Iniskin Peninsula and adjoining areas to the north. Shortly after that time, Mather (1923), accompanied by R. H. Sargent, mapped a small area near Kamishak Bay.

The Iniskin Peninsula has been mapped and studied in considerable detail by Kellum (1945) and Helmuth Wedow, Jr., in 1944, Kirschner and Minard (1949), Imlay (1953, 1959, 1961, 1962a, 1962b, and 1964), and Hartsock (1954) and Don J. Miller, Juhle (1955) and Arthur Grantz. Additional work on Iniskin Peninsula and the area immediately to the north was completed in 1958 (Detterman, 1963, and Detterman and Hartsock, 1966).

During the years 1944 and 1958, the U.S. Geological Survey investigated parts of the Iliamna quadrangle, concentrating on the coastal region north of Iniskin Bay, where there are good exposures of marine Jurassic rocks. A few small field parties concerned mainly with specific mineral resources worked in other parts of the quadrangle. One of the areas investigated was the pumice deposit on Augustine Island (Moxham, 1951). At about the same time, Moxham and Nelson (1952) did a trace-element study along the shoreline of Iliamna Lake, and the U.S. Bureau of Mines did some work on the Millett copper prospect on the north side of the lake (Rutledge and Mulligan, 1952). Muller and Coulter (1953) made a brief terrain survey of the Iliamna road for the Department of the Army in September 1953.

PRESENT INVESTIGATIONS

The present investigations in the quadrangle were an outgrowth of the detailed studies made on Iniskin Peninsula and the area adjacent to the north. Fieldwork began in 1961, when Detterman and Roger A. Hope studied the coastal mountains between Iniskin Bay and Amakdedori and briefly visited Augustine Island. Bruce L. Reed joined the project in 1962; assisted by Douglas McDowell, he mapped parts of the Iliamna, Kakhonak, Gibraltar, and Battle Lakes area. Most of the mapping was done between 1963 and 1967 by Detterman and Reed using a float-equipped airplane, a helicopter, and a skiff. They were assisted by C. E. Bickel in 1963 and 1964, Travis Hudson in 1965 and 1966, and John Erfurth in 1967.

Results of some topical studies as well as some preliminary maps have been published. The topical studies include age dating by both radiocarbon and potassium-argon methods ((Detterman, Reed, and Rubin, 1965; Detterman, Reed, and Lanphere, 1965; Reed and Lanphere, 1969, 1972, and 1973a) and spectrographic analysis of stream sediment and mineralized bedrock samples (Detterman and Reed, 1965; Reed and Detterman, 1965 and 1966; and Reed, 1967). Preliminary maps of the area include those by Detterman and Reed (1964, 1967, and 1968). A short account of the volcanic activity on Augustine

Island was published by Detterman (1968); a detailed report on the surficial materials of the quadrangle was published by Detterman and Reed (1973). The State of Alaska conducted a survey of a mineralized area along the Paint River in 1963 (Richter and Herreid, 1965).

ACKNOWLEDGMENTS

Fieldwork in the Iliamna quadrangle was greatly facilitated by the cooperation and help, both technical and nontechnical, of many individuals; it is impossible to acknowledge all of them; some of the major contributors include Mr. and Mrs. Carl G. Williams and Mr. and Mrs. Richard Williams, who helped with the logistic support of the project. We are also deeply indebted to Mr. and Mrs. Robert Walker and Mr. and Mrs. Oren Hudson.

Many individuals within the Geologic Survey gave technical assistance on some of the more specialized aspects of the program. Chief among these are Marvin A. Lanphere and Meyer Rubin, who provided radiometric age dating of rock and carbon-14 samples, and Ralph W. Imlay, David L. Jones and N. J. Silberling, who identified the many paleontologic specimens.

We appreciate the assistance of the many company geologists for their aid in the field and for beneficial exchange of ideas and geologic information. We are indebted to the personnel of Fisheries Research Institute of the University of Washington, which maintains a laboratory on Porcupine Island, for furnishing date on the bathymetry of Iliamna Lake.

GEOLOGIC SETTING

The Iliamna quadrangle is part of a mobile belt that borders the north Pacific Ocean and includes part of the active Aleutian volcanic arc. The area has been tectonically active throughout much of its recorded geologic history and continues so, as evidenced by changes in elevation resulting from the 1964 earthquake (Plafker, 1965, 1969).

The oldest rocks are part of a metamorphic complex preserved chiefly as roof pendants in the Alaska-Aleutian Range batholith. They are mainly regionally metamorphosed low-grade greenschist facies rocks that are locally upgraded to albite-epidote-amphibolite and pyroxene-hornfels facies along contacts with the batholith. Their heterogeneity suggests a wide variety of original rock types, some of which can be correlated with known Late Triassic and Early Jurassic rocks.

The quadrangle was part of an early Mesozoic magmatic arc that was nearly coincident with the modern Aleutian volcanic arc. The oldest faunally dated rocks are limestone, chert, and shale associated with submarine basalt that were deposited during Late Triassic time. Plutonism and volcanism continued throughout the Early Jurassic, when a thick sequence of volcaniclastic rocks and flows accumulated. Active volcanism subsided with the emplacement of the Alaska-Aleutian Range batholith during the late Early and early Middle Jurassic (Reed and Lanphere, 1969, 1972, 1973a). During the Middle Jurassic, the magmatic arc was uplifted and eroded to form a thick sequence of volcanic graywacke, conglomerate, siltstone, and shale in a forearc basin. By Late Jurassic time the batholith was unroofed and supplied arkosic sandstone and plutonic cobble conglomerate to the basin (Detterman and Hartsock, 1966).

In the mountainous eastern part of the quadrangle, the early Mesozoic magamatic arc and the late Mesozoic forearc basin deposits are now juxtaposed along a major high-angle reverse fault. This fault, the Bruin Bay fault, extends for several hundred kilometers in the Alaska Peninsula and Cook Inlet regions.

Volcanic activity in the Aleutian arc began in early Tertiary time and has continued to the present. Augustine Volcano, the only active center in the quadrangle (Detterman 1968, 1973), last erupted in 1976. Tertiary volcanic flows, breccia, and tuff are the chief bedrock units in the western part of the quadrangle. Several intrusive episodes associated with the magmatic arc have been identified as Early to Middle Jurassic, Late Cretaceous to early Tertiary, and middle Tertiary (Reed and Lanphere, 1969, 1972, 1973a).

The quadrangle was extensively glaciated during the Pleistocene and Holocene (Detterman and Reed, 1973). Glacial retreat left thick deposits of surficial materials mantling much of the area, particularly west of the mountains.

DESCRIPTIVE GEOLOGY

PERMIAN(?), TRIASSIC, AND JURASSIC SYSTEMS

KAKHONAK COMPLEX

The name Kakhonak Complex is here introduced for a heterogenous assemblage of metamorhpic rocks exposed in the Iliamna quadrangle. The rocks were originally of sedimentary, volcanic, and intrusive origin; their presence has been known for many years (Martin and Katz, 1912). These rocks are mainly of greenschist facies, but locally thermal metamorphism has produced pyroxene-hornfels, amphibolite, and granulite facies. The metamorphic complex in large part represents roof pendants within the Alaska-Aleutian Range batholith.

NAME AND DISTRIBUTION

The Kakhonak Complex is well exposed along Kakhonak Lake, Kakhonak River, and Kakhonak Bay and is named for these features. Exposures along Kakhonak Lake are designated the type locality; the other localities can be considered as reference localities. Owing to the wide range of rock types, no single exposure can be considered typical of the entire complex. The greater part of the Kakhonak Complex is located between Cottonwood Bay and Meadow Lake.

Most of the rocks exposed are roof pendants in the Alaska-Aleutian Range batholith in the mountainous eastern part of the quadrangle. Exposures are of very irregular shape and size; most are curvilinear, long and narrow. The smallest cover only a few hectares; the largest is about 20 km long by 2 km wide. In outcrop pattern, the rocks generally trend northeastward parallel to the main structural grain of the quadrangle. Along the western flank of the batholith near Kakhonak Lake, the strike is locally nearly at right angles to the regional strucutral grain. This local trend may in part be caused by intrusion of the plutonic rocks.

Several occurrences of metamorphic rock are west of the batholith. One of these, at Narrow Cove, on the east shore of Kukaklek Lake, is associated with an outlier of the batholith; the one at Chekok Bay, on the north side of Iliamna Lake, is associated with a Late Cretaceous to early Tertiary intrusive rather than with the main batholith. Other small metamorphic masses occur at the tip of the peninsula in Nonvianuk Lake and along the Alagnak River.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness and stratigraphic relations of the Kakhonak Complex can only be generalized. The rocks between the head of Cottonwood Bay and Meadow Lake are mainly slaty argillite, marble, quartzitic mica schist, and quartzite of low to intermediate metamorphic grade. Original bedding from which thickness can be estimated is discernible. Metasedimentary rocks in this area probably aggregate at least 1,000 m, but a reliable thickness estimate is constrained by complex faulting and folding.

At the head of Cottonwood Bay, a dark calcareous slaty argillite overlies the Cottonwood Bay Greenstone, apparently conformably. White crystalline marble, interbedded with the argillite, appears to be part of the same sequence. Farther west, near the pass between Cottonwood Bay and Meadow Lake, is a series of quartz mica schist and quartzite whose relation to the argillite is not known. These rocks are nearly surrounded by quartz diorite of the Alaska-Aleutian Range batholith. Another area of metamorphic rock enclosed in the batholith lies at the head of Meadow Lake. Here small patches of

Cottonwood Bay Greenstone are infolded with the metamorphic rocks in a way that suggests that the greenstone underlies them. All are enclosed in the pluton and thereby older than the pluton; the contact is intrusive.

Stratigraphic relations within the Kakhonak Complex are poorly known but suggest that the metamorphic rocks are overlain by, and at some places interbedded with, metavolcanic rocks. This is consistent with the lithology of the stratigraphic units we believe to be the unmetamorphosed equivalents of the complex that includes the Cottonwood Bay Greenstone, Kamishak Formation, and Talkeetna Formation. The original stratigraphic relations of quartzite and quartz mica schist are more difficult to ascertain, as there are no known unmetamorphosed equivalents in the quadrangle.

LITHOLOGY AND METAMORPHIC FACIES

Most of the rocks mapped as Kakhonak Complex are of greenschist facies metamorphic grade, locally with higher grade rocks produced by contact metamorphism. Most are preserved as roof pendants in the batholith. The metamorphic grade locally increases to the albite-epidote-amphibolite or pyroxene-hornfels facies, perhaps in response to local hot spots, or greater depth of burial.

Although numerous rocks of the Kakhonak Complex were examined in thin section, only the general characteristic mineral assemblages for each facies will be discussed. Most of these rocks are of the greenschist facies; the common minerals characteristic of nearly all rocks were albite, epidote, actinolite, and chlorite. Accessory minerals include sericite, calcite, and magnetite. Rocks included in this group range from those that are imperfectly schistose to those in which segregation banding is well developed. Locally, they show secondary kink banding.

Low-grade greenschist facies metamorphic rocks were noted nearly everywhere within the Kakhonak Complex. Perhaps most abundant is the argillite and slaty argillite at the head of Cottonwood Bay, where foliation is locally well developed. Most rocks contain abundant plagioclase and lesser, but variable, amounts of calcite, quartz, chlorite, and pyrite. These rocks probably were originally calcareous to tuffaceous mudstone. Associated with the argillaceous rocks is calcareous schist consisting mainly of calcite, quartz, and tremolite derived from impure limestone. Quartzite composed of nearly pure quartz with minor sericite and pyrite is locally present at Bruin Bay and the Cottonwood Bay-Meadow Lake pass.

Amphibolite-facies metamorphic rocks are present in a few areas. Perhaps the most notable occurrence is a small outcrop at the end of the peninsula in Nonvianuk Lake, where the rock contains fairly abundant garnet and sillimanite (sillimanite-almandine subfacies of

Williams and others, 1958) in addition to biotite, muscovite, quartz, and orthoclase. Andalusite is an accessory in a few specimens. The biotite is present as large brown flakes that commonly show kink banding. Similar rocks containing large almandine garnets occur locally at Narrow Cove and in a few small areas about 7 km southeast of Gibraltar Lake, probably originally both pelitic and quartzo-feldspathic sediments, most likely shale and sandstone.

Rocks approaching the pyroxene-hornfels facies are limited in area within the quadrangle. One small area near Pilot Lake contains a very fine grained granoblastic rock composed of quartz, feldspar, and biotite with tourmaline, magentite, and sphene as accessory minerals. A small coarsely crystalline chondrodite spinel marble occurs south of the road between Iliamna Bay and Pile Bay near Summit Pass.

AGE AND CORRELATION

Metamorphic rocks in the Iliamna quadrangle were previously mapped as Paleozoic (Martin and Katz, 1912). We believe that much of the Kakhonak Complex represents the metamorphic equivalents of Late Triassic and Early Jurassic rocks. The quartzite and quartzitic schist, however, present an anomalous situation. Permian rocks are known to crop out at Puale Bay (Hanson, 1957), and since we do not have definitive dates on the metamorphic complex, the Permian age has to be considered.

TRIASSIC SYSTEM

The oldest rocks in the Iliamna quadrangle for which there is good faunal control were deposited as a shallow-water marine carbonate during the Late Triassic. These rocks are overlain by a carbonate, shale, siltsone, and chert sequence, also of Late Triassic age, and are apparently underlain by a thick greenstone unit. The greenstone may be in part the age equivalent of the carbonate rocks; the contact relations are not entirely clear. These rocks probably are all part of an allochthonous early Mesozoic sequence and may or may not be part of the Wrangellia terrane as proposed by Jones and others (1979). In ascending order they are the Cottonwood Bay Greenstone (new) and the Kamishak Formation; the Kamishak is divided into the Bruin Limestone Member (new), middle member, and Ursus Member (new).

COTTONWOOD BAY GREENSTONE

NAME AND DISTRIBUTION

The Cottonwood Bay Greenstone is here named for a thick unit of dark-green to gray metavolcanic rocks exposed at its type locality on the south shore near the head of Cottonwood Bay. These rocks are well exposed in the mountains along the south shore of Pile Bay and near the head of Ursus Cove on the west side of Cook Inlet. Small areas of the Cottonwood Bay Greenstone were mapped west of Amakdedori and along the south shore of Kakhonak Bay; an outcrop along the upper Koktuli River in the northwestern part of the quadrangle may be part of this unit.

Locally the Cottonwood Bay Greenstone is so intensely altered as to be part of the Kakhonak Complex. Elsewhere the unit is probably mapped as Talkeetna Formation. In areas where the basal part of the Talkeetna has undergone low-grade metamorphism, the two units are difficult to distinguish from each other.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Cottonwood Bay Greenstone is probably more than 600 m thick. Flow bedding is locally discernible, but much of the greenstone has been altered to hornfels or low-grade schistose rock in which bedding is obliterated, making it impossible to obtain an accurate thickness for the unit. Beds along the south shore of Pile Bay dip 11° to 22° W. for a distance of about 5 km. If this represents continuous section, the greenstone at this locality is at least 600 m thick.

Stratigraphic relations are difficult to ascertain, as most contacts are fault bounded or are against younger intrusive rocks. Most of the evidence suggests that the greenstone is the oldest part of the Triassic sequence in the quadrangle and that it underlies the Bruin Limestone Member. Locally, as at Bruin Bay and north of Meadow Lake, a greenstone is found within the Bruin Limestone. These occurrences may represent dikes or sills of Talkeetna Formation that cannot be distinguished from the Cottonwood Bay Greenstone.

LITHOLOGY

Rocks mapped as the Cottonwood Bay Greenstone are mainly mafic volcanic rocks altered to hornfels and chloritic greenschist. The least altered rocks are found along the south shore of Pile Bay and in the mountains south of the mouth of the Iliamna River. Here the rocks consist of massive dark-green amygdaloidal basalt flows. Vesicles are now filled with the white zeolite heulandite, commonly stretched in the direction of foliation. Most of the rocks have a sugary hornfelsic texture. The surface of most exposures shows bright-green blotches of epidote 25 to 250 mm across. The rock is extremely hard and forms rugged outcrops.

In thin section, the mineralogy is variable but is mainly composed of the albite-epidote-actinolite suite of minerals associated with the greenschist facies of metamorphism. Most rocks are chloritized; a few retain the original porphyritic texture, but most are altered to hornfelsic and granoblastic textures. Phenocrysts are mainly calcic plagioclase, hornblende, and pyroxene. Quartz is absent or constitutes only a very minor part of the rocks. Magnetite and pyrite are common in nearly all specimens.

AGE

Contact relations between the Cottonwood Bay Greenstone and the associated rocks are obscure. At most localities the Bruin Limestone Member is nearby, and locally the basal part of the limestone contains volcanic beds similar to the Cottonwood Bay. On this evidence, the Cottonwood Bay Greenstone is considered to be a part of the Triassic sequence and is presumably Late Triassic. Since fossils obtained from the overlying beds are of Norian age, the greenstone probably is older than Norian.

A possible correlation exists between the Cottonwood Bay Greenstone and the Nikolai Greenstone of the McCarthy area (MacKevett, 1970a, b). The Nikolai is dated by fossils from both underlying and overlying beds as late Middle and/or early Late Triassic. The Cottonwood Bay is considerably more metamorphosed than the Nikolai but the original composition may have been similar; both are overlain by Triassic limestone.

KAMISHAK FORMATION

The Kamishak Formation was originally named by Martin and Katz (1912, p. 47) as the Kamishak Chert for a sequence of chert and limestone typically exposed on the west shore of Kamishak Bay, particularly in the vicinity of Bruin Bay. The name was later changed to Kamishak Formation by Kellum (1945, p. 203) for similar rocks exposed at Puale Bay on the Alaska Peninsula. The Kamishak Formation is herein divided into three parts, the Bruin Limestone Member, middle member, and Ursus Member.

BRUIN LIMESTONE MEMBER

NAME AND DISTRIBUTION

The Bruin Limestone Member is here named for the massive to thin-bedded light- to dark-gray limestone with minor banded green and white chert that is well exposed in its type locality, the peninsula on the south side of Bruin Bay. Most outcrops of the Bruin Limestone area in the belt of Triassic and Lower Jurasic rocks that lies just west of and parallel to the Bruin Bay fault. The southernmost outcrops are on Kenty Creek, a tributary of the Paint River, the northernmost on the south flank of Iliamna Volcano north of the quadrangle. The rocks are well exposed just north of Kirschner Lake, at Ursus Cove, on Clearwater Creek at the head of Chinitna Bay and as a narrow crescent-shaped belt about 10 km long north of Meadow Lake. A small area of the limestone is exposed at Chekok Bay on the north side of Iliamna Lake.

Thickness and stratigraphic relations

The Bruin Limestone Member is at least 610 m thick north of Meadow Lake, and a composite section about 550 m was measured at Bruin Bay (fig. 2). As all sections are incomplete, the total thickness is unknown. Most exposures are fault bounded, and the beds are generally highly crumpled; there are few good marker horizons for stratigraphic control. The Meadow Lake section may be nearly complete, but it was not measured.

The contact with the underlying Cottonwood Bay Greenstone is everywhere covered. Where a cutbank on a small stream southwest of Amakdedori exposes both formations close to the contact, the rocks appear to be concordant. Nearly every section of the member contains dikes and sills of mafic igneous rock that are megascopically similar to the Cottonwood Bay Greenstone; these intrusions may be related to the Lower Jurassic Talkeetna Formation rather than the Cottonwood Bay Greenstone.

The contact with the overlying middle member is not clearly understood. It appears to be gradational in a small stream valley 2 to 3 km north of Kirschner Lake, but the Bruin Limestone Member is more highly contorted than the overlying beds, and this would suggest the contact was not gradational.

Lithology

The Bruin Limestone Member locally contains calcareous siltstone and about 50 to 60 m of banded chert. The lower 150 m of limestone is medium-bedded to massive dark-bluish-gray biomicrosparite (Folk, 1959). The bioclastic grains are small (0.01 to 0.05 mm) and well rounded. Fossil fragments including crinoid ossicles, bryozoans, and echinoderm spines and plates are common; at Bruin Bay they form a massive echinoderm and coral bioherm. The limestone apparently was deposited in a shallow-water high-energy environment, as the rocks are well sorted and the fossils are mostly fragmented. The Meadow Lake area was closer to a landmass than the area farther south at Bruin Bay, where the rocks contain about 5 percent rounded quartz grains; the upper part of this Meadow Lake section appears to have been deposited in a protected lagoon. The rock is an intramicrite

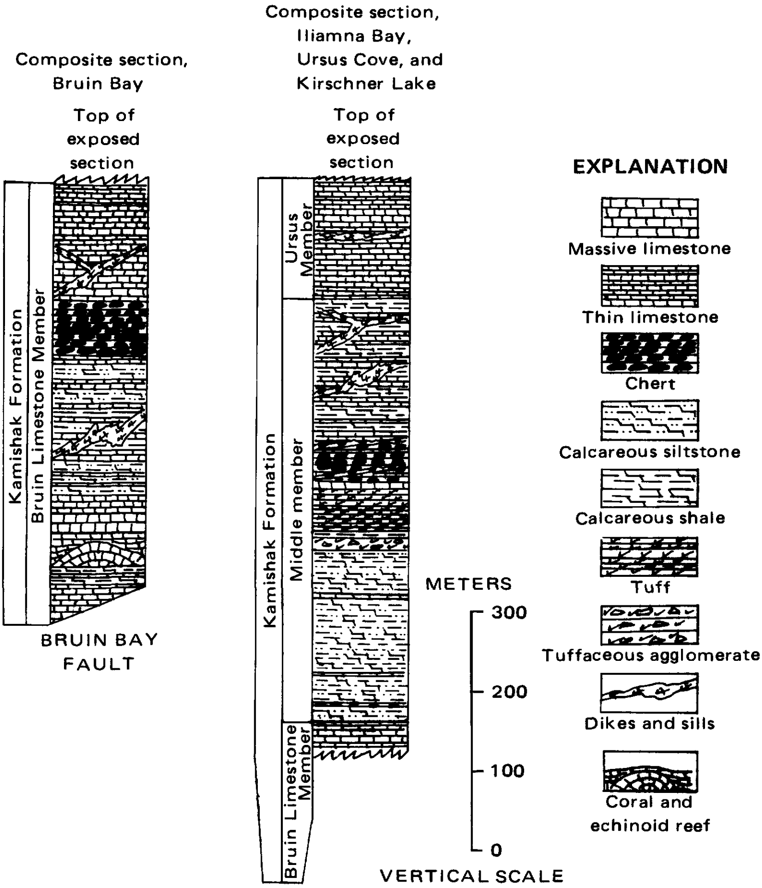


FIGURE 2.—Generalized stratigraphic sections of Kamishak Formation, Bruin Bay and Iliamna Bay, Ursus Cove, and Kirschner Lake.

in which rounded fragments of calcareous ooze are alined parallel to bedding. These same rocks contain hook-shaped masses of sparry calcite considered to be fossilized worm burrows and rounded opaque material that may be fecal pellets.

The limestone and calcareous siltstone sequence is mainly thin to medium bedded and dark gray to black. The limestone is very fine grained cacilutite or dismicrite that contains a few silt-sized quartz grains. It contains large rounded oval masses of sparry calcite, probably formed of fossil fragments. These rocks are partly dolomitized.

The banded chert in the upper part of the member is mainly green and white and locally gray to black. Most bands are 25 to 55 mm thick. The chert is highly folded and forms prominent cliffs at the south entrance to Bruin Bay.

Age and correlation

The Bruin Limestone Member contains few identifiable fossils; fragments are found in nearly all sections. Even the reeflike bioherm at Bruin Bay is composed primarily of cidarid echinoid spines and poorly preserved corals resembling schleractinian colonial forms, according to N. J. Silberling of the U.S. Geological Survey (written commun., 1961). A few specimens of *Halobia* cf. *H. dilatata* Kittl and *Monotis* (?) sp. were found in the upper part of the section at Bruin Bay. According to Silberling, these genera indicate a Norian age of the late Late Triassic. This age, though based on meager evidence, is probably correct, as the overlying members of the Kamishak Formation contain a few fossils of late Norian age.

The Bruin Limestone Member is believed to correlate with the Nizina Limestone in the McCarthy area (MacKevett, 1970a, b). The Nizina overlies the Chitistone Limestone and Nikolai Greenstone, a unit possibly equivalent to the Cottonwood Bay Greenstone, and underlies other limestone units probably correlatable with the upper two members of the Kamishak Formation.

MIDDLE MEMBER

Distribution

The middle member of the Kamishak Formation is best exposed in the cliffs along the north side of Ursus Cove in a series of faulted anticlines and synclines that extend westward about 8 km from Ursus Head as part of a northeastward-trending belt of Triassic rocks that parallels the Cook Inlet shoreline between Bruin Bay and Iniskin Bay. Good exposures are mainly in seacliffs and entrenched streams. Elsewhere heavy brush cover conceals most of the bedrock except on a few hilltops. The member is fairly well exposed at places along the Middle Fork of the Paint River in the southern part of the quadrangle and at Millits Point on the north shore of Iliamna Lake.

Thickness and stratigraphic relations

Nearly all exposures of the middle member are complexly folded, making it impossible to obtain an accurate thickness for the unit. A composite section of about 530 m was obtained from exposures between Kirschner Lake and Iliamna Bay. This section (fig. 2), compiled from exposures scattered along a 30 km belt, can only be considered a rough estimate.

The contact with the Ursus Member is gradational and is placed at the point where the dark-gray medium-bedded to massive limestone changes to thin-bedded light-gray limestone of the Ursus Member.

Because of the marked differences between the two members, this contact, though gradational and variable, is fairly easy to map.

Contact relations between the middle member and the underlying Bruin Limestone Member are not clearly understood. North of Kirschner Lake, the contact appears to be gradational, but in most exposures the Bruin is more highly contorted and faulted than the overlying beds, suggesting an interval of tectonism and possible erosion between the two members.

LITHOLOGY

Thin- to medium-bedded dark-gray to black limestone and calcilutite, black chert, and gray tuff are the main constituents of the middle member. Dark calcareous siltstone locally forms a major part of the section, particularly near Ursus Cove . At most places where exposed, dikes and sills of epidotized mafic igneous rock cut the section. Most of the dikes and sills have narrow chill zones and have not greatly altered the enclosing rock except for the introduction of some pyrite. Large offshoots of quartz diorite from the Alaska-Aleutian Range batholith have intruded the Kamishak Formation in many places, and apophyses of intrusive rock as much as 5 to 6 km^2 in extent are present within it. Locally the original sedimentary deposite has been partly assimilated, and most of the remaining rock has undergone some degree of contact metamorphism.

Examination of a few thin sections from the limestone facies of the middle member indicates that the rock is a microsparite with minor amounts of micritic ooze as laminations or as clasts; most can be classified as grainstone to packstone in the classification of Dunham (1962). A few silt-sized quartz fragments are present in most sections. The dark color, grain size, lack of fossil debris, and local alteration of calcite to chert would suggest that these rocks were deposited in a deep-basin environment.

Bedded chert associated with the limestone was not studied in thin section; it is not known if the chert is primary or secondary. As one limestone showed definite chert replacement of the calcite, at least some chert is of secondary origin. The thin section of a water-laid crystal tuff examined was composed mainly of angular fragments of plagioclase and a chloritized amphibole or pyroxene in a microcrystalline matrix. Many of the crystals showed evidence of solution.

AGE AND CORRELATION

Most of the middle member of the Kamishak Formation is devoid of fossils; several thin units do contain fossils that permit a precise age assignment to them. Fossils were obtained from a thin horizon at Millits Point on the north side of Iliamna Lake and on Sunday Creek, south of Ursus Cove. These localities may represent the same horizons. The Millits Point collection contained three corals, *Koilocoenia* cf. *K. andreaei* (Volz), *Oppelismilia* cf. *O. mojsvari* (Frech), and *Thamnasteria* sp. and the hydrozoan *Heterastridium* cf. *H. conglobotum* Reuss. The Sunday Creek collection contained the hydrozoan and *Monotis subcircularis* Gabb. According to N. J. Silberling, U.S. Geological Survey, who identified the specimens: "The age of this assemblage is Late Triassic, and a more refined age of middle to late Norian is indicated by the occurrence of *Monotis subcircularis* and the hydrozoan *Heterastridium*."

The rocks of the middle member are therefore slightly younger than rocks of the underlying Bruin Limestone Member and probably correlate with the lower member of the McCarthy Formation of the McCarthy area (Mackevett, 1970a b).

URSUS MEMBER

DISTRIBUTION

The main exposures of the Ursus Member are on ridge and mountain tops between Kirschner Lake and Iniskin Bay and between McNeil Lake and the head of the Paint River in the southern part of the quadrangle. The type locality is on the south side of Brown Peak, just north of Ursus Cove. A western belt of Triassic rocks is represented by several small scattered occurrences first appearing north of Millits Point and continuing northeast toward Lower Taximina Lake. The outcrop pattern is similar to that of the middle member but is somewhat more restricted in areal extent.

THICKNESS AND STRATIGRAPHIC RELATIONS

A composite section about 150 m thick was derived from measurements of exposure between Kirschner Lake and Iliamna Bay. Since this section is not complete, the Ursus Member may be thicker.

The contact with the overlying Talkeetna Formation is considered to be a disconformity, mainly on the basis of the difference in type of rocks involved. The contact is commonly a fault, but where it is not, the two units appear nearly conformable. The contact with the middle member is gradational.

LITHOLOGY

Thin-bedded light-gray limestone, locally dolomitic, is the main constituent of the Ursus Member. Interbedded with the limestone are a few thin beds of gray chert or porcellanite and minor units of tuff. The rocks are locally cut by dikes of mafic igneous rock and have been intruded by offshoots of the Alaska-Aleutian Range batholith.

The limestone is a fine-grained biomicrite and biosparite containing fragments of fossil material now preserved as coarsely crystalline sparry calcite. Some of the beds are composed mainly of subhedral dolomite. Most of the limestone is clean and composed primarily of carbonate grains, indicating deposition in a moderate to high-energy environment. Minor amounts of silt-sized quartz grains are present.

Specimens examined in thin section are from several localities and do not represent a stratigraphic succession of samples; they do suggest a progressive shoaling of the depositional environment with time. The lower member represents primarily a deep-water site, whereas the upper member represents mainly a shallow-water deposit.

AGE AND CORRELATION

The limestone of the Ursus Member contains a considerable amount of fragmental fossil material, but identifiable megafossils have not been found. The fragments, now largely replaced by sparry calcite, suggest echinoid spines, coral, bryozoans, and probably flat pelecypods. The fragmental material is compatible with the life forms that could be expected in a Late Triassic sea but does not yield evidence for an age assignment.

Lacking definitive age evidence, the Ursus Member is considered to be part of the Late Triassic sequence but may be Early Jurassic. An Early Jurassic limestone section was mapped at Puale Bay, 195 km south of the quadrangle by Smith (1925) and Kellum and others (1945). A similar unit, the McCarthy Formation, has been dated as both Late Triassic and Early Jurassic by MacKevett (1970a, b) in the McCarthy quadrangle 650 km to the northeast. The Ursus Member of the Kamishak Formation may be equivalent to the upper member of the McCarthy Formation.

JURASSIC SYSTEM

During most of Early Jurassic time, the Iliamna area was part of a volcano-plutonic arc where a thick accumulation of volcanic rock interbedded with a lesser amount of sedimentary rocks was formed. Jurassic plutonism began about 179 m.y. ago (Reed and Lanphere, 1969) with implacement of hornblende gabbro and other mafic igneous rocks. These early intrusions were probably a continuation of the waning phase of early Mesozoic volcanism. The quartz diorite and related granitic rock of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1969) were intruded at the beginning of the Bajocian Stage of the Middle Jurassic. Most potassium-argon age dates fall within the 160–172 m.y. range.

Marine sediments were being deposited in the area coevally with the implacement and cooling of the batholith during early Middle Jurassic, and deposition was essentially continuous throughout the remainder of Jurassic time.

The Jurassic sequence in the Iliamna quadrangle is divided into several stratigraphic and intrusive units. The Lower Jurassic volcanic unit is assigned to the Talkeetna Formation. The intrusive rocks are divided compositionally and discussed in what is believed to be their order of intrusion, from oldest to youngest: mafic and ultramafic rocks, diorite, quartz diorite, quartz monzonite, and trondhjemite. In this report, plutonic rocks are classified according to the system of Moore (1959) and Bateman and others (1963). The sedimentary units are divided into the Tuxedni Group, Chinitna, and Naknek Formations.

TALKEETNA FORMATION

NAME AND DISTRIBUTION

The name Talkeetna Formation was first applied to the thick unit of primarily volcanic rocks in the Ilianmna quadrangle by Detterman and Hartsock (1966). These bedded volcanic rocks had been known for many years (Martin, 1905 and 1926; Martin and Katz, 1912; and Moffitt, 1927). Early reports generally referred to them as the Lower Jurassic porphyries and tuffs. As a temporal and lithic correlation can be demonstrated between these rocks and the type Talkeetna Formation in the Talkeetna Mountains (Martin, 1926), the name was extended into the area. Detterman and Hartsock further divided the formation into three stratigraphic units, in ascending order: Marsh Creek Breccia Member, Portage Creek Agglomerate Member, and Horn Mountain Tuff Member. As most of the regional geologic mapping in Iliamna quadrangle was not sufficiently detailed to permit division of the formation, it was not divided on the map.

The best and most continuous exposures of the Talkeetna Formation are in a belt several kilometers wide that borders Cook Inlet between Kamishak Bay and the northeast corner of the quadrangle. This belt, separated from younger Jurassic sedimentary rocks by the Bruin Bay fault, forms the eastern flank of Alaska-Aleutian Range batholith. The formation is present on the west flank of the batholith also; good exposures can be found near Battle Lake in the south and Lower Tazimina Lake in the north.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Talkeetna Formation is about 2,255 m thick in the Chinitna Bay area (Detterman and Hartsock, 1966), probably the maximum thickness exposed in the quadrangle, although specific measurements were not made elsewhere. The only complete sections of the formation are in the Iniskin and Chinitna Bay areas. At most other places where exposed, the rocks are most like the lower part of the formation.

The contact with the underlying Triassic sedimentary rocks is a disconformity. The contact, though rarely seen, is preserved at several places between Ursus Cove and Iliamna Bay. A small area of Talkeetna overlies the Cottonwood Bay Greenstone north of Meadow Lake, where the contact would be an unconformity.

The upper contact is an angular unconformity. In the western belt of exposures, the overlying rocks are Tertiary volcanic rocks. In the main belt of exposures along the eastern flank of the batholith, the contact is between the Talkeetna and the Middle Jurassic Tuxedni Group. This unconformable relation is exposed in a small area north of the beach at Amakdedori.

LITHOLOGY

The Talkeetna Formation consists mainly of volcanic breccia, agglomerate, lava flows, and tuff. Sedimentary rocks are locally interbedded with the volcanic rocks, but they make up a very minor part of the section in the quadrangle. Although we do not formally divide the formation into members, an informal three-part division is convenient for describing its lithology.

The lower third, approximately equivalent to the Marsh Creek Breccia Member (Detterman and Hartsock, 1966), is mainly a dark-greenish volcanic breccia interbedded with lava flows. Subangular to angular volcanic clasts ranging from about 12 to 450 mm are commonly in a tuffaceous to glassy porphyritic flow matrix. The matrix in some beds is lava similar to the interbedded andesite to basaltic andesite flows. Close proximity of these beds to the batholith has resulted in considerable alteration such that the original composition cannot be easily ascertained. The original texture, where still visible, ranges from intergranular to pilotaxitic. Highly corroded plagioclase phenocrysts are common in the pilotaxitic rocks, and small clinopyroxene phenocrysts, commonly altered to epidote and chlorite, occur in the intergranular types. Near the batholith, many of these rocks are metamorphosed to hornfels and chloritic greenschist. Magnetite is a very common accessory mineral, occurring generally as small grains in the chloritized ferromagnesium minerals.

The middle third, equivalent to the Portage Creek Agglomerate Member, is well exposed in the eastern belt along Cook Inlet. This unit is mainly a fine fragmental rock with well-rounded volcanic clasts and forms massive units of pink to light-green rock. The matrix is mainly tuff; beds of lapilli tuff are common in the Iniskin Bay area.

These beds are generally less altered than the underlying volcanic breccia, but some chlorite and granular epidote is present locally. The pink color of some of these rocks is imparted by finely disseminated hematite grains, locally, the greenish color by the presence of chlorite. A fine-grained greenish-gray silty sandstone is interbedded with the agglomerate in the area between Chenik Lake and Amakdedori; a greenish argillite is present in the Chinitna Bay area.

Good exposures of the upper third of the Talkeetna Formation are present between Iniskin Bay and the northeastern corner of the quadrangle, particularly in the area around Horn Mountain north of Chinitna Bay. Well-bedded thin to massive lithic to crystal tuff is the dominant rock type. The thin-bedded units are commonly laminated and white, tan, red, green, purple, and mottled. Most of the laminated beds were water laid, and belemnite fragments are commonly found in them; some are of continental origin, for an upright tree stump was found at Horn Mountain north of Chinitna Bay.

Clastic sedimentary rock, including tuffaceous sandstone, conglomerate, and siltstone, is fairly common in the upper third of the formation. The composition of these rocks indicates a change from dominantly volcanic to marine clastic sedimentation in this part of Alaska at the end of the Early Jurassic. The marine sedimentary environment lasted for about 100 million years; the next major volcanic episode began in the early Tertiary.

AGE AND CORRELATION

Identifiable fossils have not been found in the Talkeetna Formation in the Iliamna quafrangle. A few belemnite and wood fragments are present in the tuff beds near the top of the formation near Chinitna Bay but are of little use for age determinations. Similar tuffaceous beds in the Talkeetna Mountains, about 350 km to the northeast, have produced good fossils, including the pelecypod *Weyla* sp. and the ammonites *Arnioceras* sp., *Crucilobiceras* sp., and *Acanthopleroceras* sp. These fossils suggest a Sinemurian to Pliensbachian (Early Jurassic) age for those beds. The tuff beds in the Iliamna quadrangle are believed to correlate with the fossil-bearing rocks in the Talkeetna Mountains area.

INTRUSIVE ROCKS

Intrusive igneous rocks form a major part of the rocks of Iliamna quadrangle. These rocks are part of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1969, 1973a, and 1973b), which extends from southwest of Becharof Lake on the Alaska Peninsula northeastward about 650 km to the Talkeetna Mountains. Within the quadrangle, the batholith is about 26 to 52 km wide. Potassium-argon age dates indicate that the batholith was emplaced during three discrete intrusive episodes—Early to Middle Jurassic, Late Cretaceous to early Tertiary, and middle Tertiary (Reed and Lanphere, 1969).

Plutonic rocks of Jurassic age in the Iliamna area are chiefly quartz-bearing granitic rocks, but they range in composition from pyroxenite to alaskite. Quartz diorite predominates, followed in general order of abundance, by diorite, granodiorite, quartz monzonite, hornblendite, pyroxenite, and alaskite. Geologic mapping was not done on a scale that permitted precise location of contacts between units of the various lithologies. In many places, the contacts between the plutonic rock units shown on plate 1 represent an approximate midpoint between location of samples of different lithologies. Known contact relations, together with some potassium-argon age determinations, indicate that of the Jurassic plutonic rocks, the mafic rocks are the oldest, followed in general by successively more silicic rocks.

MAFIC AND ULTRAMAFIC PLUTONIC ROCKS

Small bodies of gabbro, hornblendite, and pyroxenite occur as inclusions or small pendants within diorite and quartz diorite. In many places they are associated with metamorphic rocks (amphibolites, hornfels, and metavolcanic rocks of the Talkeetna Formation), which suggests that their mafic character could be the result of partial digestion of mafic wallrocks by a more silicic magma or, being the first to be emplaced, that they consequently came in contact with the metamorphic rocks on all sides. Many of the gabbros contain euhedral crystals and have well-developed alternating plagioclase-rich and hornblende- or pyroxene-rich layers, suggesting that they in part represent crystal accumulates that formed early in the history of the batholith.

Pyroxenite

Dark angular magnetite-bearing fragments of pyroxenite occur in plutonic breccia west of Frying Pan Lake (Reed and Detterman, 1965). Brecciation is related to the intrusion of a small body of hornblende granodiorite of Late Cretaceous or Tertiary age. The northeast and southwest extensions of the breccia are covered by surficial deposits. The pyroxenite is medium to coarse grained and dark green to black. In thin section, the texture is panidiomorphic- to allotriomorphic-granular. The main constituents are green clinopyroxene and titaniferous magnetite. The magnetite occurs as late interstitial fillings and locally replaces clinopyroxene. Other constituents are small shreds of reddish-brown biotite, partially altered interstitial labradorite, and apatite. Apatite inclusions in clinopyroxene are common and produce a well-developed poikilitic texture.

Hornblendite

Hornblendite generally occurs as small coarse-grained bodies within hornblende gabbro, diorite, and quartz diorite; bodies of hornblendite to 3 km long are present south of the Pile River. Euhedral crystals of green hornblende to 250 mm long and 60 mm across are well exposed at Pile Bay near the mouth of the Iliamna River. In general, however, hornblende crystals do not exceed 50 mm in length. Contacts with surrounding rock can be sharp or gradational, but in most places there is evidence of crosscutting by the enclosing plutonic rocks. Hornblendite typically consists of 70–90 percent euhedral green hornblende with interstital labradorite and magnetite. Accessory minerals are apatite, pyroxene, biotite, chlorite, and epidote. Magnetite can make up as much as 20 percent of the rocks but generally constitutes less than 10 percent. Poikilitic grains of hornblende commonly enclose small blebs of magnetite, or magnetite occurs in thin opaque streaks within and along the edges of hornblende crystals.

Gabbro

Gabbro occurs within diorite and quartz diorite as small bodies a few tens of meters in maximum dimension to bodies 5 km long (pl. 1). The smaller bodies are included with either diorite or quartz diorite on plate l. Gabbro is a major rock type associated with iron deposits. The ore mineral is magnetite that occurs as small crystals disseminated throughout the gabbro.

Contacts of gabbro with enclosing intrusive rocks may be gradational over hundreds of meters or abrupt. At many locations, small dikes of diorite and quartz diorite cut the gabbro, and pockets of hornblendite are found within the gabbro bodies. In general the gabbro is medium to coarse grained with a color index of about 60. In thin section, the texture is hypidiomorphic granular. Main constituents, in decreasing order of abundance, are calcic labradorite (An_{65-70}), hornblende, clinopyroxene (with subordinate orthopyroxene), magnetite, and magnesian olivine. Accessory minerals include apatite and spinel. Olivine, though not easily identified in hand specimens, is generally present in thin section. In the specimens examined, it occurs as magnesium-rich subhedral to anhedral grains enveloped by euhedral pyroxene that in turn is replaced by hornblende. Disseminated opaque iron oxides (chiefly magnetite) generally make up 5 to 10 percent of the rock; some thin sections contain as much as 20 percent.

The northern part of the group of hills in T. 11 S., R. 31 W., contains several small bodies of gabbro and layered gabbro. These bodies are surrounded by diorite (not shown on pl. 1) that is gradational to hornblende quartz diorite. A small well-exposed body of banded gabbro approximately 300 by 240 m lies within a body of hornblende diorite. Contacts with surrounding hornblende diorite are covered by rubble, but the layered gabbro is locally cut by diorite dikes. Layering, caused by alteration of light- and dark-colored layers, strikes uniformly N. 70–80° E. and dips steeply to the south. Individual layers are composed alternately of plagioclase-rich and hornblende-pyroxene-rich units that range in thickness from 10 mm to more than 300 mm. In thin section, some layers contain magnesium-rich anhedral olivine, invariably rimmed by pale-green hornblende. Olivine contains many opaque inclusions. Euhedral to subhedral plagioclase is more abundant in the lighter layers; it occurs as complexly twinned normally zoned ($An_{65\text{-}80}$) crystals. Long axes of plagioclase crystals are generally parallel to the layering of the gabbro. Clinopyroxene mantled by hornblende coronas is abundant in the olivine-deficient bands. Accessory minerals include opaque iron oxides, green spinel, and apatite. The surrounding hornblende diorite is medium grained and has a color index between 50 and 60. In thin section, the texture is hypidiomorphic granular and the main mineral constituents are normally zoned sodic labradorite, hornblende containing abundant opaque (magnetite?) dust, and late magnetite.

A body of olivine-bearing gabbro 6 km east of Mirror Lake is associated with layered gabbro similar to that described above. Contact relations between the banded gabbro and olivine gabbro could not be determined, but both rock types are cut by granodiorite. The olivine-bearing gabbro is dark and medium grained and is composed of calcic labradorite and clinopyroxene. The clinopyroxene is generally rimmed with pale-green hornblende. Disseminated magnetite (5–10 percent) and minor olivine, invariably rimmed with hornblende, are present.

DIORITE

Diorite is generally gradational into gabbro and quartz diorite. The gradation to quartz diorite is marked by a decrease in the amount of hornblende and an increase in biotite and felsic minerals. Near the contacts with amphibolite and metavolcanic rocks, inclusions are more abundant, locally making up more than 50 percent of the rock. At some places, partial assimilation of wallrocks appears to have influenced the composition of the magma. At other places, where large areas of diorite are present, for example, between Pile Bay and Iniskin Bay, there are few pendants of country rock, and the small inclusions present are thought to be refractory residuals.

The color index of diorite is between 35 and 60. Quartz is invariably present. Most diorite is equigranular to hypidiomorphic granular with the larger grains ranging between 1 and 7 mm in maximum dimension but more commonly between 1 and 3 mm.

Plagioclase ($<An_{50}$) makes up 30 to 60 percent of the rock, hornblende 10 to 25 percent, biotite 0 to 10 percent, and quartz 1 to 10 percent. Accessory minerals, in order of abundance, are chiefly magnetite, sphene, and apatite; secondary minerals include epidote, chlorite, and sericite. Plagioclase shows both normal and oscillatory zoning. Cores as calcic as An_{65} are in many places partially replaced by sericite. They generally show oscillatory zoning that is superimposed on a weak overall normal trend. Cores are rimmed by normally zoned, more sodic plagioclase (An_{30-40}). Bluish-green hornblende is more abundant than biotite. Poikilitic hornblende crystals commonly enclose grains of plagioclase and, more rarely, pyroxene.

QUARTZ DIORITE

Quartz diorite is by far the most abundant plutonic rock type in the quadrangle. The texture and composition are highly variable. Generally, as the percentage of felsic minerals increases, biotite increases at the expense of hornblende. The grain size ranges between 1 and 15 mm, but most quartz diorite has a grain size between 2 and 5 mm. The color index ranges from 4 to 30. Plagioclase makes up between 45 and 70 percent of the rock; quartz varies between 10 and 35 percent. Accessory and alteration minerals generally make up less than 5 percent of the total rock and include magnetite, potassium feldspar, sphene, apatite, chlorite, sericite (replacing plagioclase), and, rarely muscovite.

Zoned plagioclase occurs as white to light-gray subhedral grains generally twinned according to the albite law, although Carlsbad and pericline twinning are not rare. The anorthite content of cores may be as high as An_{55}, of rims as low as An_{5-7}. Oscillatory zoning is generally superimposed on an overall normal trend. Anorthite-rich cores usually show incipient replacement by sericite. A decrease in the average anorthite content of plagioclase is generally accompanied by a corresponding decrease in total mafic minerals.

Untwinned potassium feldspar is present as late interstitial grains. Both hornblende and biotite are invariably present; the proportions vary widely. Biotite occurs as single hexagonal plates to 40 mm in diameter and as small irregular flakes associated with hornblende. Hornblende is present as euhedral crystals to 25 mm long and as ragged anhedral grains. Augite is rare and was seen only as small grains poikilitically enclosed by hornblende. Chlorite most commonly occurs as a replacement of biotite and, less commonly, hornblende. Epidote, where present, replaced hornblende or calcic plagioclase.

As stated, quartz diorite grades into diorite, but in no case was quartz diorite observed to be gradational with grandiorite or quartz monzonite.

One particularly well developed concentrically zoned body lies between Venturi Lake and Gibraltar Lake. Here, a leucocratic biotite-muscovite quartz diorite core approximately 6 km in diameter is gradational outward to a biotite-quartz diorite rim 1.5 to 3 km wide. The biotite quartz diorite rim cuts surrounding biotite-hornblende quartz diorite that is gradational outward to hornblende-biotite quartz diorite. The biotite-muscovite core is very coarse grained to micropegmatitic in texture, and large biotite flakes are alined to define a concentric foliation. Muscovite makes up less than 3 percent of the core, biotite between 4 and 8 percent. The percentage of biotite in the biotite quartz diorite rim increases outward but does not exceed 10 percent. The gradational chemical composition and contact relations suggest that the zoned pluton becomes progressively more felsic inward. The outer parts of the plutons solidified, at least in part, before a trapped felsic (?) melt broke through the outer carapace of crystals.

Ten samples of quartz diorite were dated by the potassium-argon method (Reed and Lanphere, 1969, 1973b). Ages and chemical analyses of these samples are given in table 1. Age determinations on most of these samples were made on coexisting biotite and hornblende or on biotite and muscovite. Concordant ages are within the limits of analytical precision and indicate that the quartz diorite was emplaced between 168 and 154 m.y. ago.

QUARTZ MONZONITE

Quartz monzonite makes up a minor part of the Jurassic intrusive rocks along the east margin of the batholith, mainly around Bruin Bay, Iliamna Bay, and Iniskin Bay. Most areas are small, and their apparent concentration around the bays may in part be due to better exposures and more detailed mapping in these areas.

The rock is mainly medium grained and light gray with a pinkish cast due to crystals of pink orthoclase. Modal analyses and inspection of thin sections indicate that orthoclase constitutes about 20 to 30 percent of the rock, mostly as phenocrysts. Quartz and plagioclase constitute about 20 to 30 percent, respectively, mafic minerals generally less than 10 percent.

Contacts with country rock are clearly intrusive. A good example of magmatic stoping can be seen at Contact Point, where blocks of white crystalline marble 3 m in diameter are included in the quartz monzonite. The blocks have smooth outer surfaces and have been rotated with respect to one another.

Minor disseminated sulfide mineralization is associated with emplacement of the quartz monzonite. Arsenopyrite, chalcopyrite, and pyrite occur at Bruin Bay, pyrite and minor free gold at Diamond Point and chalcopyrite along with some malachite on Clearwater Creek at the head of Chinitna Bay.

TABLE 1. *Chemical analyses, CIPW norms, and potassium-argon ages and analytical data for some intrusive rocks in the Iliamna quadrangle*

[Chemical analyses by rapid-rock method. Analysts: P. L. D. Elmore, S. D. Botts, Lowell Artis, Hezekiah Smith, G. W. Chloe, J. L. Glenn, and Dennis Taylor. Potassium analyses by L. B. Schlocker and H. C. Whitehead; argon analyses by M. A. Lanphere and J. C. Von Essen. Data for Nos. 11, 18, and 32 supplied by Mobil Oil Corp.; permission to publish granted. QD, quartz diorite; QM, quartz monzonite; GD, granodiorite; D, diorite; TR, trondhjemite; HB, hornblendite; HG, hornblende gabbro; B, basalt; Kqm, Cretaceous quartz monzonite; TKi, Tertiary or Cretaceous intrusive; Jqd, Jurassic quartz diorite; Jtr, Jurassic trondhjemite; Jqm, Jurassic quartz monzonite; Jm, Jurassic mafic and ultramafic; Tqd, Tertiary quartz diorite]

Map loc. No Field No	4 65AR910	5 65AR1034	6 65AR818	7 62ALe2	8 65AR906	9 65AR905	10 67AR827	11 6–14–6	15 65ADt1084
Chemical analyses (weight percent)									
SiO_2	63.8	70.8	70.0	65.7	62.3	73.1	53.2		42.0
Al_2O_3	17.6	16.3	15.6	15.5	18.4	15.9	18.9		14.7
Fe_2O_3	1.7	1.0	1.2	2.3	2.6	.67	3.6		5.8
FeO	2.6	.76	1.3	2.3	2.3	.48	4.8		8.3
MgO	1.3	.37	.74	1.6	1.5	.35	4.3		11.6
CaO	5.4	3.2	4.3	5.2	6.3	2.5	9.0		11.4
Na_2O	4.1	4.3	4.3	3.8	4.0	4.5	3.5		1.7
K_2O	1.7	2.2	1.1	1.6	.65	1.2	.51		.23
H_2O-	.02	.06	.04	0.0	.16	.03	.03		.06
H_2O+	.52	.62	.64	.66	.75	.80	.77		1.3
TiO_2	.78	.18	.55	.80	.74	.08	.21		1.8
P_2O_5	.24	.06	.11	.18	.21	.05	.25		.08
MnO	.15	.10	.05	.12	.13	.05	.18		.18
CO_2	.05	.05	.05	.05	.05	.05	.05		.05
Total	100	100	100	100	100	100	100		100
CIPW norms (percent)									
Q	19.62	29.95	30.67	24.84	20.93	36.58	5.16		----
or	10.07	13.02	6.51	9.48	3.85	7.11	3.04		1.37
ab	34.77	36.42	36.42	32.23	33.89	38.20	29.85		12.80
an	24.65	15.5	20.04	20.56	29.92	12.11	34.62		32.09
C	----	1.17	----	----	.16	2.78	----		FF
ne	----	----	----	----	----	----	----		.93
wo	.26	----	.25	1.72	----	----	3.64		10.21
en	3.24	.92	1.84	3.99	3.99	.87	10.79		7.32
fe	2.37	.46	.58	1.29	1.10	.29	5.87		1.98
fo	----	----	----	----	----	----	----		15.30
fa	----	----	----	----	----	----	----		4.56
mt	2.47	1.45	1.74	3.34	3.77	.98	5.26		8.49
il	.34	.34	1.05	1.52	1.41	.15	.40		3.45
fa	.57	.14	.14	.26	.50	.12	.60		.19
Potassium-argon ages and analytical data									
Mineral	Bio Hbl	Hbl	Bio	Bio Hbl	Bio Hbl	Musc	Bio Hbl	Whole rock	Hbl
Average K_2O (percent)	6.76 0.965	1.10	8.30	7.80 0.856	7.60 0.855	9.84	8.09 0.293		0.270
$^{40}Ar_{rad}$ (10^{-10}moles/gram)	8.238 1.216	1.223	9.754	10.02 1.167	8.725 1.137	21.85	19.57 .0764		.6491
$^{40}Ar_{rad}/^{40}Ar_{total}$	.94 .81	.82	.95	.91 .85	.93 .81	.85	.97 .85		.79
Apparent age (m.y.)	80.7 83.4	74.1	77.9	85.0 90.1	76.1 87.9	145	157 157	170±4–174±4	156
Rock type	QD	QM	QD	GD	QD	TR	D	QM	HB
Map symbol	Kqm	Kqm	TKi	Jqd	Jqd	Jtr	Jqd	Jqm	Jm

Map loc. No	16	18	21	22	23	24	25	32	33
Field No.	62Le 1	6-26-1	64AE98	64ADt863	64ADt420A	64ADt715	64Ar612	6-27-1	66AR1289
Chemical analyses (weight percent)									
SiO_2	59.4		41.9	60.5		72.7	64.5		61.3
Al_2O_3	17.2		18.1	18.0		16.3	16.3		16.7
Fe_2O_3	2.1		7.3	2.9		.59	2.7		2.0
FeO	4.5		8.4	3.2		.46	2.6		3.9
MgO	3.1		7.6	1.7		.55	1.8		3.5
CaO	7.0		11.7	8.0		3.2	6.7		6.2
Na_2O	2.9		1.6	3.5		3.5	3.2		2.8
K_2O	1.1		.10	.33		1.0	.63		1.5
H_2O-	.04		.09	.05		.04	.05		.14
H_2O+	.93		.99	.51		.48	.58		.86
TiO_2	.94		1.5	.56		.11	.38		.69
P_2O_5	.15		.40	.47		.45	.30		.13
MnO	.14		.22	.16		.03	.16		.09
CO_2	.05		.05	.05		.05	.05		.05
Total	100		100	100		100	100		100
CIPW norms (percent)									
Q	17.50		----	20.17		42.27	26.97		19.42
or	6.54		0.59	1.95		5.95	3.73		8.89
ab	24.67		13.56	29.67		29.80	27.12		23.77
an	30.83		41.99	32.48		13.02	28.29		28.66
C	FF		FF	FF		4.75	----		----
ne	----		----	----		----	----		----
wo	1.29		5.66	1.75		----	1.27		.56
en	7.76		9.97	4.24		1.38	4.49		8.75
fe	5.26		3.86	2.86		.23	2.22		4.55
fo	----		6.30	----		----	----		----
fa	----		2.69	----		----	----		----
mt	3.06		10.60	4.21		.86	3.92		2.91
il	1.80		2.85	1.06		.21	.72		1.32
fa	.36		.95	1.2		1.07	.71		.31
Potassium-argon ages and analytical data									
Mineral	Bio Hbl	Feld	Hbl	Bio Hbl	Bio	Bio Musc	Bio Hbl	Whole rock	Bio Hbl
Average K_2O (percent)	8.78 0.952	----	0.224	5.62 0.440	7.80	7.10 9.30	9.180.414	----	8.10 0.462
$^{40}Ar_{rad}$ (10 moles/gram)	21.56 2.469	----	.6223	13.66 1.052	18.49	16.66 23.01	23.08 .9860	----	4.191 .2487
$^{40}Ar_{rad}/Ar_{total}$	.96 .77	----	.73	.90 .83	.94	.49 .71	.93 .83	----	.89 .48
Apparent age (m.y.)	160 168	155±3	179	158 155	154	152 160	163 155	5.1±1- 4.4±.5	34.7 36.1
Rock type	QD	QD	HG	QD	QD	QD	QD	B	QD
Map symbol	Jqd	Jqd	Jm	Jqd	Jqd	Jqd	Jqd	Dike	Tqd

TRONDHJEMITE

The occurrence of trondhjemite is restricted to a single small area in the central part of the batholith in the northern part of the quadrangle. Quartz and sodic plagioclase each make up 35 to 45 percent of the rock; muscovite forms 5 to 10 percent, and minor amounts of biotite may be present. Orthoclase is a minor constituent, making up less than 8 percent of the rock.

Contacts of the trondhjemite body were largely mapped from photographs. The very light coloration of the rocks is readily apparent on the photographs; where checked in the field, the contacts were accurate within the scale of the map. The contact is probably intrusive, but the evidence is not conclusive.

One potassium-argon age of 145 m.y. was obtained on muscovite from a sample (No. 9) in the center of the trondhjemite body. This age is slightly younger than the youngest concordant age determined on Jurassic intrusive rocks and may indicate that the trondhjemite represents the last phase of Jurassic plutonism in this area (Reed and Lanphere, 1969).

TUXEDNI GROUP

NAME AND DISTRIBUTION

The Tuxedni Group was originally described as the Tuxedni Sandstone by Martin and Katz (1912, p. 59). The type section is the bluffs along the south shore of Tuxedni Bay, for which it is named. This stratigraphic unit was raised to a group status and divided into six formations by Detterman (1963, p. C30-C34) as the result of the detailed investigations between Iniskin and Tuxedni Bays: in ascending stratigraphic order, the Red Glacier Formation, Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, Twist Creek Siltstone, and the Bowser Formation. These formations are described in detail in an earlier paper (Detterman and Hartsock, 1966, p. 20-40); only their general overall character is discussed in this report because the area of the earlier report partly overlaps the Iliamna quadrangle and because the small scale of the present map (pl. 1) does not permit showing the formations within the group.

Within the Iliamna quadrangle, exposures of the Tuxedni Group are almost entirely confined to the area northeast of Iniskin Bay and east of the Bruin Bay fault. Most of the good exposures are on Iniskin Peninsula, including many of the type sections for the formations. A few small areas of the Tuxedni are exposed north of Chinitna Bay, mainly outside the Iliamna quadrangle.

The Bruin Bay fault separates these slightly deformed marine sedimentary rocks on the east from more highly deformed volcanic and metamorphic rocks on the west. Only one exposure of the

Tuxedni Group is known from the area west of the fault. In the cliffs north of Amakdedori Creek, a few hundred meters of fossiliferous graywacke sandstone from the base of the Bowser Formation forms a sliver faulted into the Talkeetna Formation on the west side of Bruin Bay fault. A similar sequence of beds containing the same fossils occurs on the east side of the fault at the mouth of Portage Creek, 65 km northeast of Amakdedori Creek. Although fault displacement was primarily vertical, this suggests that a left-lateral strike-slip separation may have occurred.

THICKNESS AND STRATIGRAPHIC RELATIONS

The maximum exposed thickness of the Tuxedni Group on Iniskin Peninsula is about 1,906 m (fig. 3); Red Glacier Formation, 472.5 m; Gaikema Sandstone, 152 to 259 m; Fitz Creek Siltstone, 335 to 350 m; Cynthia Falls Sandstone, 183 to 198 m; Twist Creek Siltstone, 0 to 120 m; Bowser Formation, 457 to 549 m. All except the Red Glacier Formation are completely exposed. Subsurface information from wells drilled on Fitz Creek anticline indicates that the Red Glacier is about 1,980 m thick.

The Tuxedni Group is in fault contact with the underlying Talkeetna Formation throughout most of the area. North of the quadrangle, the Tuxedni unconformably overlies the Talkeetna. A similar relation is suggested in the seacliff north of Amakdedori Creek, the only locality within the quadrangle where the two stratigraphic units are in depositional contact. The contact with the overlying Chinitna Formation is inferred to be a disconformity. Fossils found just above and below the contact suggest a hiatus. Physical criteria indicate a conformable contact, although the two stratigraphic units are locally unconformable a few kilometers north of the quadrangle.

Contacts between the formations within the Tuxedni Group are conformable except between the Twists Creek Siltstone and Bowser Formation. The Twist Creek was progressively removed by erosion southward across the Iniskin Peninsula before deposition of the Bowser. It is 128 m thick near Chinitna Bay and is missing near Iniskin Bay.

LITHOLOGY

The main rock types of the Tuxedni Group are feldspathic, subfeldspathic, lithic, and laumontitic graywacke, conglomerate composed mainly of volcanic clasts in a graywacke matrix, siltstone and shale. Thick units of one predominant rock type are the basis for subdividing the group into the Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, and Twist Creek Siltstone. The Red Glacier Formation at the base of the group and the Bowser at the

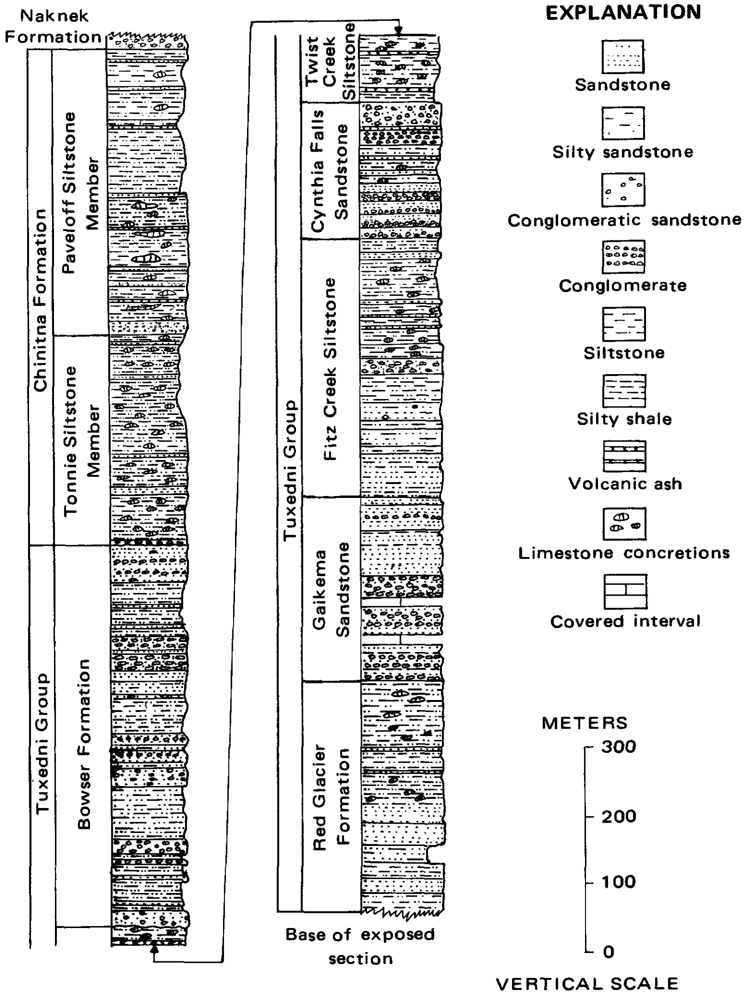


FIGURE 3.—Stratigraphic section of Tuxedni Group and Chinitna Formation, Iniskin Peninsula.

top are distinguished by the heterogeous nature of their included rocks.

The Red Glacier Formation is composed chiefly of thick units of arkosic to feldspathic arenite, arenaceous siltstone with lithic graywacke interbeds, and black fissile carbonaceous shale (fig. 3). Minor limestone is interbedded with the shale, conglomerate with the arenites. The rocks are mostly light to dark gray and tan; they weather rusty brown.

Resistant, massive, cliff-forming units of volcanic lithic graywacke and conglomerate constitute most of the Gaikema Sandstone. Graded bedding is common in these dark-gray to green rocks. Pebble- to boulder-sized conglomerate constituents are mainly volcanic rocks derived from the Talkeetna Formation. A few clasts of metasedimentary and granitic rock types are present. Siltstone with well-defined graded beds form a minor part of the formation.

Massive units of nonresistant dark siltstone characterize the Fitz Creek Siltstone throughout most of the area. The beds are locally shaly and contain a few interbeds of sandstone. Much of the siltstone and shale is concretionary weathering, and arenaceous limestone concretions are common.

The Cynthia Falls Sandstone is a massive sequence of graywacke and conglomerate. Most of the graywacke beds have a distinct mottled appearance produced by abundant greenish-gray laumontite; this zeolite mineral was probably formed diagenetically through the reaction of water rich in calcium carbonate with tuffaceous material as described by Hoare and others (1964). Conglomeratic clasts are mainly volcanic rock and quartzite. Siltstone is present locally, and many of the beds are graded.

The Twist Creek Siltsone is a soft poorly consolidated dark-gray to brown siltstone and shale that contains numerous thin beds of volcanic ash. The rocks weather dark brown and, owing to the nonresistant nature of the beds,form a distinctive unit.

The uppermost unit of the Tuxedni Group, the Bowser Formation, is a thick heterogeneous assemblage of graywacke, conglomerate, siltstone, and shale. The graywacke is commonly spotted by laumontite as in the Cynthia Falls Sandstone, and the massive units form resistant cliffs. Pebbles and granules of volcanic rock are common in the graywacke; they combine with cobbles and boulders to form massive units of conglomerate. Brown to gray siltstone units several hundred meters thick occur between the coarse clastic rocks and constitute the top of the formation.

AGE AND CORRELATION

The Tuxedni Group is entirely marine and is abundantly fossiliferous throughout. About 150 collections containing ammonites and pelecypods were obtained from beds exposed on Iniskin Peninsula. These fossils are described in numerous publications (Detterman and Hartsock, 1966; Imlay, 1961, 1962a, 1962b, 1964; Imlay and Detterman, 1973); they are discussed only in general terms here. The ammonites, in particular, provide good correlation with other areas in North America as well as in Greenland and northern Europe. In many instances, precise zonation with the standard European sections is possible. Recent evaluations of the fauna (Imlay and Detterman, 1973) indicate that the Tuxedni Group is entirely Middle Jurassic and that almost all of the Bajocian and Bathonian Stages are represented.

The key ammonites and position of each formation follows: Red Glacier, *Erycites, Tmetoceras,* and *Pseudolioceras* (lower zone), *Sonninia, Emileia,* and *Parabigotites* (middle zone), *Stemmatoceras, Stephanoceras, Normannites,* and *Witchellia* (upper zone) age—basal to early middle Bajocian. Gaikema Sandstone, *Witchellia,* age—early middle Bajocian. Fitz Creek Siltstone, *Stephanoceras, Normannites,* and *Chondroceras,* age—middle Bajocian. Cynthia Falls Sandstone, *Chondroceras,* age—late middle Bajocian. Twist Creek Siltstone, *Leptosphinctes Oppelia,* and *Megasphaeroceras,* age—early late Bajocian. Bowser Formation, *Cranocephalites* and *Arctocephalites* (lower zone), *Kheraiceras, Cobbanites,* and *Kepplerites* (upper zone) age—middle to late Bathonian.

The only collection of Tuxedni Group fossils made south of Iniskin Bay came from the sea cliffs north of Amakdedori Creek (pl. 1). These fossils include *Inoceramus ambiguus* and *Holocophylloceras* and, while not definitive as to formation, are suggestive of the Bowser. And rocks containing these fossils are similar in lithology to the Bowser.

CHINITNA FORMATION

NAME AND DISTRIBUTION

A massive arenaceous siltstone mapped as the Chinitna Formation was originally designated the Chinitna Shale by Martin and Katz (1912, p. 65–68). The type section is along the north shore of Chinitna Bay. Moffit (1927, p. 23–26) continued the use of that stratigraphic term, but Kirshchner and Minard (1949) redefined the unit as the Chinitna Siltstone. Imlay (1953 table 5) used the term formation for this same sequence of beds. A more recent revision was made by Detterman and Hartsock (1966, p. 40–47), who divided the Chinitna Formation into the Tonnie and Paveloff Siltstone Members, including a sandstone lying between two siltstone units with the upper, Paveloff, sequence of beds.

In the Iliamna quadrangle, the Chinitna Formation is exposed only north of Iniskin Bay in the northeast corner of the quadrangle. The many good exposures there were fully described in Detterman and Hartsock (1966, p. 40–47); only general details and characteristics of the formation will be given here. These rocks are all mapped as Chinitna Formation on the geologic map (pl. 1); the formation is not divided into members.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the Chinitna Formation ranges between 625 and 732 m, the thickest sections being near Iniskin Bay. A northward-thinning continues beyond the quadrangle boundary; only about 564 m is exposed at Tuxedni Bay. The apparent thinning is only in part depositional and may be mainly due to post-Chinitna erosion. The Chisik Conglomerate Member at the base of the overlying Naknek Formation locally lies in deep channels cut into the top of the Paveloff Siltstone Member. The unconformity between the Chinitna and Naknek Formations is apparent only where the conglomerate is present. Exposures near Chinitna Bay contain only sandstone overlying the Paveloff; the contact is concordant.

The contact with the underlying Bowser Formation is concordant but probably represents a disconformity. This is borne out by the fact that the basal beds of the Chinitna Formation near Iniskin Bay contain a fauna that seems to be a little older than that present in the more northerly exposures (Imlay, 1953, 1975). North of the quadrangle boundary, the contact is unconformable, and channel conglomerate locally cuts into the Tuxedni.

LITHOLOGY

The Chinitna Formation consists primarily of massive arenaceous siltstone that contains a few sandstone interbeds and numerous limestone concretions. Beds in the Tonnie Member are red brown to brownish gray and contain many small yellowish-brown-weathering concretions. Rocks of the Paveloff Siltstone Member are almost uniformly dark gray, and limestone occurs as large ellipsoidal concretions and lenticular beds. Sandy intervals in both members are mainly dark fine-grained graywacke. Small pebbles of volcanic rock occur locally in some of the graywacke.

AGE AND CORRELATION

The Chinitna Formation is entirely marine and fossiliferous throughout. The numerous collections are fully described in papers by Imlay (1953, 1975) and Detterman and Hartsock (1966) and will be discussed only in general terms here.

Diagnostic fossils of the Tonnie include *Cadoceras, C. stenocadoceras, C. pseudocadoceras, Kepplerites, Kheraiceras, Lilloettia,* and *Gowerioceras*(?). In a recent evaluation of the Callovian fauna present in the Chinitna, Imlay (1975) established two new genera of ammonites, *Iniskinites* and *Chinitnites.* Correlation with the European Standard Zones of *Sigaloceras calloviense* and lower *Kosmoceras jason* are indicated by the ammonites. The Paveloff is not as well defined by ammonites but does contain *Cadoceras, C. stenocadoceras, C. pseudocadoceras,* and *Cosmosceras,* which suggests a correlation with the upper part of *Kosmoceras jason, Erymnoceras coronatum,* and possibly part of *Peltoceras athleta* zones.

On the basis of fossil findings, the Chinitna Formation is assigned to the lower and middle Callovian Stage, which is assigned by Imlay (1975) to the Middle Jurassic. Beds of the late Callovian Stage have not been identified. The formation correlates very closely with the Chinitna as mapped in the Talkeetna Mountains by Grantz (1960a, b) and with the Shelikof Formation on the Alaska Peninsula (Burk, 1965, p. 28). Correlation with Callovian rocks exposed in British Columbia and in Oregon and California is made primarily on the included fauna, which suggests a close tie with both the Pacific and Boreal realm during the Callovian (Imlay and Detterman, 1973).

NAKNEK FORMATION

NAME AND DISTRIBUTION

The Naknek Formation was first referred to as the Naknek Series by Spurr (1900), who gave that name to a great thickness of arkose and conglomerate exposed along the upper part of Naknek Lake and the Savonoski River on the Alaska Peninsula, 48 km south of Nonvianuk Lake. Martin (1905, p. 52–53) first used the name for similar rocks exposed in Cook Inlet area. Martin and Katz (1912) defined the Chisik Conglomerate from exposures at Chisik Island, 25 km northeast of the quadrangle, and Martin (1926) reduced its rank and assigned it to a member of the Naknek Formation. Moffit (1927), Kirschner and Minard (1949), and Detterman and Hartsock (1966) further divided the Naknek Formation in the Iniskin Peninsula area. A fourfold division of the Naknek Formation is currently used (Detterman and Hartsock, 1966): in ascending order, the Chisik Conglomerate, lower sandstone, Snug Harbor Siltstone, and Pomeroy Arkose Members.

Field investigations in the southern part of the Iliamna quadrangle, particulary along Kamishak Bay, have confirmed the suggestion made by Detterman and Hartsock (1966, p. 48) that beds in the Iniskin Peninsula area may represent only part of the formation. Stratigraphic and faunal evidence indicate that much of the section exposed in the Kamishak Bay area is indeed younger than the rocks on Iniskin Peninsula. These younger beds are herein informally referred to as the upper sandstone member of the Naknek Formation. The formation is undivided on the geologic map (pl 1).

Exposures of the Naknek Formation are confined to the area east of the Bruin Bay fault. For most of the distance across the quadrangle, the fault juxtaposes the Naknek on the southeast against the older, more highly deformed rocks northwest of the fault. Complete sections of the formation are present only on Iniskin Peninsula and at the head of Kamishak Bay (fig. 4). Elsewhere only small parts of the section remain east of the fault.

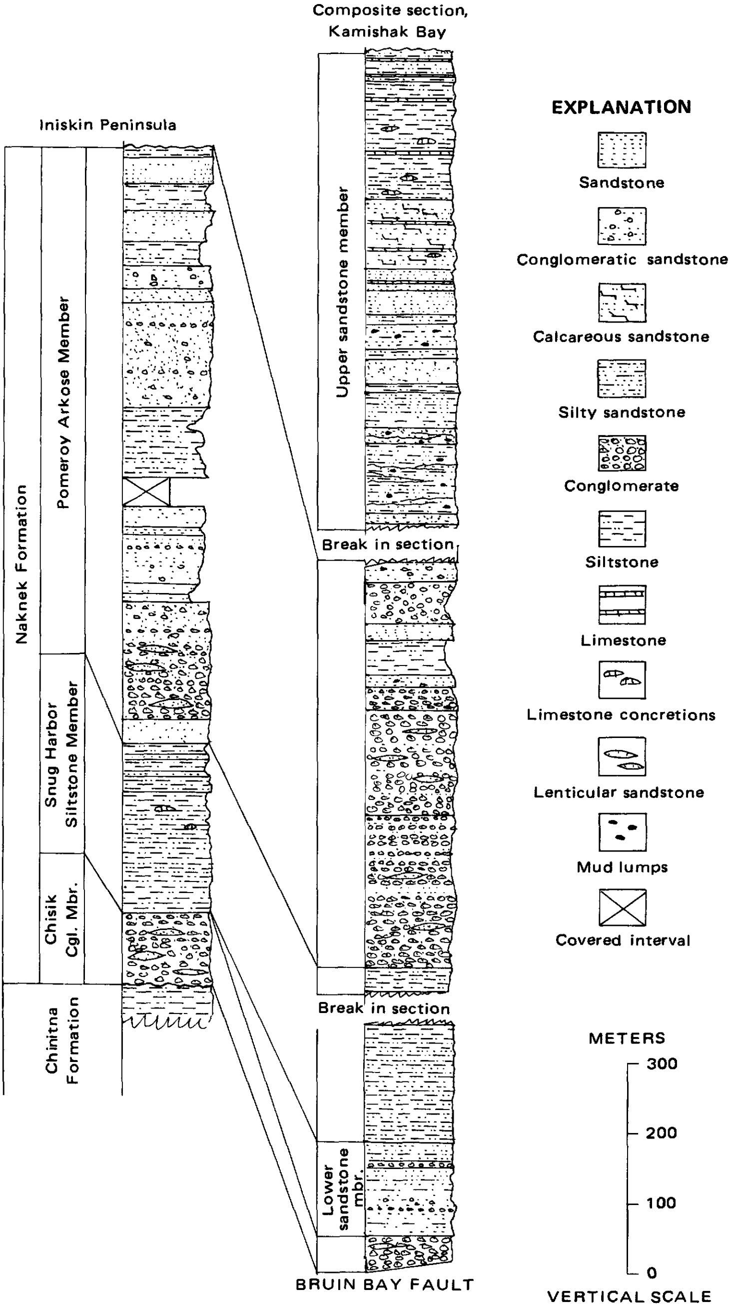


FIGURE 4.—Stratigraphic sections of Naknek Formation, Iniskin Peninsula and Kamishak Bay.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Naknek Formation is about 1,082 m in thickness on the Iniskin Peninsula. Beds in the Kamishak Bay area were not measured in detail, but a composite section pieced together from several outcrops suggests a minimum thickness of about 1,585 m, possibly as much as 1,828 m. Nearly all of the additional section in the Kamishak Bay area is at the top of the formation and represents beds that have been removed by erosion in the areas farther north.

About one hundred meters of Naknek Formation is exposed on Augustine Island. Rocks of the Naknek crop out along the south shore and on the south flank of the volcano at about the 300-m level. On the basis of lithology and faunal evidence, these beds are considered the highest exposed rocks of the formation in the quadrangle. Part of this same sequence of beds is exposed on the easternmost of the two islands near the mouth of the Douglas River.

The contact of the Naknek with the underlying Chinitna Formation is exposed only on Iniskin Peninsula. At most places where exposed there, the stratigraphic units are conformable. Exposures at Iniskin Bay, however, show slight channeling of the uppermost Chinitna beds by the basal Chisik Conglomerate Member such that the contact is considered to be locally unconformable. The contact with the overlying Kaguyak Formation is poorly exposed and confined primarily to rubble on two ridgetops at the south edge of the map. The beds appear to be conformable; however, a Lower Cretaceous sequence present a few kilometers farther south is missing here, and the contact must be considered a disconformity. A minor diastem within the upper part of the formation is indicated by slightly disconcordant beds on the easternmost island off the mouth of the Douglas River. The diastem was not noted elsewhere.

LITHOLOGY

The Naknek Formation consists mainly of arkosic arenite, arkosic and lithic wacke, conglomerate, and sandy siltstone. The base of the formation is everywhere a massive cobble-boulder conglomerate (Chisik Conglomerate Member). Well-rounded clasts of granitic and volcanic rock make up the bulk of the material in the Chisik. Locally, metasedimentary and intraformational sandstone clasts, firmly cemented by an arkosic sandstone matrix, constitute 10 to 15 percent. Local channeling of underlying beds and the presence of a few clasts to 2.5 m would indicate deposition near the source area. In the northern part of Iniskin Peninsula and in some parts of the Kamishak Bay area, the Chisik grades laterally into arkosic sandstone. These rapid facies changes would further indicate deposition near the source area.

The sandy beds are included in the lower sandstone unit, locally as much as 120 m thick. The Chisik attains a thickness of about 90 to 120 m in the Iliamna quadrangle.

A greenish-gray siltstone unit, the Snug Harbor Siltstone Member, overlies the Chisik in all exposures. This siltstone ranges between 180 and 220 m in thickness and generally contains thin interbeds of lithic to arkosic wacke. The amount of argillaceous material in the sands increases upward, and some beds are cemented with calcite. Molluscan fossils are found throughout the siltstone, and plant fragments commonly occur in the graywacke. The fossils are mainly thick-shelled pelecypods that lived in a nearshore high-energy environment and a few ammonites.

A thick sequence of arkose and conglomerate, the Pomeroy Arkose Member, overlies the siltstone unit. At Chinitna Bay, the section contains only a few stringers of conglomerate, but at Iniskin Bay the basal 150 m is a massive cobble conglomerate in an arkosic sandstone matrix. The conglomerate content increases to the south; near Chinik Lake almost the entire unit of 520 m is composed of pebble-cobble conglomerate. Crossbedded arkosic sandstone interbeds a few meters to a few tens of meters thick are common throughout but increase in number upward in the section. In the Kamishak Bay area, this conglomeratic unit is deceptively similar to the Chisik Conglomerate Member, but clast lithologies help distinguish the two conglomeratic sequences. Intrusive and volcanic rock clasts, in about equal amounts, form about 70 to 80 percent of the Chisik; the rest is made up of metasedimentary and intraformational clasts. In the Kamishak Bay area, clasts in the Pomeroy are mainly volcanic rock. Granitic rocks constitute no more than 10 to 15 percent.

The informally designated upper sandstone member of the Naknek Formation is almost completely exposed along the south shore of Kamishak Bay. The gently dipping strata are exposed in the seacliffs along the shore and extend out into the bay as a wave-cut bedrock platform exposed at low tide. A composite section from the seacliffs suggests a thickness of about 600 m. The contact between this section and the underlying Pomeroy was not seen but is probably gradational. The lower part of the section is primarily arkosic sandstone that grades from arkosic arenite to arkosic wacke. Upward in the section, the argillaceous content increases, and more of the rock is wacke. The arkosic arenites are very similar to the underlying Pomeroy. Crossbedding and channeling are common near the base. The sandstone forms massive units 3 to 15 m thick; most is light gray to tan. Brown to greenish-gray sandy siltstone interbeds begin about 180 m above the base and become more numerous upward in the section. In contrast to the massive units at the base, sandstone associated with the siltstone is fine grained and thin bedded. Limestone layers and concretions are present in the predominantly siltstone sequence near the top of the section. Thin fine-grained brown flaggy sandstone forms the highest exposed beds of the formation on Augustine Island and on the island near the mouth of the Douglas River.

AGE AND CORRELATION

The Naknek Formation is determined from pelecypods and ammonites to be of Oxfordian to Tithonian age of the Late Jurassic. The *Cardioceras* sp. ammonite fauna characteristic of the early Oxfordian stage is obtained only from beds exposed in the Iniskin Peninsula and farther north. Fossils from the Iniskin Peninsula are listed and described by Detterman and Hartsock (1966). Naknek collections from other parts of the quadrangle are listed in table 2; the collection site is shown on plate 1.

Most of the collections are from the upper part of the formation and contain a succession of the Late Jurassic pelecypod *Buchia*. One collection from Augustine Island contains the late Tithonian form *Buchia* cf. *B. piochii,* the first occurrence of this fossil from an outcrop section in the Cook Inlet area, although it is fairly common in beds exposed near the tip of the Alaska Peninsula. Other key elements of this pelecypod fauna include *Buchia concentrica* (Sowerby), which by itself indicates a correlation with the upper Oxfordian Stage and in association with *B. rugosa* (Fishcer) and *B. mosquensis* (Von Buch) indicates a correlation with the middle Kimmeridgian Stage. *B. rugosa* by itself is of middle Kimmeridgian to early Tithonian age. The few ammonites obtained with these collections are of little use for age determinations.

JURASSIC OR CRETACEOUS SYSTEMS

SEDIMENTARY ROCKS, UNDIVIDED

Four small areas of clastic sedimentary rocks of Jurassic or Cretaceous age in the northern and northwestern parts of the quadrangle are mapped as sedimentary rocks, undivided. The largest of these areas is a rounded hill 686 m high in the extreme northwest corner of the quadrangle. At this locality, the hill is capped by Tertiary volcanic rock. Two low hills of sedimentary rock, about 3 km apart, lie just west of Kaskanak Creek in T. 6 S., R. 39 W. The larger of these hills is capped by Tertiary volcanic rock. The lowland between the hills is mantled by surficial deposits that obscure bedrock, but rocks of the two localities are probably all part of the same unit. The fourth exposure is on a low roches moutonnée on the north shore of Lower Tazimina Lake at the north edge of the quadrangle.

TABLE 2.—*Geographic and stratigraphic distribution of fossils in the Naknek Formation*

[Fossils identified by R. W. Imlay and D. L. Jones]

Member	Upper sandstone member											Pomeroy Arkose Member								Snug Harbor Siltstone Member				
Geographic location	Augustine Island		Kamishak Bay area									Augustine Island								Fortification Bluff area				
Map Loc. No.	14		19	20	19	18			17	22	21	13								6	8		5	
Stratigraphic position above base (meters)	Top		1432–1524	1402	1219–1370	1158			Top	1097	1127–1142	731–823								213–366				
USGS Mesozoic loc	6009	6032	5348	5341	5347	5342	5343	5344	30765	5345	5346	6008	6037	6038	6039	6040	6041	6042	6044	30764	5339	5340	61ADt44	61AHe55
Meleagrinella sp.	----	----	----	----	----	----	----	×	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Grammatodon sp.	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Buchia cf. *B. piochii*	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
rugosa (Fisher)	×	----	×	×	----	----	----	×	×	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----
cf. *B. mosquensis* (Von Buch)	----	----	×	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
concentrica (Sewerby)	×	----	----	----	----	----	----	----	----	×	----	×	×	----	----	----	×	----	×	----	----	----	----	×
sp. undet	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Camptonectes sp.	×	----	----	----	----	----	----	----	----	----	----	----	×	----	×	×	×	×	×	----	----	----	----	----
Pleuromya sp.	----	×	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	×	----	----
Mytilus sp.	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Corbicula(?) sp.	×	----	----	----	----	----	----	----	----	----	----	×	----	×	×	----	×	----	×	----	----	----	----	----
Tancredia(?) sp.	----	----	----	----	----	×	×	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Quenstedtia sp.	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	×	----
Phylloceras sp.	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	×	----	----	----	----
Phylloceras (Partschiceras) sp.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Macrophylloceras sp.	----	----	×	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Pachyteuthis sp.	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Cylindroteuthis sp.	----	----	----	----	----	----	----	----	----	----	×	----	----	----	----	----	----	----	----	----	----	----	----	----
Belemnite guard	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	×	----	----	----

THICKNESS AND STRATIGRAPHIC RELATIONS

The sedimentary rocks are poorly exposed, and no more than a few hundred meters is present at any one locality. The absence of any reliable marker beds makes it difficult to obtain an accurate thickness. Assuming the strike and dip to remain constant across the belt of rubble exposures and that there are no structural complications, a rough estimate of 1,830 to 3,048 m can be made at the hill in the northwest corner of the quadrangle.

At two of the localities, Tertiary lava flows unconformably overlie the sedimentary rock with angular discordance of 60° to 80°. The stratigraphic relation of these clastic rocks to underlying units is unknown.

LITHOLOGY

Dark-gray to green lithic metagraywacke, polymictic conglomerate, and argillite are the main rock types found in all exposures of the sedimentary rock unit. All the rocks have undergone low-grade metamorphism, primarily of the prehnite-pumpellyite to greenschist facies, and locally albite and epidote have formed. At all places observed, the original sedimentary character of the rocks is preserved. Bedding features are still readily apparent: large- and small-scale crossbeds, cross lamination, and cut-and-fill channels in the conglomerate. Graded beds are common in the graywacke. Structural data within each outcrop indicate an upward transition from coarse- to fine-grained clastic rocks.

The Lower Tazimina Lake locality contains a massive lower polymictic conglomerate containing well-rounded waterworn clasts of quartz, quartzite, red chert, metavolcanics, metasedimentary rock, and, rarely, granitic rocks. Clasts are mainly in the 25- to 75-mm range with a general upward decrease in size; a few 250- to 450-mm fragments were seen near the base at several places. The graywacke matrix of the conglomerate increases in abundance upward and becomes the dominant rock type. In thin section the graywacke is seen to contain 25 to 35 percent rock fragments of the same composition as the conglomeratic clasts of the lower beds. This rock is extremely well indurated. Dark-gray to black finely laminated and cross-laminated argillite and siltstone overlie the lithic graywacke beds. The siltstone occurs in beds 5 to 75 mm thick and commonly shows well-preserved graded-bedding features. Flame structures are preserved locally, suggesting turbidite deposition for this part of the sequence.

AGE AND CORRELATION

The age and correlation of the sedimentary beds is uncertain. The minimum age is indicated by the presence of Tertiary volcanic rock unconformably overlying several of the outcrops, but the exact age of the Tertiary flows is unknown. A maximum age of Middle Jurassic is suggested by the granitic clasts in the conglomerate, as the oldest granitic rocks in this part of Alaska are of Early Jurassic age (Reed and Lanphere, 1969). A nearly identical suite of rocks in the Nushagak Bay quadrangle, 241 km to the southwest, has been dated as Middle Jurassic on the basis of a few fossils found near Kulukak Bay (Hoare and others, 1975). This is consistent with what we consider to be the age of the rocks described here, but a Cretaceous age cannot be ruled out.

CRETACEOUS SYSTEM

KAGUYAK FORMATION

NAME AND DISTRIBUTION

The name Kaguyak Formation was first used by Keller and Reiser (1959) for a sequence of marine clastic sedimentary rocks of Late Cretaceous age that is typically exposed at Kaguyak Bay in the Mount Katmai area about 40 km south of the Iliamna quadrangle. The type section at Kaguyak Bay is about 1,386 m thick and was informally divided into three units by Keller and Reiser: a lower fossiliferous siltstone, a middle massively bedded concretionary sandstone and siltstone, and an upper thin-bedded sandstone and siltstone.

Three small areas of this formation are mapped in the Iliamna quadrangle, two on ridgetops at the south edge of the quadrangle about 6.5 km south of Kamishak Bay and one on Augustine Island. The locality on Augustine Island is confined to two small adjacent gullies on the south flank of the volcano where the streams have cut through the overlying volcanic rock.

THICKNESS AND STRATIGRAPHIC RELATIONS

Only incomplete sections of Kaguyak are exposed within the Iliamna quadrangle. About 60 m, most of which is rubble, is exposed on the ridgetops south of Kamishak Bay. Rocks exposed on Augustine Island consist of about 7 to 10 m of section in the bottom of gullies.

The strata in the Kamishak Hills disconformably overlie the Naknek Formation of Late Jurassic age. These same beds were seen to overlie a thin Lower Cretaceous sequence about 16 km south of the quadrangle (Jones and Detterman, 1966). The contact with the Lower Cretaceous strata is a slight angular unconformity. The Kaguyak is the youngest sedimentary rock exposed in the Kamishak Hills but is locally overlain by Tertiary and Quaternary volcanic rocks (Keller and Reiser, 1959). At the Augustine Island locality, the formation is overlain by Holocene volcanic rock. The lower contact was not seen, but since the Naknek Formation is exposed nearby, the Kaguyak probably disconformably overlies it here, as in the Kamishak Hills.

LITHOLOGY

Rocks the Kaguyak exposed consist of silty, thin-bedded to massive, fine- to medium-grained, green to gray arkosic wacke sandstone with interbedded siltstone. The sandstone contains dark-red-brown calcareous sandstone concretions. Both the sandstone and concretions contain abundant fossils. The exact position of these beds within the formation is unknown, but they probably correlate with the lower part as defined by Keller and Reiser (1959), who reported abundant fossils, primarily in siltstone in that part of the sequence. Sandstone in considerable amounts was noted in the fossil-bearing beds in the Kamishak Hills by Jones and Detterman (1966). As rock exposed in the Iliamna quadrangle part of the Kamishak Hills is mainly rubble, it is impossible to obtain a reliable estimate of the amount of sandstone and siltstone.

AGE AND CORRELATION

The Kaguyak Formation is assigned to the Campanian and Maestrichtian Stages of the Late Cretaceous. This age is based on both ammonites and pelecypods, mainly *Diplomoceras notabile* Whiteves, *Pachydiscus (Neodesmoceras)* sp., and *Inoceramus* ex. gr. *I. subundatus* Meek. The collections from this quadrangle and the adjoining Katmai area are discussed in detail by Jones (1963), Jones and Detterman (1966), and Detterman and Jones (1974). The fossils are considered good indicators of age and are assigned to the *Pachydiscus kamishakensis* zone of latest Campanian to early Maestrichtian age. This correlates with the upper third of the Matanuska Formation and is slightly younger than the Chignik Formation exposed at Chignik and Herendeen Bays on the Alaska Peninsula. The association of ammonites with the thick-shelled pelecypod *Inoceramus* and gastropods would indicate deposition in the shallow neritic zone of a continental shelf.

QUARTZ MONZONITE

Quartz monzonite intruded as part of the second major pulse, tentatively assigned a Late Cretaceous age, lies along the west side of the batholith at the upper end of Iliamna Lake. It forms part of Porcupine and Flat Islands and numerous other small islands in the vicinity of Knutson Bay and Pedro Bay. The main mass of the pluton lies in the mountains north of Knutson Bay. This is the southernmost pluton along the west side of the Alaska-Aleutian Range batholith for which age determinations have been made (Reed and Lanphere, 1969, 1973b).

The quartz monzonite is massive coarse-grained light-gray prophyritic rock in which orthoclase is commonly found as phenocrysts to 25 mm across, distinctive of this rock unit. Sample 5 (table 1), probably typical of the quartz monzonite of Knutson Bay, contains about 24 percent quartz, 25 percent orthoclase, 46 percent plagioclase, about 4 percent hornblende, and minor accessory minerals. The quartz monzonite locally grades into granodiorite through a reduction in orthoclase phenocrysts and an increase in plagioclase with minor biotite. Biotite and hornblende generally constitute less than 8 percent of the rock.

Contacts between late Cretaceous and early Tertiary plutons and Jurassic intrusive rocks in the Alaska-Aleutian Range batholith are generally sharp and well defined. The contact between the body of quartz monzonite at Knutson Bay and the surrounding intrusive rocks is poorly understood because field data are insufficient for definition. North of Knutson Bay altered rhyolite porphyry (middle Tertiary age, B. L. Reed unpub. data, 1977), granodiorite, quartz diorite, and coarse-grained quartz monzonite is similar to that at Knutson Bay. The contact relations of these rocks are unknown.

Coexisting hornblende and biotite from a quartz diorite north of Knutson Bay (included with the quartz monzonite on pl. 1) yielded ages of 83.4 and 80.7 m.y., respectively, and hornblende from quartz monzonite at Knutson Bay an age of 74.1 m.y. (Reed and Lanphere, 1969). Because the affinities of the several intrusive rock types north of Knutson Bay are not clear, these rocks are included with the quartz monzonite and tentatively assigned a Cretaceous age.

CRETACEOUS OR TERTIARY SYSTEMS

GRANODIORITE AND QUARTZ MONZONITE

Several large granodiorite and quartz monzonite bodies are mapped along the west side of the batholith in the Iliamna quadrangle. South of Iliamna Lake, most of these bodies intrude the Jurassic part of the batholith as well as the older Talkeetna Formation lying along the west margin. Contacts with the Talkeetna Formation are sharp, and dikes cut the volcanic rock. Xenoliths of the volcanic rock are locally present along the margin of the intrusive body.

The composition of intrusive rocks of this age is varied. Granodiorite and quartz monzonite are the most common; quartz diorite is present locally. These rocks are medium to coarse grained, generally light gray with pink orthoclase common in quartz monzonite. Both hornblende and biotite are generally present, constituting less than 10 percent of the rock except for the quartz diorite. The rocks are not foliated and in general are unaltered.

Potassium-argon ages are not available for the rocks here assigned a Cretaceous or Tertiary age. Several plutons of similar composition and geologic setting north of the Iliamna quadrangle yield Late Cretaceous or early Tertiary and middle Tertiary ages (Reed and Lanphere, 1969, 1973a, and unpub. data, 1977). Some of the early Tertiary volcanic rocks in the western part of the quadrangle are probably related to this plutonism.

TERTIARY SYSTEM

Rocks of the Tertiary System are confined primarily to the area west of the mountains, where, except at a few places, they are the only rocks exposed. This part of the quadrangle is characterized by low rolling hills and mesas that rise above the thick mantle of glacial debris. Most of these hills are capped by volcanic rocks, and the mesas are almost invariably nearly flat lying basalt. Tertiary volcanic rocks probably underlie most of the lowlands mantled by the surficial deposits. Within the mountains and along the shore of Cook Inlet, rocks of Tertiary age are confined to a few small, widely scattered areas. North and south of the quadrangle (Detterman and Hartsock, 1966; Keller and Reiser, 1959), thick Tertiary sedimentary sequences are exposed adjacent to Cook Inlet.

Volcanic rocks constitute about 75 percent of the exposed Tertiary section. Nonmarine sedimentary and intrusive rocks, in about equal proportions, form the rest. Most of the volcanic rocks are divided into three units, basalt and andesite, tuff, and volcanic rubble and breccia. These rocks probably represent several Tertiary volcanic episodes that cannot be precisely correlated, partly because the exposures are widely scattered. Rocks believed, on stratigraphic evidence, to represent a young Tertiary volcanic episode are included in two named formations, the Gibralter Lake Tuff and Intricate Basalt. The intrusive rocks are unnamed and consist of small stocks of quartz diorite, quartz monzonite, granodiorite, and many volcanic necks, plugs, veins, and dikes associated with the eruptive centers. One small quartz diorite pluton south of McNeil Lake is potassium-argon age dated at 34 to 36 m.y. (Reed and Lanphere, 1969).

Most of the sedimentary rocks are grouped into one formation, the Copper Lake formation, which is divisible into three unnamed members. A few widely scattered outcrops of tuffaceous strata much younger than the Copper Lake Formation are mapped separately.

COPPER LAKE FORMATION

The Copper Lake Formation is here named for a series of sedimentary beds about 1,555 m thick that are best exposed in the mountains south of Upper and Lower Copper Lake and northwest of Kakhonak Lake. The type section is a composite of the type sections of its members. The formation is essentially confined to a northeast-trending belt about 29 km long and as much as 10 km wide between Upper Copper Lake and Sid Larson Bay. A few small outliers of the formation occur 9.6 km south of Sid Larson Bay, probably small remnants of a once much more extensive Tertiary sedimentary section similar to, or correlative with, rocks exposed north and south of the quadrangle. Other small exposures of the upper part of the formation are near Spectacle Lake in the southern part of the quadrangle, probably a continuation of the more extensive deposits mapped to the south in the Katmai area by Keller and Reiser (1959, p. 278–282).

LOWER CONGLOMERATE MEMBER

The lower conglomerate member is best exposed in the ridges south of Upper Copper Lake. The type section is here designated as the east end of a ridge 2.5 km S. 45° E. of the outlet of Upper Copper Lake; this section is about 91 m thick (fig. 5). Several small exposures are near the outlet of Kakhonak Lake and along the Kakhonak River just downstream from the lake. The maximum thickness exposed at any of these localities is about 30 to 45 m. The largest area underlain by the member is between the north shore of Kakhonak Lake and Lower Copper Lake. As this area is almost completely covered by brush and spruce, the rock crops out as small isolated knobs that expose only small parts of section at any one locality.

The polymictic conglomerate is extremely well indurated and fractures through the clasts, mainly of small cobble size with average diameter of 50 to 70 mm but ranging from about 25 to 380 mm. Clasts are subround to angular and about 25 percent altered volcanic rock similar to the Talkeetna Formation and dissimilar to the fresh-appearing Tertiary volcanic rocks. The remaining clasts are quartz diorite, gneiss, schist, greenstone, white vein quartz, and limestone. The matrix is a medium- to dark-green fine-grained feldspathic graywacke with silica cement and considerable secondary quartz overgrowths. The quartz grains show solution pits and many interlocking grains.

The conglomerate forms massive units 3 to 15 m thick, with a gradual decrease in clast size upward in the section. Interbedded between the massive conglomerate units are well-bedded medium-green fine- to medium-grained arkosic graywacke and siltstone. The

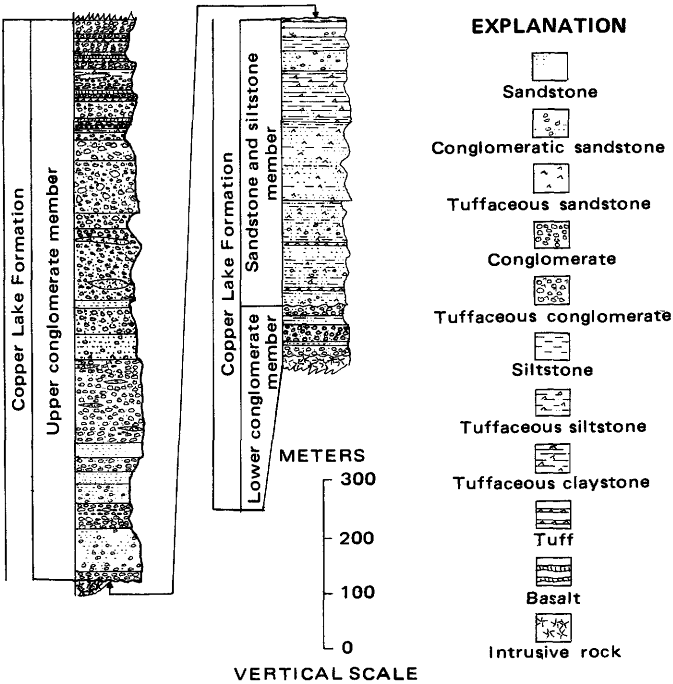


FIGURE 5.—Type section of Copper Lake Formation, Upper and Lower Copper Lake and Kakhonak Lake area.

graywacke and siltstone contain a few small pebbles and rock fragments of the same general composition as the clasts in the conglomerate. In thin section, carbonaceous fragments make up about 2 percent of the rock. Some of the carbonaceous fragments are probably pollen grains, but they are too poorly preserved to identify.

The conglomerate nonconformably overlies quartz diorite plutonic rocks of early Middle Jurassic age. The upper contact was not observed, but the attitude of beds near the contact suggests a disconformity; it appears to be an onlapping contact, as the overlying sandstone and siltstone locally overlie the quartz diorite and schist as well as the conglomerate.

SANDSTONE AND SILTSTONE MEMBER

The sandstone and siltstone member of the Copper Lake Formation is well exposed where it caps the ridge between Upper Copper and Kakhonak Lakes. The type section is here designated as the east slope of peak 2432, 1.6 km south of the west end of Boot Lake, where about 503 m is exposed (fig. 5). This probably is not a complete section, for the member overlies the quartz diorite pluton rather than the lower conglomerate member. The member is exposed in a few small areas along the north side of Kakhonak Lake, where it locally overlies the lower conglomerate; since most of the exposures are faulted, contact relations are obscure.

The sandy facies of the type section is chiefly a lithic wacke with abundant quartz, schist, volcanic, and granitic rock fragments and an occasional rounded small pebble of material similar to the rock fragments. The rock is fine to medium grained and thin bedded in the lower part and becomes medium to coarse grained near the top. The color is a fairly consistent medium gray to greenish gray. Tuffaceous and carbonaceous material is locally abundant, and there are a few thin tuff beds.

Siltstone and claystone are interbedded with the sandy facies. The siltstone is similar in color and composition to the lithic wacke. The claystone is mainly micaceous clay containing a small amount of montmorillonite and is medium to dark gray. It is thin bedded, brittle, and has a conchoidal fracture. One unit about 46 m thick 42 m below the top of the type section contains a thin unit of claystone breccia near the top. The angular fragments are about 12 mm in maximum dimension and are recemented with clay and silt; this rock is probably a desiccation breccia that would suggest that the source rocks were deposited in shallow water. Carbonaceous material is common in all the fine-grained clastic rocks and may include a few poorly preserved pollen grains.

UPPER CONGLOMERATE MEMBER

The upper conglomerate member is the thickest and most widely exposed part of the formation. A good section about 975 m thick, here designated the type section (fig. 5), is exposed in a ravine cutting the east face of the ridge between Fog and Kakhonak Lakes, 4 km S. 65° E. of Fog Lake. Good exposures are found along the lower Kakhonak River and in Sid Larson Bay. Volcanic conglomerate correlated with the member crops out near Spectacle Lake and about 6.4 km south of Sid Larson Bay. A small exposure on the south shore of Iliamna Lake east of Big Mountain is included.

The rock is mainly a volcanic pebble-cobble to cobble-pebble conglomerate with average clast size of 25 to 76 mm; on the south shore of Iliamna Lake, a few clasts are as large as 304 mm. The upper part of the member may be an agglomerate rather than conglomerate. The overall composition of the clasts changes upward from about 50 percent to 100 percent volcanic rock, mostly fresh appearing and of probably Tertiary age. Quartzite, schist, greenstone, rose quartz, limestone, and granitic clasts are present in the lower part of the member. Most are well rounded to slightly flattened and locally show imbrication suggesting an eastern source area.

The matrix of the lower conglomerate member varies from arkosic arenite in the lower part to a lithic, feldspathic, tuffaceous wacke in the upper part; rocks of the same composition form lenticular units and beds throughout the section. One sandy unit is about 30 m thick. The sandstone is medium to coarse grained and medium gray to greenish gray. In the type section, hematite forms 3 to 5 percent, imparting a red stain. Tuffaceous material, usually as detrital grains, is present in nearly all sections and becomes increasingly abundant upward. Carbonaceous material is present in the finer grained rocks, and a few leaves were found in one lenticular sandy unit in the lower part of the section.

The upper conglomerate member is unconformably overlain by volcanic breccia and flows that probably originated during the same volcanic episode that produced the clasts and matrix in the upper part of the member. The lower contact is unconformable onto the quartz diorite or the Kakhonak Complex. Elsewhere it is disconformable onto the sandstone and siltstone member.

The Copper Lake Formation is a subaerial deposit that contains no known invertebrate or vertebrate fossils. Carbonaceous debris and a few poorly preserved pollen grains are present in the lower two members, and a few leaves were found in a sandy interbed near the base of the upper conglomerate member. The leaves were identified by J. A. Wolfe, of the U.S. Geological Survey, who provisionally referred them to *Acer disputabilis* Hollick (written commun., 1970) of Eocene (probably early Eocene) age. This genus is of dicotyledon flora reported from Paleocene strata on the Alaska Peninsula by Burk (1965, p. 233–236) and from the Paleocene Chickaloon Formation in the Matanuska Valley by Wolfe (1966b, p. B2–B3).

The lithology and degree of induration of the upper conglomerate member suggests that it is closely correlative with the early Eocene West Foreland Formation of the Cook Inlet area (Magoon and others, 1976). The highly indurated sandstone, siltstone, claystone, and conglomerate underlying the upper conglomerate member are more typical of the Arkose Ridge Formation of Cretaceous(?) age (Csejtey and others, 1977) and may be correlative with it. The Arkose Ridge Formation is known only from the Matanuska Valley north of the Castle Mountain fault.

SEDIMENTARY ROCKS, UNDIVIDED

Two small mapped areas of Tertiary sedimentary rock in the quadrangle do not fit lithologically or stratigraphically into any of the previously described Tertiary units. The best exposed is on the south shore of Iliamna Lake about 12 km east of Tommy Point, where 32 m of section was measured. A second small area is on an island in Intricate Bay, about 9.6 km southwest of the first locality. In these localities, the rocks are similar in lithology and thickness, and all are distinctly different in their degree of induration and coloration from any of the other Tertiary sedimentary rocks described.

The rocks are mainly fine- to medium-grained tuffaceous, feldspathic to arkosic wacke and siltstone with scattered pebbles and lenticular beds of pebble conglomerate. Most of the rocks are light to medium gray and light tan; a few of the siltstones are green. Micaceous clay and silt with moderately abundant glass shreds make up 40 to 60 percent. Chlorite is moderately abundant, and glauconite is present in a few of the thin sections examined. Small rock and pumice fragments and a few volcanic bombs were noted in the wackes. All of these rocks show only a moderate degree of induration. The rocks are in thin- to medium-bedded units that are lenticular to wedge shaped and pinch out over short distances.

Plant debris and carbonaceous material is common. Most of the material is not identifiable; one specimen was identified by J. A. Wolfe, of the U.S. Geological Survey, as *Picea* sp. Wolfe stated (written commun., 1963) that no precise age within the Tertiary could be assigned to the collection but that a middle or late Tertiary age was likely. These beds cannot be correlated with any other Tertiary sedimentary rocks in the Iliamna quadrangle but are lithologically very similar to rocks exposed along the north shore of Chinitna Bay (Detterman and Hartsock, 1966), about 1.6 km east of the quadrangle. Plants from the Chinitna Bay locality are assigned by Wolfe to the Seldovian Stage (Wolfe, 1966a, p. A16–A17). If these rocks can be correlated with the Tertiary section at Chinitna Bay, they probably are of early and middle Miocene age.

VOLCANIC ROCKS

Most of the bedrock in the western part of the Iliamna quadrangle and along the west flank of the Alaska and Aleutian Ranges is composed of volcanic and volcaniclastic rock of Tertiary age. Glacial debris mantles much of the area west of the mountains; however, nearly all of the hills are capped by volcanic rock, and volcanic rock probably underlies the surficial materials. These rocks represent an episode that began in early Tertiary time and is still continuing on Augustine Island and at Iliamna Volcano. The rocks have not been dated by the potassium-argon method, but field relations and stratigraphic evidence suggest that the eruptive activity was episodic.

Numerous eruptive centers can be identified. Some are necks that represent remnants of former volcanoes that have been eroded, in part by glacial action. An excellent example is Peters Plug on the south side of Iliamna Lake, just east of Big Mountain. This basalt spire standing 133 m above the surrounding lowlands is the core of a former volcano. Other eruptions were from fissures, as in the southwestern part of the quadrangle. Apparently some eruptions were mild, others explosive. The central part of Porcupine Island is the remnant of a collapsed caldera. Roadhouse Mountain was another major early Tertiary eruptive center. The conical 991-m-high mountain is mainly formed of welded volcanic agglomerate and breccia; parts of the solidified intrusive magma chamber are exposed on the south side of the mountain.

The volcanic rock exposed is highly varied in composition. Most rocks are in the intermediate class of andesite to basaltic andesite, but they range from sodic rhyolite to olivine basalt. Because age determinations were not made on these volcanic rocks, their division on the geologic map (pl. 1) is based chiefly on lithology. The general informal units used are basalt and andesite, tuff, and volcanic rubble. In some areas, the field mapping was broadly reconnaissance, and the volcanic rocks are mapped as undivided. Two distinctive units that on stratigraphic relations are clearly younger than most of the volcanic rocks are formally named the Gibraltar Lake Tuff and Intricate Basalt. In addition to these units, a late Tertiary or early Quaternary sequence can be mapped at Seven Sisters Mountain and just west of West Glacier Creek.

BASALT AND ANDESITE

Distribution

Flows of generally dark-gray to green glassy to porphyritic lava are a major part of the Tertiary volcanic sequence. Glacially scuptured lava tors cap many of the low hills in the western part of the quadrangle, remnants of formerly much more extensive flows, some of which probably underlie the surficial materials. An aeromagnetic map of part of the adjoining Dillingham quadrangle (Henderson and Vargo, 1963) indicates that magnetic rocks, probably Tertiary flows, underlie some of the glaciated lowlands. Most of the isolated remnants are believed to represent fissure eruptions, as vents cannot be located for them.

Several eruptive centers that were probably active for millions of years account for most of the volcanic rock in the quadrangle. One center extended from Nonvianuk Lake northeastward along the west flank of the Aleutian Range for about 52 km, part of a volcanic province that extended another 45 km to the southwest as far as Naknek Lake in the Mount Katmai quadrangle (Keller and Reiser, 1959). Eight vents that trend roughly N. 45° E., parallel to the mountain range, were mapped in the Iliamna quadrangle, and there may be others. Another major center, also on the west flank of the range, extended from Kakhonak Bay to Pile Bay, a distance of 52 km; five vents were mapped in this segment, including the caldera on Porcupine Island.

The northwestern part of the quadrangle was a major area of Tertiary volcanism that contains several vents and feeder dikes clustered around a granodiorite pluton at VABM Kaskanak. The pluton may be genetically related to the extrusive rocks, as most of the flows in this area are andesitic to rhyolitic in composition. Basaltic flows are concentrated around Groundhog Mountain, possibly an eruptive center, although actual vents were not seen.

Roadhouse Mountain is the remnant of a large volcano that produced the flows along the north side of Iliamna Lake near the village of Iliamna. A cluster of several small vents occurs in the mountains north and east of Roadhouse Mountain, along the contact with the older Jurassic volcanics.

Several small Tertiary flows are present along the west shore of Cook Inlet, at Bruin Bay, Iliamna Bay, Iniskin Bay, and Chinitna Bay. None is more than about a hectare in extent, and their source is not known. A generalized sequence can be worked out for the main eruptive centers, each having distinguishing characteristics. The center southwest of Gibraltar Lake and the one in the northwestern part of the quadrangle were in general more explosive, and most of the rocks are in the andesitic to rhyolitic range. The Intricate Bay-Pile Bay center was mainly basaltic and contains less evidence of explosive ejecta.

Thickness and stratigraphic relations

Detailed information on the thickness of the Tertiary lava flows was not obtained. Any precise statement of thickness would be meaningless because lave flows, tuffs, and rubble flows are intimately mixed and change rapidly within a short distance. A rough estimate for all units of about 1,000 m can be obtained for the area between Intricate Bay and Pile Bay, probably a maximum for the quadrangle.

Thickness of most individual lava flows examined ranges between 2 and 15 m; a few are as much as 46 m thick. Locally, successive outpouring of lava built a sequence of flows as much as 150 m thick, mainly in the area north of Copper River and at Groundhog Mountain.

Locally, Tertiary volcanic rocks unconformably overlie all rock units west of the Bruin Bay fault. East of the fault in the Iliamna quadrangle, there are no known Tertiary volcanic rocks. Quaternary volcanic rock is present east of the fault, and a few basalt dikes of Tertiary age cut the Middle and Late Jurassic sedimentary sequence.

Lithology

Tertiary flows in the Iliamna quadrangle range from dark gray, green, and black to light tan and red. Most are porphyritic, but they range from highly vesicular to aphanitic and glassy. Rocks of dark color and porphyritic to glomeroporphyritic pilotaxitic texture predominate; most can be classified as andesite or basaltic andesite. Basalt, dacite, and rhyolite are common locally. Columnar jointing is generally well developed in the basaltic and andesitic flows.

In thin section, the andesite is pilotaxitic porphyritic to glomeroporphyritic. Phenocrysts are plagioclase (andesine or labradorite) and a combination of hornblende, biotite, and clinopyroxene. A few are hypersthene-augite andesites. Granular magnetite is fairly abundant in most thin sections. A textural change to holocrystalline and intergranular is characteristic of rocks classified as basalt and basaltic andesite. Associated with the change in texture, particularly in the intergranular samples, is a marked increase in clinopyroxene. Most basaltic rocks contain olivine in varying amounts, and the feldspar is commonly labradorite. The glassy rocks commonly have some palagonite.

Vitrophyric dacite associated with the Porcupine Island caldera has been found on some of the islands just west of Porcupine Island. Most contains sanidine and a few percent quartz. Porphyritic rhyolite that contains 10 to 12 percent quartz and about 25 percent sanidine phenocrysts is found in T. 2 S., R. 30 W., along the north edge of the quadrangle. Some of the flows are high in sodium and contain a bright blue sodic amphibole.

Chemical analyses for a few of the Tertiary volcanic rocks are given in table 3; sampling sites are located on plate 1. Rocks from sampling sites 1, 12, 13, and 14 from localities mapped as basalt and andesite indicate the range of chemical composition found in these rocks.

Age and Correlation

Rocks mapped as part of the Tertiary volcanic squence are not dated by the potassium-argon method. An olivine basalt dike cutting the Naknek Formation on the south shore of Kamishak Bay yielded dates of 5.0 ± 1 m.y. and 4.4 ± 0.5 m.y. on whole-rock analysis (published by written permission of Mobil Oil Corp. Dec. 8, 1975). Age data on intrusive rocks (Reed and Lanphere, 1969, 1973a, and 1973b) define two Tertiary plutonic events in this part of Alaska. One actually began in Late Cretaceous but continued into the Tertiary; the other occurred about 35 m.y. ago. It is believed that these Tertiary intrusive centers locally vented to the surface and that the Tertiary volcanic rocks mapped are related to these eruptions.

TABLE 3.—*Chemical analysis of selected Tertiary volcanic rock*

[Analysis by rapid-rock method. Analysts, P. L. D. Elmore, Gillison Chloe, James Kelsey, J. L. Glenn, S. D. Botts, Hezekiah Smith, and Lowell Artis]

Map loc. No	1	2	12	13	14	20
Map symbol	Tvba	Tvt	Tvba	Tvba	Tvba	Tgll
Rock type	Hypersthene-augite andesite	Lithic tuff	Augite andesite	Augite andesite	Basalt	Welded rhyolite tuff
Lab No	M105604W	M105603W	M105602W	M105601W	M105600W	M105605W
Field No	65ADt909	65ADt921	64ADt681	64ADt643	63ADt400	66ADt1405
SiO_2	52.9	54.2	59.4	63.7	53.8	72.4
Al_2O_3	17.4	16.1	17.0	13.8	17.4	14.0
Fe_2O_3	2.2	2.5	3.8	2.1	3.1	1.8
FeO	6.8	6.0	2.4	3.2	5.6	.76
MgO	4.3	4.6	3.0	1.5	3.9	.72
CaO	8.2	7.4	6.0	4.3	9.0	1.9
Na_2O	3.0	2.4	3.5	3.5	2.3	3.7
K_2O	1.8	1.8	1.4	.88	.75	2.3
H_2O-	.37	.43	1.0	1.9	.76	.58
H_2O+	1.2	2.5	1.3	3.9	2.0	1.3
TiO_2	1.3	1.3	.72	.84	.93	.36
P_2O_5	.39	.52	.22	.22	.17	.08
MnO	.17	.17	.13	.11	.15	.05
CO_2	<.05	.05	.09	.10	.21	<.05
Total	100	100	100	100	100	100

Stratigraphic evidence supports a Tertiary age for the volcanic rocks. The lower and middle members of the sedimentary Copper Lake Formation do not contain fresh volcanic rock clasts, but the upper conglomerate member contains abundant clasts of fresh volcanic rock as well as beds of tuff. A few leaves identified by J. A. Wolfe (U.S. Geol. Survey) as *Acer disputabilis* Hollick (written commun., 1970) of probable early Eocene age are found interbedded with these clasts. Another area of sediments interbedded with volcanic rock and containing plant material is located about 13 km east of Tommy Point on the south shore of Iliamna Lake. Wolfe identified *Picea* sp. from these beds and suggested a middle to late Tertiary age for the enclosing rock.

Extensive Tertiary volcanism is known from the adjoining Mount Katmai quadrangle (Keller and Reiser, 1959) and from farther south on the Alaska Peninsula (Burk, 1965). These rocks are considered a part of the southwestern Alaska Tertiary volcanic province. A possible Late Cretaceous age for some of the volcanic rocks cannot be ruled out but most probably formed episodically throughout the Tertiary. If volcanism were associated with plutonism, then the first major activity probably occurred in late Paleocene to early Eocene time; later activity occurred during the Oligocene. The Gibralter Lake Tuff and Intricate Basalt are probably younger than most of the rocks mapped as basalt and andesite.

TUFF

DISTRIBUTION

Bedded tuff is a major component of the Tertiary volcanic sequence in the quadrangle. As tuff units can be traced to all eruptive centers, each center had one or more explosive phase. Many of the areas mapped as volcanic rocks, undivided, contain tuffs, and some isolated outcrops suggest that a large part of the glacially mantled lowland may also be underlain by tuff.

The Big Mountain, Porcupine Island, Roadhouse Mountain, and Gibraltar Lake areas were the major sources of tuff in the quadrangle. Deposits from Gibraltar Lake are much younger than the tuffs from the other source areas and are mapped as the Gibralter Lake Tuffs, discussed below. Peters Plug is the neck of the volcano that produced the tuffs of Big Mountain, which spread out to the southwest for at least 40 km.

The center of Porcupine Island is a collapsed caldera filled with welded crystal to lithic dacitic tuff. Only 85 m of this caldera remains above the water of Iliamna Lake. Dacite on many of the surrounding islands, for example Flat Island, and on the high ridges along the south shore of Pile Bay probably came from this major eruptive center before it collapsed.

THICKNESS AND STRATIGRAPHIC RELATIONS

Only very general estimates of the amount of tuff extruded can be made. Moderately to steeply dipping beds in the cliffs at the base of the Big Mountain would indicate a minimum of at least 2,000 m of welded crystal and lithic tuff. Tuff of a similar thickness is probably contained in the mountains south of Porcupine Island. It is not known if these tuffs represent one major eruption or a series of minor events, but the tuffs of Big Mountain appear to be internally conformable and probably were extruded as a nuée ardente type eruption similar to that of Mount Katmai and Novarupta in 1912 (Curits, 1968). A minimum area of 500 km^2 is covered by tuff in the Iliamna quadrangle.

LITHOLOGY

Light-gray to tan welded crystal and lithic tuffs are common rock types. The tuffs from the Porcupine caldera are somewhat darker in color than all other tuffs, a result of the andesitic to dacitic character of the rocks at that locality. Most of the rocks examined in thin section contain 40 to 70 percent glass, some of which shows good fluidal banding; others are made up almost entirely of welded shards. Shattered phenocrysts of plagioclase and quartz are common throughout, and many specimens contain pumice fragments. Pumice lapilli show all gradations from flat to well rounded and vesicular, depending on the degree of welding. Quartz and potassium feldspar generally form about 5 to 15 percent of the rock, and biotite and hornblende make up as much as 10 percent but generally no more than a few percent. One chemical analysis of a sample of this lithology is included in table 3 (No. 2).

Lithic fragments are abundant in tuffs on Porcupine Island and Roadhouse Mountain, particularly on Roadhouse Mountain. At that locality an agglomerate is composed of numerous volcanic rock clasts in a tuffaceous matrix. The clasts are as much as 25 mm long near the top of the mountain and become progressively smaller on the lower slopes and around the base. A few granitic clasts included in the tuff presumably represent fragments torn from the walls of the magma chamber during eruption.

Zeolite minerals are fairly common. Madonna (1973) reported that mordenite, clinoptilolite, heulandite, analcime, and laumontite were found as alteration products in the tuffs of Iliamna quadrangle.

VOLCANIC RUBBLE AND BRECCIA

DISTRIBUTION

Volcanic rubble and breccia flows, some of which probably originated as lahars, are found throughout the quadrangle interbedded with the other volcanic rocks. Rubble and breccia are not as abundant as tuffs or lava flows. The deposits are somewhat more abundant near volcanic centers north of Iliamna Lake than south of the lake; the southern centers were more explosive and thick tuff deposits have covered most of the area near the vents. Locally, near lake shores or streams, the tuff has been eroded to reveal underlying rubble and breccia.

THICKNESS AND STRATIGRAPHIC RELATIONS

Most rubble and breccia deposits are probably thin, as generally no more than 30 to 45 m is exposed at any one point. About 60 m of such rock was seen in the cliff along the south shore of Iliamna Lake east of Eagle Bluff. A deposit of similar thickness is exposed along Ole Creek in the southwestern part of the quadrangle.

LITHOLOGY

Most of the rock is dull, dark, and poorly consolidated. Some deposits have been partially welded, but clasts readily weather out. Nearly all clasts are of volcanic rock and range from fine granules to blocks 1 m across; most are about 5 to 12.5 mm and are distinctly angular. A few granitic clasts are included locally, particularly in the Canyon Creek flow from Knutson Mountain. Agate is commonly found in cavities in the rubble.

GIBRALTAR LAKE TUFF

The name Gibraltar Lake Tuff is here proposed for a light-gray to tan rhyolitic crystal and lithic tuff that unconformably overlies a series of other Tertiary volcanic rocks in a manner suggesting that it is a late event not directly related to the main Tertiary eruptions. A massive accumulation of these tuffs is well exposed in the mountains west of Gibraltar Lake, after which they are named. The best exposures are on a mountain west of Emerald Lake, designated its type locality. The stratigraphic unit is divided into a lower member composed of welded tuff and a nonwelded upper member.

AGE

These deposits are related to the Tertiary volcanic sequence and were deposited at the same time. Precise age limits for individual flows cannot be made except east of Eagle Bluff, where the rubble includes some late Tertiary plant material.

LOWER MEMBER

DISTRIBUTION

The main area of accumulation for the welded tuffs of the lower member of the Gibraltar Lake Tuff is in the mountains west of Gibraltar Lake, where these rocks cover an area of about 60 km^2 centered on the eruptive center west of Emerald Lake. Tuff covers a small area of about 4 km^2 between Funnel and Moraine Creeks a few kilometers southwest of the main mass, probably an erosional remnant of the main flow. More tuff undoubtedly underlies glacial moraine in the lowland north and west of Gibraltar Lake.

THICKNESS AND STRATIGRAPHIC RELATIONS

The lower member is at least 300 m thick, possibly as much as 730 m in the area around Emerald Lake. The upper surface, though fairly smooth, is somewhat modified by erosion. A gorge 300 m deep cut into the tuff is occupied by Emerald Lake. Elsewhere the surface slopes gently and is uncomformable on older rock units as found in the exposed contact with basalt along the southwest shore of Gibraltar Lake for about 6.5 km.

LITHOLOGY

Welded light- to medium-gray and tan rhyolitic crystal and lithic tuff are the main rocks forming the lower member of the Gibraltar Lake Tuff. The degree of welding ranges from slight to intense, as indicated by collapse of pumice lapilli and broken and bent glass shards. In some rocks, the pumice lapilli are only slightly crushed and most shards are unbroken, whereas in others the lapilli are completely flattened and all the shards are fractured and have flowed around the pumice and phenocrysts.

In thin section, these rocks are seen to contain about 45 to 70 percent glass, 10 to 15 percent quartz, 12 to 18 percent orthoclase and (or) sanidine, 3 to 5 percent biotite, and, generally, a few percent plagioclase. Lithic clasts form 10 to 15 percent of some rocks but are not seen in others. Chemical analysis of one sample from west of Emerald Lake is included in table 3 (No. 20). Many of the phenocrysts are shattered, and most show rounding by solution. The feldspars show considerable alteration to sericite and kaolin. Pore space in some uncrushed pumice lapilli is filled with chalcedony. Granular magnetite is present in some of the rocks but generally in minor amounts.

Porphyritic rhyolite flows are locally interbedded with the welded tuff. Most are somewhat glassy and are difficult to distinguish in the field from the massive welded tuffs that do not contain indications of bedding. Examination in detail might reveal minor differences and variations in welding that could be used for stratigraphic differentiation.

AGE AND CORRELATION

The rock unconformably overlies most of the older Tertiary volcanic sequence; locally along the shore of Gibraltar Lake, there is evidence of a weathered zone between the tuff and the underlying basalt. Moreover, the topography developed on the welded tuff is that of a young region not greatly altered by erosion, whereas the older Tertiary volcanic units are deeply eroded. On this evidence, these rocks are considered as being Oligocene(?) to Pliocene (?) in age. The younger date is probably more nearly correct.

UPPER MEMBER

DISTRIBUTION

A light-gray to white ash-flow tuff overlies the welded tuff at a number of localities. The largest area is west of Emerald Lake, where the upper part of the mountains is mainly composed of this tuff underlying a caprock of basalt. Most of the flow moved southwest, one lobe for an extent of about 6 to 7 km. A small remnant preserved about 6 km farther west may be part of this same flow.

Thickness and stratigraphic relations

A maximum of 152 to 182 m of ash-flow tuff caps the ridges west of Emerald Lake, the main accumulation area. The deposit rapidly diminishes away from this center. The locality near Funnel Creek probably has no more than 30 m of tuff.

The ash-flow tuff of the upper member unconformably overlies the older Tertiary volcanic rock wherever it has been found. As the tuff does not extend over any pre-Tertiary rock units, it is the product of a minor eruptive event.

Lithology

White chalky ash-flow tuff and white-to-gray crystal tuff are the main constituents of the upper member. Locally west of Emerald Lake, small areas of bedded unconsolidated volcanic sand and lapilli pumice and a few beds of lithic tuff are included with this unit. The rocks are mostly poorly consolidated. The few beds that are well consolidated are mostly glassy, and the shards and pumice lapilli are completely undeformed. The well-indurated crystal tuffs contain large (2–4 mm) phenocrysts of quartz and feldspar, the feldspar commonly showing the effects of corrosion and resorption. Minor chloritized biotite is commonly present. The alteration of these minerals was probably caused by degassing during cooling and compaction of the ash flow. Abundant irregular masses of agate and chalcedony are found within cavities in the flow west of Battle Lake.

Age and correlation

The age of the upper member is unknown, but its stratigraphic position, poor consolidation, and largely unmodified topographic expression indicate that it is young. As the deposit was modified somewhat by glaciers, it predates the late Pleistocene, and it is locally overlain by the Intricate Basalt, which we consider Pliocene(?). On this basis, the member is assigned a Pliocene(?) age.

INTRICATE BASALT

Distribution

The Intricate Basalt is here named for a sequence of olivine-augite basalts exposed at Intricate Bay, its type locality at the southeast end of Iliamna Lake. The bay contains a myriad of irregular-shaped islands composed mainly of this basalt. The source for these rocks was a vent at Lookout Mountain on the peninsula between Intricate and Kakhonak Bays, and most of this rock type is confined to an area of about 16 km^2 in the immediate vicinity.

A few other localities have a similar young basalt that is mapped as part of this rock unit. The Gibraltar Lake Tuff in the mountains west of Emerald Lake is locally capped by several small masses of basalt that were originally all part of one flow unit.

Thickness and stratigraphic relations

The greatest accumulation of basalt is in the Intricate Bay area, where a succession of flows built a pile 100 to 150 m thick. Most individual flows are on the order of 5 to 20 m thick and overlie preceding flows disconformably. The caprock flows west of Emerald Lake are generally no more than 15 to 20 m thick, and most were produced by a single outpouring of lava. The Intricate Basalt disconformably to unconformably overlies the other Tertiary volcanic rocks.

Lithology

Glassy to porphyritic black to dark-green olivine-augite basalt is the main rock type of the Intricate Basalt. In thin section, these rocks are mainly intergranular; a few specimens show a tendency toward subophitic texture; the glassier samples are hyaloophitic. Plagioclase, mainly labradorite with some andesine, constitutes about 40 to 60 percent of these rocks, mainly as small laths; phenocrysts were noted in a few samples. Clinopyroxene, generally augite, makes up another 20 to 30 percent, commonly as small granules. Olivine as large euhedral to subhedral phenocrysts was present in all thin sections, generally forming about 5 to 15 percent. Granular magnetite was present in all sections, constituting about 3 to 8 percent. One glassy section contained nearly 50 percent glass and only about 5 percent each of olivine and clinopyroxene; the rest was plagioclase.

Nearly all of the basalt exhibits well-developed columnar jointing; individual columns are generally 0.3 to 0.6 m across. A basal flow breccia locally occurs between successive flows; it generally is less than 1 m thick.

Age

The Intricate Basalt overlies all other Tertiary units including the Gibraltar Lake Tuff, which is Oligocene (?) to Pliocene (?), its upper member most likely Pliocene (?). In the absence of positive evidence, the Intricate Basalt is assigned a Pliocene (?) age.

INTRUSIVE ROCKS

Tertiary intrusive rocks are mapped at a number of localities in the Iliamna quadrangle. Most are small stocks of quartz diorite or granodiorite that are associated with or cut the Tertiary volcanic sequence.

QUARTZ DIORITE

A small pluton of quartz diorite that intrudes Jurassic quartz diorite crops out on the ridge south of McNeil Lake in the southern part of the quadrangle. This small stock represents a middle Tertiary pulse of magma generation in the Alaska-Aleutian Range batholith and is the only dated middle Tertiary rock in the quadrangle. The McNeil stock is about 36 m.y. old, the oldest in a series of mid-Tertiary stocks in the general area (Reed and Lanphere, 1973b). Other stocks lie 12 to 20 km south in the Mount Katmai quadrangle. The McNeil stock covers about 5 km^2 and is a coarse-grained hornblende-biotite quartz diorite. A chemical analysis of this rock is included in table 1 (No. 33). Modal plots for this sample are given in Reed and Lanphere (1969, p. 39).

INTRUSIVE ROCKS, UNDIVIDED

Most small Tertiary granodiorite and quartz diorite plutons are mapped as intrusive rocks, undivided (pl. 1). Nearly all are along the flanks of the Alaska-Aleutian Range batholith. Several are present between Kakhonak Lake and Copper Lake, where they intrude the early Tertiary Copper Lake Formation. These small bodies may be connected at depth, and nearby basaltic andesite flows may also be part of the igneous sequence.

The largest exposed intrusive is the granodiorite on the south flank of Roadhouse Mountain, largely covered by agglomerate and lava flows produced from surface eruptions. A smaller body, about 9.5 km to the north, intrudes Early Jurassic volcanic rock.

The west end of Flat Island is composed of Tertiary granodiorite. Its relation to the Porcupine Island caldera is unknown. Several small areas of pinkish granodiorite lie on the east side of the batholith at the north entrance to Iliamna Bay and the west entrance to Iniskin Bay. Dikes from these bodies cut the Jurassic quartz diorite and volcanic rock.

Another area of Tertiary intrusive rock is the biotite diorite to quartz diorite that forms Shaw Island at the southeast corner of the quadrangle. This highly fractured fine-grained dark rock may be related to some of the volcanic flows in the Katmai area just south of the quadrangle.

Most of the Tertiary intrusive rock is a medium-grained hornblende-biotite quartz diorite or granodiorite, generally light colored. Hornblende is usually the dominant mafic mineral, in some bodies present as small randomly oriented needle-shaped crystals. Such crystals were noted only in the Tertiary intrusive rocks, but not all the Tertiary intrusive rocks contain them. Light-pink coarse-grained potassium feldspar is common in the two small bodies at the mouth of Iliamna and Iniskin Bays. The Roadhouse Mountain and Tazimina River stocks are fine-grained dark hornblende diorite similar to that at Shaw Island.

Several of the bodies between Kakhonak and Copper Lake intrude the Copper Lake Formation. The upper conglomerate member of this formation is of Eocene age. The best estimate for the age of the intrusive rocks is middle Tertiary.

VOLCANIC NECKS, SILLS, AND DIKES

Spires of basalt and diabase representing the solidified core or vent of volcanoes are found throughout the quadrangle. Most are located around the main eruptive centers. Twenty-two vents are associated with the Tertiary volcanic rocks, not including the Porcupine Island caldera.

The main cluster of vents fall on a N. 45° E. line roughly parallel to the west flank of the batholith and the structural grain of the bedrock; another trend of vents and eruptive centers may exist. The south shore of Kamishak Bay is a major indentation 95 km long in lower Cook Inlet that strikes nearly transverse to the structural grain of the bedrock and is reflected by a weak gravity anomaly (Barnes, 1976). Projected westward, this line intersects Big Mountain, and five vents fall on or near it. The main part of the southern eruptive center would be just south of this line. A similar line drawn from Augustine Volcano to the northwestern part of the quadrangle passes through the large eruptive center between Kakhonak and Pile Bays and continues into the volcanic center in the northwestern part of the quadrangle.

East of Big Mountain, Peters Plug, the largest volcanic neck in the area, rises 133 m above the surrounding plain. The top is about 150 m across and is composed of columnar-jointed basalt as is the neck on north shore of Nonvianuk Lake, which is about 75 m high. Sections of two vents can be seen in a cirque and landslide headwall northeast of Mirror Lake, and a 75-m section is present 6.5 km south of Squirrel Point.

Rocks from the six volcanic necks and plugs were examined in thin section. One from northeast of Mirror Lake is a pyroxene diabase; the others were basalt or basaltic andesite with an intergranular to glomeroporphyritic texture. Labradorite is the most abundant mineral, forming 50 to 60 percent of the rocks. Small granular clinopyroxene was nearly as abundant. Phenocrysts of olivine constitute 2 to 3 percent. Granular magnetite and ilmenite are constituents. The necks are similar in composition to many of the flows.

Only a few of the larger dikes and sills are shown on the geologic map (pl. 1). Most appear to be basalt or basaltic andesite, but the rocks were not examined in thin section. Most are near eruptive centers. One isolated dike of olivine basalt 10 m thick that cuts the Naknek Formation on the south shore of Kamishak Bay is about 5 m.y. old. Dikes and sills were probably intruded throughout the Tertiary.

TERTIARY OR QUATERNARY SYSTEMS

VOLCANIC ROCKS, UNDIVIDED

Tertiary or Quaternary volcanic rocks from two small eruptive centers are mapped as undivided. The larger of the two forms Seven Sisters, 8 km northwest of Bruin Bay. The other is about 1.5 km west of the Left Fork of West Glacier Creek in the northeastern part of the quadrangle. Both centers are within the Alaska-Aleutian Range batholith.

Seven Sisters is a sharp-crested volcano surmounted by seven spires, whence its name. The spires are intrusive rock formed by the volcanic neck and feeder-dike system; as they were not examined in detail, the composition of the rock is not known. The bulk of the eruptive rock is a scoriaceous olivine basalt in which white zeolite minerals fill amygdules. Olivine occurs primarily as large phenocrysts several millimeters across in the fine-grained intergranular textured rock. The microlitic groundmass is mainly plagioclase ((labradorite) and clinopyroxene. Many of the olivine phenocrysts are rimmed with iddingsite and magnetite. Seven Sisters was visited briefly; other volcanic rock types may be present.

The eruptive center near West Glacier Creek was first observed briefly in 1972 during an investigation of the Alaska-Aleutian Range batholith. The character of these rocks is incompletely known. They appear to be primarily andesitic in composition and to be made up mainly of tuff and volcanic breccia, although some gray columnar jointed flows were seen. The fairly smooth to gently rounded topographic expression of this volcanic mass is suggestive of an area underlain by tuff and pumice rather than more resistant flows.

Both eruptive centers lie within the quartz diorite part of the Alaska-Aleutian Range batholith, but the composition and character of the rock extruded from each center differ markedly. The northern mass, not investigated in detail, appears to be very similar to the

Pleistocene and Holocene volcanic rock of Iliamna and Augustine Volcanoes. The olivine basalt of Seven Sisters is more closely related to the Intricate Basalt, which was extruded from a center about 23 km northwest of the Seven Sisters, also olivine bearing.

Neither of the eruptive centers has been dated; consequently, the age assignment is based on morphology and physical characteristics. The northern low rounded mass appears to have been strongly modified by glacial action. There are numerous modern glaciers nearby to the north and east, but the hill was last overridden by ice during the Wisconsin Glaciation. Seven Sisters volcano is sharp crested and rugged and appears to have been only slightly modified by glaciers; it is considerably removed from any active modern source of glaciers. Along the south and west flanks of the volcano, volcanic rock appears to overlap an old glacial moraine, but this aspect might be produced by landslides that formed on the steep slopes of the volcano.

The volcanic rocks, undivided, could be as old as Pliocene or as young as late Pleistocene. In the absence of definitive dates, we consider these rocks to be Pliocene or Pleistocene.

QUATERNARY SYSTEM

VOLCANIC ROCKS, UNDIVIDED

Volcanic rocks of Quaternary age in the Iliamna quadrangle are confined to small areas around Iliamna Volcano, a composite volcano that is part of the Aleutian volcanic arc and intermittently active. North and South Twins, in the northeast corner of the quadrangle, are part of an Iliamna crater. The main part of the present volcano is just outside the quadrangle, but flows radiate from it down East, Middle, and West Glacier Creeks.

Rocks erupted from Augustine Volcano were named the Augustine Volcanics by Detterman (1973); this term is not appropriate for eruptives from Iliamna Volcano, as the Iliamna rocks are mainly lava flows whereas Augustine eruptions are chiefly tephra. For this reason, rocks from Iliamna are mapped as Quaternary volcanic rocks, undivided (pl. 1), rocks from Augustine as Augustine Volcanics.

Lava from Iliamna Volcano is light-gray hypersthene-augite andesite. Phenocrysts of plagioclase, hypersthene, and augite are embedded in a pilotaxitic groundmass of andesine microlites. A complete description of these rocks is given in Juhle (1955). The largest Iliamna flow in the quadrangle is about 60 m thick and extends about 6.5 km down East Glacier Creek valley. A basal breccia zone separates the flow from the underlying Middle Jurassic clastic rocks. This flow crosses the Bruin Bay fault and shows no evidence of offset along the fault; the rock has not been dated. Several other flows are nearly as long as the East Glacier flow. North Twin is formed of yellow-gray opalized-tuff crater fillings; South Twin is mainly lava. More volcanic rock underlies ice and snow on the upper flanks of the volcano, but the type is unknown.

AUGUSTINE VOLCANICS

The name Augustine Volcanics is applied to all volcanic rocks forming the bulk of Augustine Island (Detterman, 1973). They include pumice, ash, scoria, volcanic mud and rubble flows, and lava flows. Tephra deposits, by far the most abundant, form thick units on the island. Augustine Volcano has been intermittently active during historic time (Coats, 1950). The last major eruption occurred in 1976, only 12 years after the previous eruption. Similar activity apparently has continued for thousands of years to form a composite cone about 1,300 m high.

LAVA FLOWS

Lava flows form only a minor part of the rocks on Augustine Island. They are found at isolated localities around the periphery of the island, and most occurrences are nearly covered by subsequent rubble and pumice flows. A dacite dome formed on Augustine after each historic eruption. Most were destroyed by the next eruption, but parts of several still remain; one fragment is at VABM Kamishak (pl. 1).

Lava from Augustine Volcano is of intermediate composition and can be classified as hypersthene-augite andesite with a pilotaxitic texture. Some of the more glass-rich rocks are hyalopilitic. The lavas were particularly gas rich, and solidified flow rocks are highly vesicular. The rocks are all porphyritic with large phenocrysts of plagioclase, mainly andesine, 2 to 3 mm long in a groundmass of plagioclase microlites. Small phenocrysts of hypersthene and augite are common. Euhedral quartz was noted only in samples from a vent at VABM Kamishak. The quartz-bearing rocks may be transitional to dacite. Chemical analyses of selected rocks from Augustine Volcano are listed in table 4.

VOLCANIC RUBBLE AND MUDFLOWS

Most of the rock exposed on Augustine Island is formed of volcanic rubble and mudflows. Many individual flows can be mapped; most probably originate as lahars both during and after eruptions. At least some of the flows were hot, for one very fluid flow in 1963 scalded the vegetation in its path (Detterman, 1968). The viscosity of the flows varied greatly, as some formed short steep-sided masses, whereas others spread out thinly over a wide area. The included fragments

TABLE 4.—*Chemical analysis of selected rocks from Augustine Island*
[Analysis by rapid-rock method. Analysts, P. L. D. Elmore, Gillison Chloe, James Kelsey, J. L. Glenn, S. D. Botts, Hezekiah Smith, and Lowell Artis]

Map loc. No	27	28	29	30	31	------
Lab. No	M105598W	M105596W	M105595W	M105597W	M105599W	M128125
Field No.	67ADt1515	67ADt1511	67ADt1503	67ADt1512	67AEu23	Airfall ash Jan. 23, 1976
Rock type	Hypersthene-augite andesite	Rhyolitic pumice	Hypersthene-augite andesite	Hypersthene-augite andesite	Dacite	Rhyolitic ash
SiO_2	57.8	61.6	58.8	58.8	59.5	63.58
Al_2O_3	17.3	17.2	17.1	16.7	18.9	16.43
Fe_2O_3	2.9	2.0	3.7	2.1	1.8	2.31
FeO	3.8	3.6	2.8	4.3	2.2	2.48
MgO	4.5	3.2	4.6	4.6	2.6	2.27
CaO	8.0	6.6	7.8	7.3	5.3	5.84
Na_2O	3.1	3.0	2.8	3.3	3.4	3.82
K_2O	.80	.90	.84	.90	1.0	1.23
H_2O-	.11	.07	.05	.02	1.1	.18
H_2O+	.59	1.0	.46	.78	2.4	.12
TiO_2	.67	.56	.62	.64	.58	.59
P_2O_5	.14	.14	.14	.17	.16	.15
MnO	.14	.13	.15	.15	.11	.09
CO_2	<.05	<.05	<.05	<.05	<.05	.06
Cl	----	----	----	----	----	.14
S	----	----	----	----	----	.16
Total	100	100	100	100	100	99.45

range from silt size to blocks as large as a small house. Vesicular siliceous lava is included in minor amounts with some of the flows. Old flows are extremely well indurated and take on the gray color and consistency of concrete.

PUMICE AND SCORIA

Augustine Volcano has produced extensive pumice deposits that range in thickness from a meter to as much as 100 m. Iliamna Volcano, on the other hand, has produced very little pumice. This difference probably indicates that the two volcanoes are dissimilar in style of eruption. The initial phase of the 1963 and 1976 Augustine eruptions were of the nuée ardente type, and eye-witness accounts of some earlier eruptions would suggest that they were nuée ardentes, similar to the 1912 eruption of Novarupta that produced the Valley of Ten Thousand Smokes in the Katmai area (Davidson, 1884; Fenner, 1923; Curtis, 1968). Most of the pumice is in the lapilli to coarse-ash size range; a few fragments are 1 m long. Much of the pumice is light gray to tan, but it ranges from white to dark gray and is mainly of rhyolitic to andesitic composition. The color variations common within single flows may indicate that the volcano is supplied by several magma chambers, as has been suggested for Mount Katmai and Novarupta (Curtis, 1968).

Small amounts of scoria and cinders are produced by Augustine and Iliamna Volcanoes. From Augustine, at least, these rocks are generally the last to be ejected and generally do not form large discrete deposits.

SURFICIAL DEPOSITS

Surficial deposits, primarily of Pleistocene and Holocene age, cover about 60 percent of the Iliamna quadrangle. The deposits are mainly the products of glaciation with subsequent modification by glaciofluvial, lacustrine, and marine processes. These deposits were discussed in detail in chapter A of this bulletin (Detterman and Reed, 1973) and will be only briefly mentioned here. They are included on the geologic map, plate 1, as surficial deposits, undivided.

The quadrangle has a complete and well-defined glacial record for the Brooks Lake Glaciation of Wisconsin (late Pleistocene) age and the Alaskan Glaciation of Holocene age. The oldest glacial deposits are correlated with the Mak Hill Glaciation of early Wisconsin age. The Brooks Lake Glaciation is represented by four major named stades, Kvichak, Iliamna, Newhalen, and Iliuk. The Alaskan Glaciation is recorded by two major stades, Tustumena and Tunnel, each with several advances and recessions.

Iliamna Lake owes its present size and shape to confining moraine of the Iliamna Stade. The original lake was dammed by the Kvichak Stade and was nearly twice the size of the modern lake, the largest in Alaska. Five strand levels of well-defined beach deposits around the lake attest to the complex history of lake development. The highest level was about 31.5 m above the modern lake level. Radiocarbon-dated material from the 24.3 m level indicates that the lake was at that position by at least 8,520 B.P. By 5,520 B.P. the lake was 16.2 m higher than at present.

Numerous marine beach, terrace, and bedrock platform levels are preserved along the shore of Cook Inlet. Some of these undoubtedly result from changes in sea level during the Pleistocene and Holocene, others from isostatic uplift during deglaciation. Radiocarbon-dated beach deposits indicate uplift of about 0.6 m a century for the west side of Cook Inlet (Detterman and Reed, 1973). A radiocarbon sample obtained in 1975 from a 16-m bedrock platform at Rocky Cove was dated at 2,520 ± 250 years B.P. (W–3285).

Many of the unconsolidated surficial deposits have been reworked several times during the course of their long and complex history, and many are being reworked at this time.

STRUCTURAL GEOLOGY

REGIONAL SETTING

The Iliamna quadrangle forms part of the northern circum-Pacific orogenic belt, a part of Alaska structurally controlled by the complex tectonic characteristics of an active continental margin. Recent interpretations of the tectonic history of southern Alaska (Dickinson, 1975; Grantz and Kirschner, 1976) are primarily based on plate tectonic theory.

The structural features of the quadrangle apparently began to develop with the formation of a volcanic island arc on the Kula plate (Grow and Atwater, 1970) formed by underthrusting of the Kula plate by the North American plate (Richter and Jones, 1973); the arc was largely completed by early Mesozoic time. The Kula plate was followed by the Pacific plate (Grow and Atwater, 1970), which at this time is possibly being consumed at a rate of about 66 mm a year (Turner and others, 1973).

The present structural trend in southern Alaska consists of a marked oroclinal bend in the Cook Inlet region (Grantz, 1966; Grantz and Kirschner, 1976). The Iliamna quadrangle is on the west flank of this southern Alaska bend, where the structural grain trends about N. 40° E. This structural trend is imprinted on the deposits of the arc-trench gap and back-arc basins, in the sense of Dickinson (1974) and Karig (1972), which, together with a magmatic arc (Alaska-Aleutian Range batholith), are the main structural features of the quadrangle. The arc-trench gap basin and the magmatic arc are the Matanuska geosyncline and Talkeetna geanticline of Payne (1955).

An aeromagnetic survey of the Cook Inlet area (Grantz and others, 1963) defines several structural features in the Iliamna quadrangle. Two prominent features are the Moquawkie contact and the Cook Inlet magnetic anomaly. The Moquawkie contact represents a change in magnetic character at the western edge of the low-gradient magnetic pattern over Cook Inlet. The position of the contact parallels the Bruin Bay fault and is believed to represent magnetic intrusive and volcanic rocks west of the fault in contact with less magnetic rocks east of the fault. The Cook Inlet magnetic anomaly is broadly arched with amplitude of about 500 gammas. This broad arch is attributed to a large rock mass, probably igneous, that may be as much as 8 to 16 km deep. A moderate-gradient anomaly about 24 km northeast of Augustine Island would fall approximately on the Augustine-Seldovia arch (Fisher, 1976) and may indicate that the arch is related to volcanic or intrusive rock.

The Chinitna gradient, another feature identified by Grantz and others (1963), consists of a 200- to 400-gamma drop in magnetic intensity along the west shore of Cook Inlet. Such a drop could be caused by a fault along the shoreline, for which there is no good field evidence, or it may mark the west boundary of the magnetic mass forming the Cook Inlet anomaly. Irregularities in the gradient on Iniskin Peninsula, termed the Iniskin pattern by Grantz and others

(1963), are probably related to igneous dikes in the sedimentary rock; several are mapped on plate 1.

FOLDS

The style and character of folding changes markedly across the Bruin Bay fault. Bedded sedimentary rock east of the fault is only moderately deformed and shows a rapid decrease in degree of deformation away from the fault. Beds near the fault commonly dip 50° to 70° NW., and small tightly folded anticlines and synclines generally lie parallel to and within 0.3 km of the fault. Buckling of beds near the fault is probably caused by compression from the southeast. Eastward from the fault, the rocks are gently warped into a series of broad open folds with a general trend of N. 20°–30° E.

Several anticlinal folds were determined from marine seismic data (Fisher, 1976). Their general trend is northeasterly, similar to trend of the structures on land (pl. 1). The seismic data suggest that the folds were formed during the burial of the A horizon.

The Upper Jurassic Naknek Formation has been deformed into several large anticlines in the Kamishak Bay area. These are broad open structures that probably have some closure, but our work was not detailed enough to determine the amount and position. Several cross faults cut the area, and the axial plane of one anticline, 6.4 km west of the Douglas River, is faulted; an oil seep on the south shore of Kamishak Bay is associated with this anticline. Augustine Island lies on the trend of this anticline, and Upper Jurassic strata similar to that exposed at the mouth of the Douglas River is exposed on the south shore of Augustine Island. This would indicate either little or no plunge on the structure or an equal amount of reversal in plunge.

FAULTS

BRUIN BAY FAULT

Faults and fractures are prominent structural features in the mountainous eastern part of the Iliamna quadrangle. The Bruin Bay fault, a major feature, runs diagonally across the quadrangle along the east flank of the Aleutian and Alaska Ranges. It is a part of the Bruin Bay fault system, which extends for 482 km from near Mount Susitna, northwest of Anchorage, to Becharof Lake on the Alaska Peninsula. The Bruin Bay fault may be a splay of the Castle Mountain fault system (Detterman and others, 1976), but the actual conjunction of the two systems cannot be proved owing to a thick cover of surficial materials in the Mount Susitna area.

A 142-km segment of the Bruin Bay fault system crosses the quadrangle subparallel to the west shore of Cook Inlet. Although movement was mainly concentrated on one break, this feature is appropriately called a fault system because there are four or five subparallel faults along most of its length. The zone of subparallel faults is about 6 to 8 km wide and mainly cuts Late Triassic and Early Jurassic sedimentary and volcanic rocks. The major break separates these rocks west of the fault, marine sediments of Middle to Late Jurassic age east of the fault. The fault movement is high-angle reverse with as much as 3 km of stratigraphic throw. This amount can be accounted for by vertical displacement, but a sinistral strike-slip component is possible, as a small sliver of overturned graywacke (part of the Bowser Formation of the Tuxedni Group) present in the cliffs north of Amakdedori beach has fossils and lithology identical to the Bowser Formation exposed on the opposite side of the fault on the shore of Right Arm, Iniskin Bay, 65 km to the northeast. These similarities are rather tenuous evidence for sinistral displacement but consistent with displacement postulated for the fault in the Iniskin-Tuxedni area immediately north of the quadrangle (Detterman and Hartsock, 1966).

The segment of the Bruin Bay fault crossing the Iliamna quadrangle is not active at this time and probably has not moved since Oligocene time. A small stock of granodiorite dated at 26 m.y. (Reed and Lanphere, 1973a) lies athwart the fault 15 km south of the quadrangle with no apparent offset. A Quaternary lava flow from the Iliamna Volcano shows no evidence of displacement across the fault. Uplift of approximately 300 to 330 mm along the west side of Cook Inlet as a result of the 1964 Alaskan earthquake (Plafker, 1965, 1969; Detterman, 1968) apparently was not related to the Bruin Bay fault but rather is part of a continuing process that has elevated the west shore of Cook Inlet about 14 m during the past 2,600 years as based on carbon-14 age dates (Detterman and Reed, 1973).

The Lake Clark fault, a probable splay of the Castle Mountain fault system, may cut the western part of the quadrangle. The fault is last seen at the northeast end of Lake Clark 77 km northeast of the Iliamna quadrangle. If the fault continues southwest, it enters the quadrangle near Sixmile Lake. The fault has about 5 km of dextral offset north of Lake Clark (Plafker and others, 1975).

Most other faults in the quadrangle have a maximum length of about 24 km and a maximum throw of about 150 m. Most are normal faults except for faults of the subparallel system associated with Bruin Bay fault, which are high-angle reverse. Cross faulting is common in the sedimentary rocks east of the Bruin Bay fault.

GEOLOGIC HISTORY

Events in the geologic history of the Iliamna quadrangle are based on the lithologic character of the rock units, their depositional and structural relations, and their ages. Only that part of geologic time from Triassic to present can be determined with confidence. Permian rocks may be present as part of the Kakhonak Complex.

When the oldest known rocks were being deposited in the quadrangle during early Late Triassic time, this part of Alaska was a volcanic arc (Reed and Lanphere, 1973a). Deep- to shallow-water limestone, chert, and lime mudstone accompanied the waning stages of volcanism associated with quiet lagoons and local reef building.

Volcanism, in part subaerial, continued throughout the Early Jurassic. Massive units of breccia, agglomerate, and flows, mainly of andesitic composition, were extruded until 2,000–3,000 m had accumulated. These volcanic materials were locally reworked and became part of the sedimentary sequence interbedded with the volcanic rocks. The waning phase of the Early Jurassic volcanism mainly produced thin-bedded tuff in the quadrangle. The Early Jurassic volcanoes were surface vents for large bodies of granitic magma that represent the roots of an ancient magmatic arc now exposed as the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973b). Potassium-argon ages indicate that parts of this magma began to crystallize about 179 m.y. ago (Reed and Lanphere, 1969) and that most of the intrusive rock crystallized about 154 to 168 m.y. ago, contemporaneous with the Middle and Late Jurassic deposition.

By Middle Jurassic time, the structural grain for this part of Alaska was established. The volcanic arc underlain by a batholithic core was uplifted and supplied clastic sediment to a subsiding marginal shelf and trough (an arc-trench gap basin) now called the Matanuska geosyncline (Payne, 1955). The trench deposits associated with the magmatic arc are thought to be represented 140 km to the southeast by early Mesozoic pillow lava and chert, ultramafic bodies, and pervasively sheared slate and graywacke interbedded with greenstone and limestone on the southeast side of Cook Inlet, near Seldovia, and along the northwest side of Kodiak Island (Moore, 1973; Reed and Lanphere, 1973b). During the Bajocian and Bathonian Stages of the Middle Jurassic, graywacke, conglomerate, siltstone, and shale formed in thick units until nearly 3,000 m had accumulated. These rocks are richly fossiliferous and permit close correlation with other parts of the boreal realm. Clastic debris supplied to the basin was almost entirely of volcanic detritus; repeated periods of uplift can be defined by the cyclic nature of the sediments, massive conglomerate that grades to graywacke, then siltstone, and finally shale. Several breaks in deposition can be determined by unconformities or interruptions in faunal succession. A few thin ash layers attest to intermittent volcanic activity.

By late Middle Jurassic time, the Matanuska geosyncline was receiving fine-grained clastic sediments at a slow rate; over a period of several million years during the Callovian, about 800 m of siltstone and shale was deposited. During the Oxfordian Stage of Late Jurassic time, renewed uplift occurred and massive units of arkosic sandstone and granitic cobble-boulder conglomerates were laid down. This uplift may have been in part transmitted as high-angle reverse movement along the Bruin Bay fault.

The arc-trench gap basin continued to receive sediments throughout the Cretaceous. Differential uplift and erosion continued stripping Early Cretaceous sediments before the Late Cretaceous beds were deposited, an unconformity preserved about 20 km south of the quadrangle (Jones and Detterman, 1966). Renewed plutonic activity began in Late Cretaceous time and continued into the early part of the Tertiary (Reed and Lanphere, 1973a).

The Tertiary was a time of considerable magmatic activity in the Iliamna quadrangle that produced a thick pile of Tertiary volcanic rocks. Numerous small plutons, mainly quartz monzonite and granodiorite, represent magma that crystallized before reaching the surface. Other magmas were subaerially extruded, forming volcanic rock that provided sedimentary materials to local basins.

Northward underthrusting of the Kula plate and destruction of the Kula ridge (Grow and Atwater, 1970) with subsequent formation of the modern Aleutian arc-trench system, subparallel to, and south of, the old trench, was probably initiated in middle Tertiary time. Renewed andesitic to rhyolitic volcanic and plutonic activity in the Iliamna quadrangle about 25 to 30 m.y. ago may be related to this underthrusting.

The present landform is mainly the product of Pleistocene and Holocene glaciation with subsequent modification by fluvial action. The high rugged mountains along the coast are formed by the Alaska-Aleutian Range batholith; flanking lower Mesozoic volcanic, sedimentary, and metamorphic rock are highly resistant to erosion. Tertiary flows and pyroclastic rock are much less resistant; as a consequence, the topography of the western part of the quadrangle is greatly subdued. The easily eroded Tertiary volcanic rocks are the main constituents of the thick glacial deposits that mantle much of the quadrangle.

ECONOMIC GEOLOGY

Detailed structural and stratigraphic studies for petroleum have been completed on the Iniskin Peninsula (Detterman and Hartsock, 1966). During the course of field mapping in the rest of the quadrangle, stream-sediment samples and mineralized bedrock samples were taken as an aid to better determining the metallic mineral resources within the quadrangle. The 322 sediment samples collected are not sufficient to provide an adequate geochemical assessment of the entire quadrangle, but they do indicate that the most promising mineralized areas are associated with Tertiary intrusive and extrusive rocks. Results of this work are given in Detterman and Reed (1964, 1965), Reed and Detterman (1965, 1966), Reed (1967), and Detterman (1969). Some of the most promising areas were resampled and briefly described by Reed (1967). The location of known mineralized areas and oil seeps are shown on figure 6. This report summarizes the work completed to date; additional geochemical sampling and detailed mapping of individual mineral occurrences are necessary before the mineral potential of the quadrangle can be fully known.

PETROLEUM

Evidence of petroleum in the form of numerous seepages on Iniskin Peninsula first directed attention to the Iliamna area in 1853 (Martin, 1905), when Russian explorer Paveloff collected the first oil, but active exploration and drilling did not start until 1898. During this early phase of drilling, four wells were completed near Oil Bay and two near Dry Bay (Martin, 1905, p. 37–49; 1926, p. 51–55; Martin and Katz, 1912, p. 126–130; Moffit, 1927, p. 48–54). The wells were all shallow, less than 300 m, and were located near oil seeps without regard to geologic structure. Small amounts of oil and gas were reported in all wells, but no commercial quantities were found. All activity stopped in 1903, when the equipment broke down and the wells were abandoned.

The second stage of drilling started in 1936 on Iniskin Peninsula following publication by Moffit (1927, p. 48–54) of a description of the Fitz Creek anticline. Three wells were drilled, Iniskin Bay Association well 1 (T.D. 2,677 m), Beal well 1 (T.D. 2,972 m), and Antonio Zappa well 1 (T.D. 3,417 m). The location of the wells and their relation to structure is given in Detterman and Hartsock (1966, pl. 6). Zappa 1 was drilled on the west flank of Fitz Creek anticline in the best structural position of all the wells. As interpreted from the structure contour map, however, it was located about 2 km southwest of the structural high point of the anticline. All wells encountered a small amount of oil and gas, some of which was recovered for local use. Analysis of oil samples from IBA well 1 revealed an API gravity of 47.6, specific gravity of 0.790, pour point of −0°F, sulfur 0.11, and intermediate base. The gas was 75.1 percent methane, 7.1 percent ethane, 2.8 percent propane, and 13.5 percent nitrogen, with minor amounts of butane, pentane, hexane, and carbon dioxide.

Drilling activity on Iniskin Peninsula stopped with the completion of Zappa 1 in 1960. When last visited in 1972, the well was bleeding oil through the cement plug at the top of the well. This well is reported to have encountered a salt-water flow of 600 bbl/day from the unconformity between the Talkeetna and Red Glacier Formations. This suggests that a well located higher on the structure would probably produce oil or gas.

Current interest in petroleum in the Iliamna quadrangle is mainly confined to offshore targets in lower Cook Inlet, an area that has the added attraction of several thousand meters of nonmarine Tertiary clastic sedimentary rock overlying beds similar to those exposed on Iniskin Peninsula. Peripheral beds from this Tertiary basin are exposed onshore just north of Chinitna Bay (Detterman and Hartsock, 1966, p. 55–56), at Cape Douglas just beyond the southeast corner of the quadrangle (Magoon and others, 1976), and on the east side of Cook Inlet (Barnes and Cobb, 1959). The Tertiary sequence in upper Cook Inlet has produced about 608×10^6 bbl of petroleum and 815×10^9 ft^3 of gas as of April 21, 1975 (Magoon and others, 1975). These same beds underlie lower Cook Inlet, and the presence of anticlinal structures within the section was confirmed by 450 km of 36-fold marine seismic data obtained in 1975 (Fisher, 1976). The seismic profiles reveal northeastward-trending anticlines with average wavelengths of 8 to 12 km. Some anticlines are breached on the flank facing the deeper part of the basin by faults similar to the structures in upper Cook Inlet (Kirschner and Lyon, 1973). An eastward-trending arch termed the Augustine-Seldovia arch (Fisher, 1976) extends from Ursus Head across Cook Inlet to near Seldovia. This arch passes just north of Augustine Island and probably gives closure to some of the anticlinal structures that juncture at an angle with it. The potential for petroleum is considered to be very good in that part of the basin at approximately 59°30′ N. at the east edge of the Iliamna quadrangle and extending eastward from that point. A resource estimate for lower Cook Inlet basin prepared by the U.S. Geological Survey (Magoon and others, 1975) suggests that this 5,600 km^2 area could contain 0.3 to 1.4 billion barrels of oil and 0.6 to 2.7 trillion cubic meters of natural gas. About 10 percent of this area is within the Iliamna quadrangle.

The petroleum potential of offshore areas of Kamishak Bay should be explored, for several broad anticlines observed on the north shore of the bay can be expected to continue under the bay. The exposed rocks, the upper part of the Naknek Formation, are underlain by the richly fossiliferous beds of the Tuxedni Group and

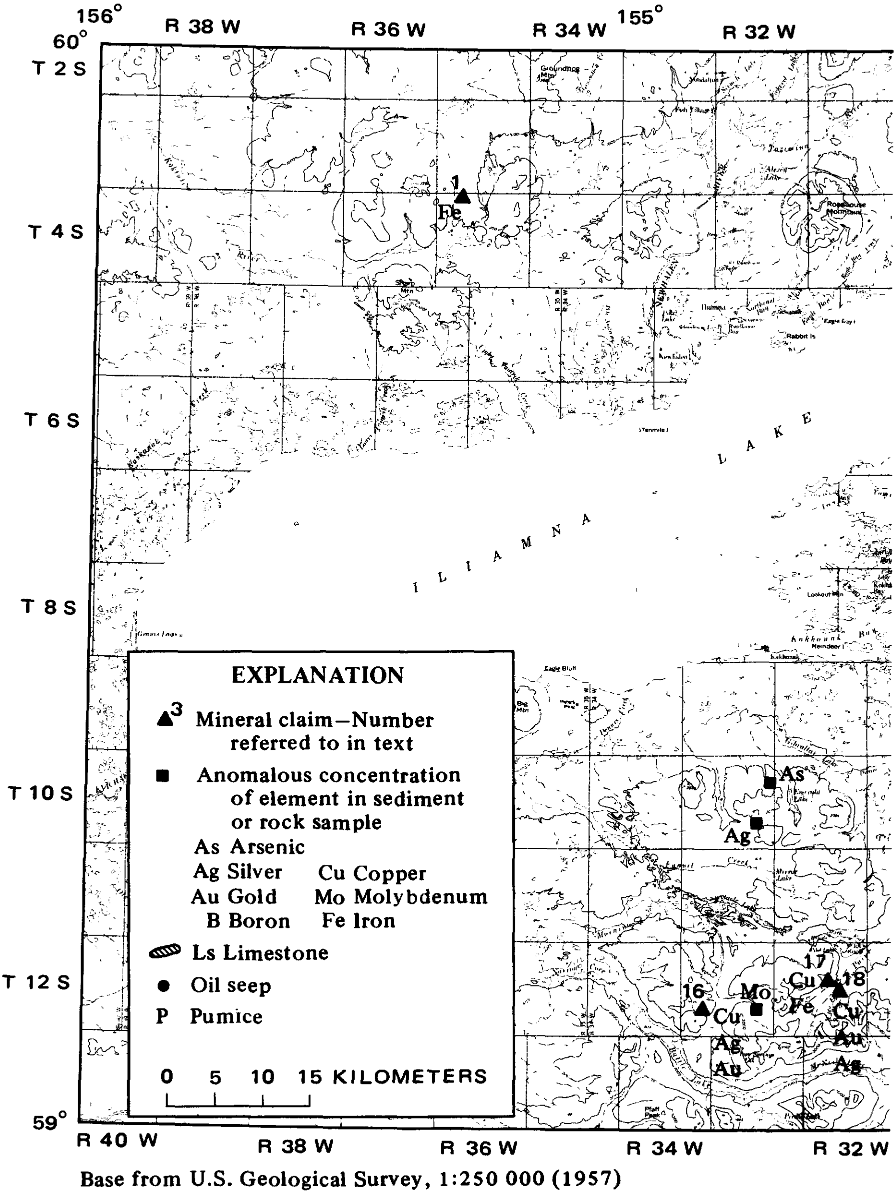
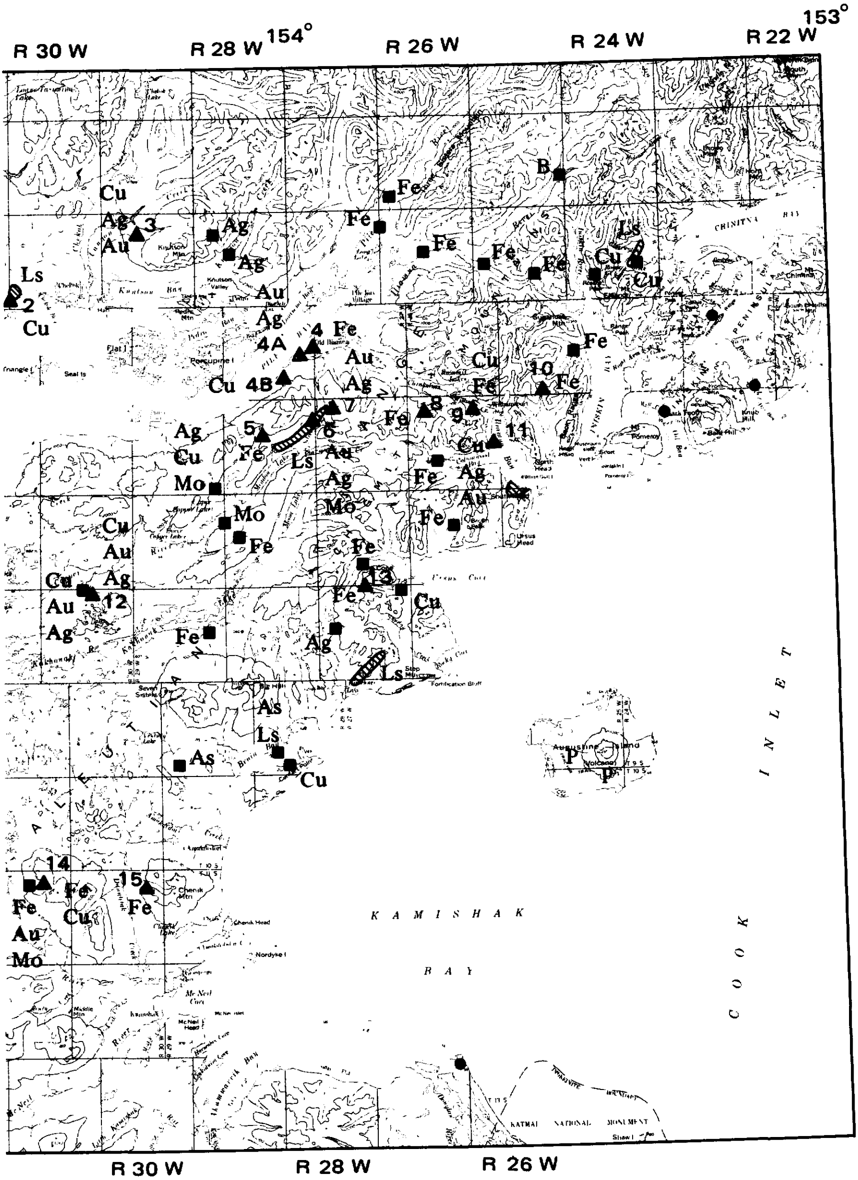


FIGURE 6.—Location of natural resources in the Iliamna quadrangle,

Chinitna Formation. Evidence of petroleum is present in an oil seepage near the anticlinal axis just west of the mouth of the Douglas River (fig. 6). Another oil seep reported by Mather (1923, p. 177) as 50 yards off the the southern entrance to Bruin Bay was not located.



Alaska. Base from U.S. Geological Survey, 1:250,000 (1957).

COPPER

Evidence of metallic mineralization, particularly copper staining, first attracted the attention of early prospectors to the Iliamna area in about 1901. In that year the area known as the Dutton prospect was staked 3.2 km northeast of Meadow Lake (see fig. 6, No. 6). Word of the copper discovery soon drew many more prospectors to the area, and in the next few years five prospects were staked between Iliamna Bay and Iliamna Lake. The presence of a native village with good trails across the mountains probably accounted for the concentration of effort in this area. Some of the claims were for gold and silver as well as copper.

At about this same time, in 1906, the Millet claims (fig. 6, No. 2) were staked for copper on the north shore of Iliamna Lake about 19 km east of Iliamna. That same year the most important copper discovery in this part of the Alaska Peninsula was made by Charles Brooks on Kasna Creek, 16 km north of the quadrangle near Kontrashibuna Lake on property now owned by the St. Eugene Mining Co. Diamond drilling between 1965 and 1970 has proved the presence of a large contact-metamorphic copper-iron deposit. Mining operations await suitable transportation and settlemennt of lànd status by Alaska Native Claims Settlement Act.

Claims for copper, silver, and gold were staked by C.H. McNeil in 1923 on Crevice Creek in the southern part of the area. A small amount of ore was reported to be shipped from this mine (Mather, 1923, p. 173), probably the only ore shipped from the quadrangle to this time. Assay values obtained from samples of several claims are given in Martin and Katz (1912, p. 116–126).

The geologic setting is the same for all claims staked for copper. All are contact metamorphic skarn deposits formed at the contact between Triassic limestone, greenstone, or Talkeetna Formation with intrusive rocks. Mineralization is developed along the contact with the instrusive rocks and within adjacent beds. The skarn mineralization consists mainly of chalcopyrite, magnetite, specular hematite, pyrite, amphibole, calcite, garnet, and quartz. The intrusive bodies associatied with mineralization are of Late Cretaceous or Tertiary age. No significant areas of sulfide mineralization are known to occur in association with the Jurassic plutonic rocks.

The original copper prospects are described in considerable detail in other reports and will not be elaborated on here. Claims described in Martin and Katz (1912, p. 117–124) include the Dutton claims, Durand claim, Millet claims, Knutson prospect, and the Copper King group (shown on fig. 6, Nos. 6, 4A, 2, 3, 9, respectively). Additional work on the Millet claims by diamond drilling and trenching was done by the U. S. Bureau of Mines in 1949 and 1950. Thirty-seven trenches, each 30–100 m long, were excavated across the mineralized zone, and six diamond drill cores, each 100–142 m in length, were obtained. The results of this investigation, including complete analysis of all samples, are described in Rutledge and Mulligan

(1952). Rocks along the west side of the mineralized Triassic limestone are volcanic rock of the Talkeetna Formation rather than diorite as indicated in the early geologic reports. Volcanic breccia along the south edge is part of the Tertiary volcanic sequence. Mineralized dikes that cut the limestone are probably offshoots from the Cretaceous or Tertiary granodiorite that lies along the east edge of the deposit. Most of the samples analyzed contained less than 1 percent copper. A few contained 3 to 4 percent with minor amounts of silver and gold. The mineralized zone is 6–12 m wide and has been traced on the surface for about 1,000 m.

A brief account of the McNeil claims (fig. 6, No. 18) is contained in Mather (1923, p. 173). His report gives little information on the geology of the deposit; a more complete discussion of the McNeil and adjoining Sargent claims (fig. 6, No. 17) is given in Richter and Herreid (1965). These claims include a series of small tactite skarn deposits formed by the intrusion of Cretaceous or Tertiary granodiorite into the Talkeetna and Kamishak Formations.

The largest of the epidote-garnet tactite bodies extends for about 760 m along the volcanic-sedimentary rock contact north of Crevice Creek. Chalcopyrite and pyrite are the most abundant sulfide minerals; some chalcocite and secondary malachite and azurite are present. Locally actinolite crystals occur in radiating clusters as mush as 0.6 m across. Assessment work is continuing on some of the Sargent claims.

Stream-sediment samples containing high values ($\geqslant$200 ppm) of copper were taken at a number of localities in the Copper River valley (fig. 6). Sediment samples from two streams that drain into the north and south sides of Copper Lake contain 10 to 20 ppm molybdenum in addition to copper. Additional geochemical exploration and prospecting should be done in this area, particularly where Tertiary intrusive and volcanic rocks are present.

Sulfide-rich quartz diorite rock samples from the area east of the lake at the head of Lake Fork, Paint River (fig. 6, No. 14), contained 6.5 percent copper (Reed, 1967). The areas near Battle Lake (Reed, 1967) and on Clearwater Creek (Detterman and Hartsock, 1966), near Chinitna Bay, are probably best described as interesting occurrences of copper mineralization.

GOLD AND SILVER

Gold and silver have historically attracted prospectors, and the Iliamna quadrangle received its share of attention as a result of the gold rush that started in 1898. One of the first areas to be staked, in about 1901 or 1902, was the Duryea claims on Silver Creek (fig. 6, No. 7) about 2 km east of the Dutton copper prospect in an argentiferous galena-sphalerite vein in brecciated limestone; minor amounts of chalcopyrite, pyrite, and limonite are present in the weathered rock. Manganiferous gossan containing minor silver occurs near the eastern end of the mineralized zone, which continues for a distance of about 2 km with an average width of approximately 23 m. Intermittent outcrops of limestone were seen to continue northeasterly but did not appear to be mineralized. Owners of the claims reported in 1909 that samples yielded 80 to 196 oz per ton (2,268 to 5,557 g) silver, gold valued at $20, 35 to 50 percent lead, and 15 to 20 percent zinc (Martin and Katz, 1912). The black manganiferous gossan contained 2 to 6 oz silver.

A lode claim at Diamond Point in Iliamna Bay (fig. 6, No. 11) was located in the early years of this century. At this locality, Jurassic quartz monzonite intrudes Triassic limestone and greenstone and Lower Jurassic volcanic sequence. Both the granitic and country rock are shattered and impregnated with veins and stringers of pyrite. The rocks are highly stained from oxidation of the pyrite, particularly north of the point, but no other mineralization was noted. These rocks were rumored to contain about $2 per ton gold (Martin and Katz, 1912).

Sediment, pan concentrate, and rock samples from a few areas in the quadrangle contained moderately high values of gold and silver. Analyses and discussion of these areas are given in Reed (1966). Sediment samples from a north-flowing stream that drains into Fog Pond contained 1.3 ppm gold and 1 ppm silver. A single pan concentrate contained 41 ppm gold and 5 ppm silver. Selected samples of bedrock containing pyrite stringers showed 38 ppm gold and minor silver. Although most of the pyrite stringers contained gold, they are generally quite narrow (less than 1 cm wide) and sparse. Bedrock along the stream consists of quartz porphyry that intrudes a sequence of Tertiary flows, tuffs, and conglomerate. Much of the quartz prophyry is altered to quartz sericite and pyrite, and the volcanics are propylitized. The rocks are locally stained with iron oxide; copper staining is not evident, although some bedrock samples contained as much as 5 percent copper.

Another area of interest is along a small stream draining westward into the lake at the head of Lake Fork, Paint River. Selected bedrock samples from locality 14 (fig. 6) contained 18 ppm gold, 0.5 percent copper, and minor amounts of silver (Reed, 1967). Mineralization is restricted to igneous breccia in quartz diorite intruding hornblende gabbro. The breccia zone is about 45 m wide and contains many sulfide-rich veins, some of which show malachite staining. The main ore minerals are pyrite, chalcopyrite, and malachite.

A gold-silver-copper-bearing quartz vein discovered by Ernest Plaff about 3.2 km north of Battle Lake (fig. 6, No. 16) locally contains visible gold. Systematic samples were not taken on the vein, but selected samples contain between (14.18 and 1,247 g) per ton gold, (227 to 5,783 g) per ton silver and several percent copper. Where observed, the vein varies in width from a few centimeters to 2 m. It has a discontinuous strike length of at least 300 m. Mineralization is exceedingly sporadic within the vein, and results of a diamond-drilling program undertaken in 1965 were not encouraging. Ore minerals consist of free gold, chalcopyrite, malachite, pyrite, and an unidentified silver-sulphosalt mineral(s). The quartz vein cuts locally propylitized interbedded volcanic breccia and dacitic flows of Tertiary age. This area of Tertiary volcanic and intrusive rocks warrants further prospecting and geochemical sampling for precious and base-metal deposits.

IRON

The most recent mineral exploration in the quadrangle has been for iron. During the course of an aeromagnetic survey of Cook Inlet by industry, strong magnetic anomalies were recorded on the mainland to the west. Subsequent aeromagnetic surveys within the quadrangle located several high magnetic anomalies. These were briefly examined in 1963, and in 1964 nearly 500 claims were filed. Investigations of the magnetic anomalies were made by the Geological Survey in 1964 and 1965.

The ore mineral in all of the known deposits of iron is magnetite. It occurs mainly as disseminated grains, small lenses, veinlets, and pods in gabbro and diorite and, to a lesser extent, in quartz diorite. Magnetite occurs in hornblendite as discrete grains within hornblende or as fine grains along hornblende boundaries and as a few lenses and clots, generally not more than 15–20 cm in maximum dimension. A maximum estimate of the amount of magnetite in the hornblendite bodies examined is between 15 and 20 percent; at most places, magnetite makes up less than 10 percent of the rock.

Magnetite, though not visible in hand specimens, is present locally as finely disseminated grains in hornfels or greenstone. North of Meadow Lake (fig 6, No. 5), samples of greenstone collected within a few tens of meters of a granodiorite contact are weakly magnetic; the average magnetite content is estimated to be about 5 percent. A small area of plutonic breccia, approximately 2 km^2, consisting of angular pyroxenite fragments enclosed within granodiorite, occurs 3 km west of Frying Pan Lake (fig. 6, No. 1). The pyroxenite contains between 16 and 24 percent iron (expressed as FeO) and is titaniferous. A description and analytical data for this occurrence are given in Reed and Detterman (1965).

Small bodies of magnetite-quartz and magnetic-rich tactite occur in the Paint River area (fig. 6, No. 14). Ten of these bodies have been mapped in an area of about 2.5 hectares (Richter and Herreid, 1965). The largest body is about 3 m wide and 23 m long. Somewhat larger bodies exist in this area, but their true extent is not known owing to a cover of overburden or snow when they were examined. Reconnaissance magnetometer surveys over this area suggest that the known magnetic bodies do not increase in size with depth, but magnetic anomalies not associated with surface exposures suggest that additional magnetite deposits are present (Richter and Herreid, 1965). Although these magnetite deposits are very rich, the tonnage indicated is small. Their proximity to the seacoast and the presence of associated, though sporadic, copper and gold mineralization warrant additional detailed geologic mapping, ground magnetometer, and geochemical investigations.

The disseminated iron deposits have been studied by private industry, but data sufficient for the appraisal of their iron-ore resource potential are not publicly available. There no doubt exists within the quadrangle several billion tons of mafic intrusive rock that contains an estimated average of perhaps 12 to 15 percent iron expressed as FeO. The deposits are titaniferous, however, and although the total recoverable iron content of these rocks is unknown, chemical analyses indicate that the total FeO content of these rocks is several times lower than that of ore bodies in currently operating mines.

LIMESTONE

The quadrangle contains a number of nonmetallic natural resources, in addition to petroleum, that could be of considerable value to the economic development of Alaska. Chief among these are limestone for cement and pumice for lightweight aggregate.

Limestone of a quality for cement is restricted to beds of Late Triassic age, but locally these beds are so silicified or altered by intrusive rock that impurities reduce their value. The limestone is locally dolomitized, but magnesium is not a major constituent in most areas.

The Bruin Limestone Member and Kamishak Formation, both of Late Triassic age, contain several beds of limestone suitable for the manufacture of cement (fig. 6). One large area of Bruin Limestone at Bruin Bay and several beds of the Kamishak Formation at Iliamna Bay were analyzed. The results are given in Detterman (1969) and Detterman and Reed (1973). The limestone of both areas is at sea level and therefore readily accessible.

Along the north side of Meadow Lake, about 150 to 200 m of Bruin Limestone is exposed in a belt about 9 km long (pl. 1). A small area of limestone in the upper part of Kamishak formation is exposed at

Millets Point on the north side of Iliamna Lake, and several beds of good limestone are present near Kirschner Lake (fig. 2).

PUMICE

Pumice as a source of lightweight aggregate occurs on Augustine Island. The major deposits, except for the most recent (1976) eruption, are shown in plate 1; analyses of selected samples are given in table 4.

Between 1946 and 1949, pumice was mined on Augustine Island by the Alaska Katmalite Corp. (Moxham, 1951). The main source at that time was a 3-m-thick bed on the south slope of the volcano at about 380 m elevation and about 8 km east of the dock area in the lagoon on the west side of the island. Numerous other beds of about the same thickness are present in this area, but much of the deposit consists of 50- to 75-mm lapilli fragments that would require additional crushing before use.

A major deterrent to any development of mining operations on the island is the continued threat of a major volcanic eruption similar to the one of 1976, which formed a growing avalanche that flowed about 6.5 km down the northeast flank of the volcano and into Cook Inlet. Several buildings were destroyed, and all exposed driftwood was charred.

MISCELLANEOUS MINERALS

A few other minerals should perhaps be mentioned here, more as interesting occurrences than as economic deposits. Agate and dumortierite of gem quality are found in the quadrangle, and large crystals of mineral-specimen quality actinolite occur in a number of localities.

Agate is present in cavities associated with Tertiary volcanic rubble flows at many localities. Gem-quality orange agate is found along the north shore of Nonvianuk Lake and on the island in Kukaklek Lake. White, gray, and blue agate is present in the Narrow Cove area, Intricate Bay, and many of the islands in Iliamna Lake. Many large unfractured pieces can be found at these localities.

Pale-blue to violet dumortierite is found as glacial erratics along the north shore of Iliamna Lake and on the Pile River. The source was not located but is most likely between the upper Iliamna and Pile River drainages. Stream-sediment samples in this area contained 50 to 150 ppm boron, probably reflecting the presence of this aluminum borosilicate mineral (fig. 6) (Reed and Detterman, 1965).

Large radiating crystals of actinolite as much as two-thirds m across are found in the Crevice Creek area (fig. 6, No. 17), and specimens nearly as large were seen near the mouth of the Iliamna River (fig. 6, No. 4). These large crystals are of mineral-specimen quality.

REFERENCES CITED

Barnes, D.F., 1976, Bouger gravity map of Alaska: U.S. Geological Survey Open-File Report 76–70, scale 1:2,500,000, 1 sheet.

Barnes, F. F., and Cobb, E. H., 1959, Geology and coal resources of the Homer district, Kenai coal field, Alaska: U.S. Geological Survey Bulletin 1058–F, p. F217–F260

Bateman, P.C., Clark, L.D., Huber, N. K., Moore, J. G. and Reinhart, C. D., 1963, The Sierra Nevada batholith—a synthesis of recent work across the central part: U.S. Geological Survey Professional Paper 414–D, p. 46

Burk, C. A., 1965, Geology of the Alaska Peninsula—Island arc and continental margin: Geological Society of America Memoir 99, 250 p., 1 geologic map, 1 tectonic map.

Coats, R. R., 1950 Volcanic activity in the Aleutian arc: U.S. Geological Survey Bulletin 974–B, p. B35–B49

Csejtey, Béla, Jr., Nelson, W. H., Eberlein, G. D., Lanphere, M. A., and Smith, J. G., 1977, New data concerning age of the Arkose Ridge Formation, south-central Alaska: U.S. Geological Survey Circular 751–B, p. B62–B64.

Curtis, G. H., 1968, The stratigraphy of the ejectamenta of the 1912 eruption of Mount Katmai and Novarupta, Alaska, *in* R. R. Coats, R. L. Hay, and C. A. Anderson, eds., Studies in volcanism: Geological Society of America Memoir 116, p. 153–211.

Davidson, George, 1884, Notes on the eruption of Mount St. Augustine, Alaska, October 6, 1883; Science, v. 3, no. 54, p. 186–189.

Detterman, R. L., 1963, Revised stratigraphic nomenclature and age of the Tuxedni Group in the Cook Inlet region, Alaska, *in* Geological Survey research 1963: U.S. Geological Survey Professional Paper 475–C, p. C30–C34.

———1968, Recent volcanic activity on Augustine Island, Alaska, *in* Geological Survey research 1968: U.S. Geological Survey Professional Paper 600–C, p. C126–C129.

———1969, Analysis of selected limestone samples from Iliamna and Bruin Bays, Iliamna quadrangle, Alaska: U.S. Geological Survey Open-File Report, 6 p.

———1973, Geologic map of the Iliamna B–2 quadrangle, Augustine Island, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-1068, with text, scale 1:63,360.

Detterman, R. L., and Hartsock, J.K., 1966, Geology of the Iniskin-Tuxedni region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p.

Detterman, R. L., Hudson, Travis, Plafker, George, Tysdal, R. G., and Hoare, J. M., 1976, Reconnaissance geologic map along the Bruin Bay and Lake Clark faults in the Kenai and Tyonek quadrangles, Alaska: U. S. Geological Survey Open-File Report 76-477.

Detterman, R. L., and Jones, D. L., 1974, Mesozoic fossils from Augustine Island, Cook Inlet, Alaska: American Association of Petroleum Geologists Bulletin, v. 58, no. 4, p. 868-870.

Detterman, R. L., and Reed, B., L., 1964, Preliminary map of the geology of the Iliamna quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–407, scale 1:250,000.

———1965, Geochemical reconnaissance of stream sediments in the Iliamna quadrangle, Alaska: U. S. Geological Survey Open-File Report, scale 1:500,000.

———1968, Geologic map of the Iliamna quadrangle, Alaska: U.S. Geological Survey Open-File Map, scale 1:200,000.

———1973, Surficial deposits of the Iliamna quadrangle, Alaska: U.S. Geological Survey Bulletin 1368–A, p. A1–A64.

Detterman, R. L, Reed, B. L., and Lanphere, M. A., 1965, Jurassic plutonism in the Cook Inlet region, Alaska, *in* Geological Survey research 1965: U.S. Geological Survey Professional Paper 525–D, p. D16–D21.

Detterman, R. L., Reed, B. L., and Rubin, Meyer, 1965, Radiocarbon dates from Iliamna Lake, Alaska, *in* Geological Survey research 1965: U.S. Geological Survey Professional Paper 525-D, p. D34–D36.

Dickinson, W. R.,1974, Sedimentation within and beside ancient and modern magmatic arcs, *in* Dott, R. H., Jr., and Shaver, R.H. eds., Modern and ancient geosynclinal sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 19, p. 230–239.

———1975, Sedimentary basin development during evolution of Mesozoic-Cenozoic arc-trench system in western North America, *in* Minato, Masao, ed., Pacific Geology: Tokyo, Japan.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, *in* Classification of carbonate rocks—A symposium: American Association of Petroleum Geologists Memoir 1, p. 108–121.

Fenner, C. N., 1923, The origin and mode of emplacement of the great tuff deposit of the Valley of Ten Thousand Smokes: National Geographic Society Contributed Technical Papers, Katmai Series, no. 1, 74 p.

Fisher, M.A., 1976, Preliminary interpretation of seismic data from lower Cook Inlet, Alaska: U..S. Geological Survey Open-File Report.

Folk, L., 1959, Practical petrographic classification of limestones: American Association of Petroleum Geologists Bulletin, v. 43, no. 1, p. 1–38.

Grantz, Arthur, 1960a, Geologic map of Talkeetna Mountains (A–2) quadrangle, Alaska, and the contiguous area to north and northwest: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–313, scale 1:48,000.

———1960b, Geologic map of Talkeetna Mountains (A–1) quadrangle, and south third of Talkeetna Mountains (B–1) quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–314, scale 1:48,000 .

———1966, Strike-slip faults in Alaska: U.S. Geological Survey Open-File Report 267.

Grantz, Arthur, and Kirschner, C. E., 1976, Tectonic framework of petroliferous rocks in Alaska, *in* Halbauty, M. T., Maher, J. C., and Lian, H. M., eds., Circum-Pacific energy and mineral resources: American Association of Petroleum Geologists Memoir 25, p. 291–307.

Grantz, Arthur, Zietz, Isidore, and Andreasen, G. E., 1963, An aeromagnetic reconnaissance of the Cook Inlet area, Alaska: U.S. Geological Survey Professional Paper 316–G, p. G117–G134.

Grow, J. A., and Atwater, Tanya, 1970, Mid-Tertiary tectonic transition in the Aleutian arc: Geological Society of America Bulletin, v. 81, p. 3715–3722.

Hanson, B. M., 1957, Middle Permian limestone on Pacific side of Alaska Peninsula: American Association of Petroleum Geologists Bulletin, v. 41, p. 2376–2378.

Hartsock, J. K., 1954, Geologic map and structure sections of the Iniskin Peninsula and adjacent areas of Alaska: U.S. Geological Survey Open-File Report.

Henderson, J. R., and Vargo, J. L., 1963, Aeromagnetic map of part of the Dillingham quadrangle, Alaska: U.S. Geological Survey Geophysical Investigations Map GP–352, scale 1:125,000.

Hoare, J. M., Condon, W. H., and Patton, W. W., Jr., 1964, Occurrence and origin of laumontite in Cretaceous sedimentary rocks in western Alaska, *in* Geological Survey research: U.S. Geological Survey Professional Paper 501–C, p. C74–C78.

Hoare, J. M., Coonrad, W. L., Detterman, R. L, and Jones, D. L., 1975, Preliminary geologic map of the Goodnews A-3 quadrangle and parts of the A-2 and B-2 quadrangles, Alaska: U.S. Geological Survey Open-File Report, 75–308, 14 p., 1 map.

Imlay, R. W., 1953, Alaska Peninsula and Cook Inlet regions, Pt. 2 of Callovian (Jurassic) ammonites from United States and Alaska: U.S. Geological Survey Professional Paper 249–B, p. B41–B108.

———1959, Succession and speciation of the pelecypod *Aucella:* U.S. Geological Survey Professional Paper 314–G, p. G155–G169.

———1961, New genera and subgenera of Jurassic (Bajocian) ammonites from Alaska: Journal of Paleontology, v. 35, no. 3, p. 467–474.

———1962a, Late Bajocian ammonites from the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 418–A, p. A1–A15.

———1962b, Jurassic (Bathonian and early Callovian) ammonites from Alaska and Montana: U.S. Geological Survey Professional Paper 374–C, p. C1–C32.

———1964, Middle Bajocian ammonites from the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 418–B, p. B1–B61.

———1975, Stratigraphic distribution and zonation of Jurassic (Callovian) ammonites in southern Alaska: U.S. Geological Survey Professional Paper 836, 28 p.

Imlay, R. W., and Detterman, R. L., 1973, Jurassic paleobiogeography of Alaska: U.S. Geological Survey Professional Paper 801, 34 p.

Jones, D. L., 1963, Upper Cretaceous (Campanian and Maestrichtian) ammonites from southern Alaska: U.S. Geological Survey Professional Paper 432, 53 p.

Jones, D. L., and Detterman, R. L., 1966, Cretaceous stratigraphy of Kamishak Hills, Alaska Peninsula: U.S. Geological Survey Professional Paper 550–D, p. D53–D58.

Jones, D. L., Silberling, N. J., and Hillhouse, John, 1979, Wrangellia—A displaced continental block in northwestern North America: Geological Society of America Bulletin (in press).

Juhle, R. W., 1955, Iliamna Volcano and its basement: US. Geological Survey open-file report, 74 p., 38 pls.

Karig, D. E., 1972, Remanent arcs: Geological Society of America Bulletin, v. 83, p. 1057–1068.

Keller, A. S., and Reiser, H. N., 1959, Geology of the Mount Katmai area, Alaska: U.S. Geological Survey Bulletin 1058–G, p. G261–G298.

Kellum, L. B., 1945, Jurassic stratigraphy of Alaska and petroleum exploration in northwestern America: New York Academy of Sciences Transactions, ser. 2, v. 7, no. 8, p. 201–209.

Kellum, L. B., Daviess, S. N., and Swinney, C. M., 1945, Geology and oil possibilities of the southwestern part of the Wide Bay anticline, Alaska: U.S. Geological Survey open-file report, 17 p.

Kirschner, C. E., and Lyon, C. A., 1973, Stratigraphic and tectonic development of Cook Inlet Petroleum Province, *in* Pitcher, M. G., ed., Arctic Geology: Proceedings of the Second International Symposium on Arctic Geology: American Association of Petroleum Geologists Memoir 19, p. 396–407.

Kirschner, C. E., and Minard, D. L., 1949, Geology of the Iniskin Peninsula: U.S. Geological Survey Oil and Gas Investigations Map OM–95, scale 1:48,000.

MacKevett, E. M., Jr., 1970a, Geology of the McCarthy B–4 quadrangle, Alaska: U.S. Geological Survey Bulletin 1333, p. 31.

———1970b, Geologic map of the McCarthy C–4 quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ–844, with text.

Madonna, J.A., 1973, Zeolite occurrences in Alaska: University of Alaska, College, M.S. thesis.

Magoon, L.B., Adkison, W. L., and Egbart, R. M., 1976, Map showing geology, wildcat wells, Tertiary plant localities, K-Ar dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–1019, scale 1:250,000.

Magoon, L. B., Hampton, M. A., Sable, E. G., Smith, R. A., and Chemlik, F. B., 1975, Hydrocarbon potential, geologic hazards, and the technology, timeframe, and infrastructure for exploration and development of the lower Cook Inlet, Alaska—a preliminary assessment: U.S. Geological Survey open-file report 75–549, 74 p.

Martin, G. C., 1905, The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: U.S. Geological Survey Bulletin 250, 64 p.

———1926, The Mesozoic stratigraphy of Alaska: U.S. Geological Survey Bulletin 776, 493 p.

Martin, G. C., and Katz, F. J., 1909, Outline of the geology and mineral resources of the Iliamna and Clark Lakes region: U.S. Geological Survey Bulletin 442, p. 179–200.

———1912, A geologic reconnaissance of the Iliamna region, Alaska: U.S. Geological Survey Bulletin 485, 138 p.

Mather, K. F., 1923, Mineral resources of the Kamishak Bay region (Alaska): U.S. Geological Survey Bulletin 773, p. 159–182.

Moffit, F. H., 1922, The Iniskin Bay district (Alaska): U.S. Geological Survey Bulletin 739–C, p. C117–C132.

———1927, The Iniskin-Chinitna Peninsula and Snug Harbor district, Alaska: U.S. Geological Survey Bulletin 789, 71 p.

Moore, J. C., 1973, Cretaceous continental sedimentation, southwestern Alaska: Geological Society of American Bulletin, v. 84, p. 595–614.

Moore, J. G., 1959, The quartz diorite boundary line in the western United States: Journal of Geology, v. 67, p. 198–210.

Moxham, R. M., 1951, Pumice deposits in the Alaska Peninsula-Cook Inlet region, Alaska: U.S. Geological Survey open-file report, 25 p.

Moxham, R. M., and Nelson, A. E., 1952, Reconnaissance for radioactive deposits in the Iliamna Lake-Lake Clark region, southwestern Alaska: U.S. Geological Survey TEI–190, issued by U.S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tenn.

Muller, E. H., and Coulter, H. W., 1953, Reconnaissance of the Iliamna Tote Road from Cook Inlet to Iliamna Lake, Alaska: U.S. Department of the Army, Office of Chief Engineers, Engineer Intelligence Study 118, 14 p., 1 pl.

Payne, T. G., 1955, Mesozoic and Cenozoic tectonic elements of Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–84, scale 1:5,000,000.

Plafker, George, 1965, Tectonic deformation associated with the 1964 Alaska earthquake: Science, v. 148, no. 3678, p. 1675–1687.

———1969, Tectonics of the March 27, 1964, Alaska earthquake: U.S. Geological Survey Professional Paper 543–I, p. I1–I74.

Plafker, George, Detterman, R. L, and Hudson, Travis, 1975, New data on displacement history of the Lake Clark fault, *in* Yount, M. E., ed., United States Geological Survey Alaska program 1975: U.S. Geological Survey Circular 722, p. 44–45.

Reed, B. L., 1967, Results of stream sediment sampling and bedrock analysis in the eastern part of the Iliamna quadrangle, and at Kasna Creek, Lake Clark quadrangle, Alaska: U.S. Geological Survey open-file report, 10 p.

Reed, B. L., and Detterman, R. L., 1965, A preliminary report on some magnetite-bearing rocks near Frying Pan Lake, Iliamna D–7 quadrangle, Alaska: U.S. Geological Survey open-file report, 3 p.

———1966, Results of stream sediment sampling in the Iliamna quadrangle, Alaska: U.S. Geological Survey open-file report, 1 p.

Reed, B. L., and Lanphere, M. A., 1969, Age and chemistry of Mesozoic and Tertiary plutonic rocks in south-central Alaska: Geological Society of America Bulletin, v. 80, p. 23–44.

———1972, The Alaska-Aleutian Range batholith showing potassium-argon ages of the plutonic rocks: U.S. Geological Survey Miscellaneous Field Studies Map MF–372, 2 sheets, scale 1:1,000,000.

———1973a, Alaska-Aleutian Range batholith geochronology, chemistry, and relation to circum-Pacific plutonism; Geological Society of America Bulletin, v. 84, p. 2583–2610.

———1973b, Plutonic rocks of the Alaska-Aleutian Range batholith, *in* Pitcher, M. G., ed., Arctic Geology, Proceedings of the Second International Symposium on Arctic

Geology: American Association of Petroleum Geologists Memoir 19, p. 421–428.

———1974, Chemical variations across the Alaska-Aleutian Range batholith: U.S. Geological Survey Journal of Research, v. 2, no. 3, p. 343–352.

Richter, D. H., and Herreid, Gordon, 1965, Geology of the Paint River area, Iliamna quadrangle, Alaska: Alaska Division of Mines and Minerals Geologic Report 8, 17 p.

Richter, D. H., and Jones, D. L., 1973, Structure and stratigraphy of eastern Alaska Range, *in* Pitcher, M. G., ed., Arctic Geology, Proceedings of the Second International Symposium on Arctic Geology: American Association of Petroleum Geologists Memoir 19, p. 408–420.

Rutledge, F. A., and Mulligan, J. J., 1952, Investigations of the Millett copper deposit, Iliamna Lake, southwestern Alaska: U.S. Bureau of Mines Report of Investigations 4890, 22p.

Smith, W. R., 1925, Geology and oil development of the Cold Bay district: U.S. Geological Survey Bulletin 783, p. 63–88.

Spurr, J. E., 1900, A reconnaissance in southwestern Alaska in 1898: U.S. Geological Survey 20th Annual Report, pt. 7, p. 31–264.

Stanton, T. W., and Martin, G. C., 1905, Mesozoic section on Cook Inlet and Alaska Peninsula: Geological Society of America Bulletin, v. 16, p. 391–410.

Turner, D. L., Forbes, R. B., and Naeser, C. W., 1973, Radiometric ages of Kodiak Seamount and Giacamini Guyot, Gulf of Alaska: Implications for circum-Pacific tectonics: Science, v. 182, no. 4112, p. 579–581.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1958, Petrography, an introduction to the study of rocks in thin section: San Francisco, W. H. Freeman, 406 p.

Wolfe, J. A., 1966a, Tertiary stratigraphy and paleobotany of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 398–A, p. A1–A29.

———1966b, Tertiary plants from the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 398–B, p. B1–B32.

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