

# Geology of the Iniskin-Tuxedni Region, Alaska

By ROBERT L. DETTERMAN and JOHN K. HARTSOCK

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*A study of the highly fossiliferous Jurassic rocks  
on the west side of Cook Inlet and an account of  
the petroleum exploration on Iniskin Peninsula*



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# GEOLOGY OF THE INISKIN-TUXEDNI REGION, ALASKA

By ROBERT L. DETTERMAN and JOHN K. HARTSOCK

## ABSTRACT

The Iniskin-Tuxedni region, on the west side of Cook Inlet, Alaska, is an area of about 710 square miles between Iniskin Bay and Tuxedni Bay. Systematic geologic work was begun along the coast in 1903, 1904, and 1909 by the U.S. Geological Survey. Additional work was done in 1920 and 1921. More intensive exploration was started in 1944 and continued in 1946, 1948-51, and 1957-58 as part of the Geological Survey program of investigations of the natural resources of Alaska.

Iliamna Volcano (10,016 ft) dominates this mountainous region; the average relief is about 2,500-3,500 feet. Ten glaciers radiate from Iliamna Volcano and cover about 15 percent of the area. Tuxedni Glacier, the largest, is 16 miles long and extends to the tidal flats at Tuxedni Bay. The region has a cool maritime climate with abundant rainfall in summer and snow in winter. Dense brush and grass cover the lowlands and mountains to about 2,000 feet; spruce and cottonwood grow to about 800 feet.

The oldest rocks exposed are metalimestone, metachert, quartzite, argillite, and metabasalt of Late(?) Triassic age. These rocks are in discontinuous bands in the Chigmit Mountains, a segment of the Aleutian Range, along the western side of the region.

The Iniskin-Tuxedni region has what may be one of the thickest and most nearly complete sequences of bedded Jurassic rocks in the United States. As much as 26,600 feet of Lower, Middle, and Upper Jurassic rocks are exposed. These rocks are divided into nine formations, three of which are subdivided into eight members.

The Talkeetna Formation of Early Jurassic age is 5,900-9,000 feet thick and consists mostly of volcanic breccia, agglomerate, lava flows, and tuff containing interbeds of siltstone, sandstone, and argillite. In this region the formation can be divided into three members: Marsh Creek Breccia, Portage Creek Agglomerate, and Horn Mountain Tuff Members.

The Tuxedni Group of Middle and Late Jurassic age is 4,970-9,715 feet thick and unconformably overlies the Talkeetna Formation. The marine sedimentary rocks of the Tuxedni Group were deposited in an epicugeosynclinal environment; they consist of thick units of graywacke-type sandstone, conglomerate, siltstone, and shale derived from sediments of a nearby landmass to the northwest. Fluctuations in the amount and types of sediment supplied to the eugeosyncline caused the deposition of alternating thick units of predominantly coarse and predominantly fine clastic rocks mapped as the following formations of the Tuxedni Group: Red Glacier Formation, Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, Twist Creek Siltstone, and Bowser Formation.

Marine invertebrate fossils, particularly ammonites and pelecypods, are abundant throughout most of the Tuxedni Group. Correlation of the ammonites with similar genera from northwest Europe indicates that most of the European standard zones of the Bajocian (early Middle Jurassic) as well as the upper Bathonian (late Middle Jurassic) are present in this

region. Breaks in the faunal record are marked by corresponding local unconformities in the stratigraphic sequence.

The Chinitna Formation of Late Jurassic (Callovian) age has a maximum thickness of 2,680 feet in this region. The formation is predominantly a massive arenaceous siltstone, but it can be divided into two members separated by an interval of sandstone. The Tonnie Siltstone Member, at the base, is mainly a red-brown-weathering siltstone containing small limestone concretions; it is overlain by the Paveloff Siltstone Member, which weathers gray and has large ellipsoidal limestone concretions. Ammonites and pelecypods found in the formation indicate a correlation with middle Callovian faunal zones of northwest Europe.

The Naknek Formation of Late Jurassic (Oxfordian and Kimmeridgian) age is as much as 5,200 feet thick and is divided into four members: Chisik Conglomerate, lower sandstone, Snug Harbor Siltstone, and Pomeroy Arkose Members. A local unconformity is present at the base of the formation.

The Kenai Formation of Oligocene(?) and Miocene age overlies the Upper Jurassic sequence with an angular unconformity. About 1,050 feet of nonmarine conglomerate, sandstone, and siltstone is present at one locality near Red Glacier.

A quartz diorite to quartz monzonite batholith intruded the core of the Aleutian Range during late Early Jurassic to early Middle Jurassic time. By Late Jurassic time, the batholith was exposed to erosion; it became an important source of sediments for the Naknek Formation. Tertiary lava flows are found at a few localities, and Iliamna Volcano is Quaternary.

Quaternary surficial deposits, which are separated from the underlying rocks by an angular unconformity, cover about 15 percent of the region. Glacial moraines of the Naptowne Glaciation and Tustumena and Tunnel Stades of the Alaskan Glaciation of Wisconsin to post-Wisconsin age are present north of Chinitna Bay. Landslides are a common feature in this mountainous region; one slide forms the dam for Hickerson Lake.

The main structural feature of the region is the Bruin Bay fault, which is a continuation of the major fault on the Alaska Peninsula. Offsetting of beds across the fault indicates a possible left-lateral movement of as much as 12 miles. The main movement along the fault dates from middle to late Tertiary. Most of the folding and associated faulting is contemporaneous with the movement along the Bruin Bay fault, but some may be associated with eruptions from Iliamna Volcano.

Seepages of oil and gas were first discovered on Iniskin Peninsula in 1853. Six wells were drilled at Oil Bay and Dry Bay during the years 1898-1906. Small quantities of oil and gas were produced, but not enough for commercial development. Recent exploration for oil started in 1936 with the drilling of Iniskin Bay Association well 1 on Fitz Creek anticline. Beal well 1 was drilled in 1954-56 and Antonio Zappa well 1 in 1958-59. All three wells tapped minor quantities of oil and gas near zones of faulting or fracturing.

The Fitz Creek structure is a faulted asymmetrical anticline that bifurcates northeast of the structural high. Closure is on the Fitz Creek fault and may be as much as 1,000 feet. The structural high is between two cross faults. Oil and gas are known to be present but the generally impervious nature of the rocks diminishes the value of the structure as an oil trap. Any possible major production will have to come from zones of faulting and fracturing or from the unconformity between the Lower and Middle Jurassic rocks.

The only evidence of mineralization in the region is a small magnetite deposit at Tuxedni Bay and small veins of copper and magnetite on Iniskin Bay and Marsh Creek.

## INTRODUCTION

### LOCATION AND AREA

The Iniskin-Tuxedni region is on the west side of Cook Inlet about 125 miles southwest of Anchorage, Alaska, and 50 miles northwest across Cook Inlet from Homer, Alaska (fig. 1). The region is about 710 square miles in area and extends from Iniskin Bay on the south to Tuxedni Bay on the north, a distance of about 47 miles. The area included in this report is 8–23 miles wide; it extends inland from the shoreline of Cook Inlet to the Chigmit Mountains and includes the offshore islands. Chinitna Bay bisects

the region, and the area between Chinitna and Iniskin Bays is referred to as the Iniskin Peninsula.

### EARLY GEOLOGIC INVESTIGATIONS

The first publication on the geology of the region apparently was that by Eichwald (1871, p. 91), a German scientist attached to a Russian exploration party. He mentioned sandstone and shale containing ammonites at Chisik Island and Fossil Point across Tuxedni Channel from Chisik Island. Rather brief descriptions of the rocks and fossils in Tuxedni Bay by Dall (1896, p. 869–870) and Hyatt (1896, p. 907–908) are reported as part of a mineral-resources investigation of Alaska by the U.S. Geological Survey.

In 1903 Martin (1905, p. 37–49) visited Oil Bay, where several oil wells were being drilled. This visit yielded the first report on the oil possibilities of the region based on field investigations by the Geological Survey. The next year Stanton and Martin (1905, p. 393–395, 401–402) visited Chinitna, Iniskin, and Oil Bays, where they studied and measured in detail numerous sections of Jurassic rocks. The report of the 1909 survey by Martin and Katz (1912, p. 59–64, 77–78) in the Iliamna region included a discussion

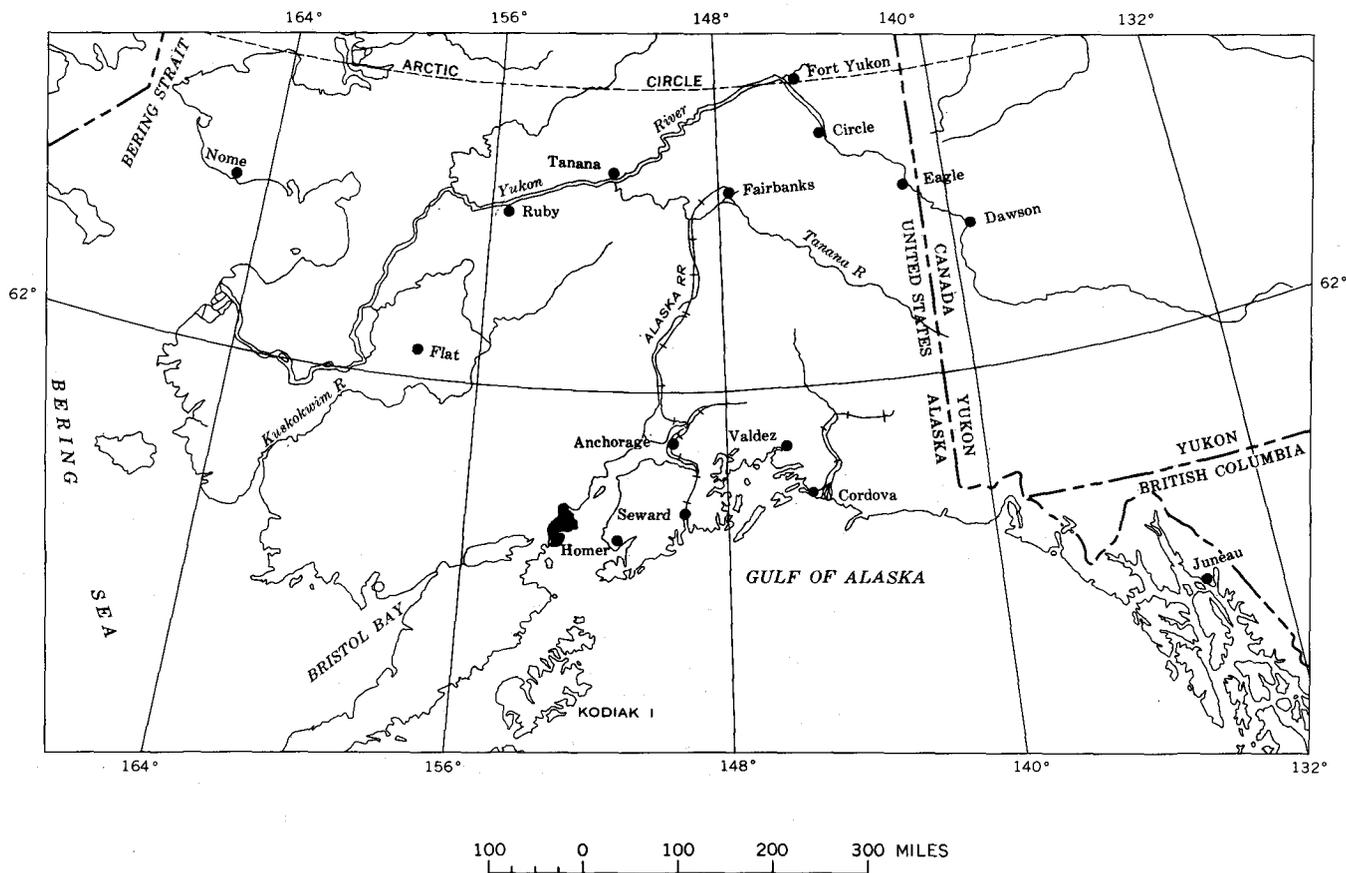


FIGURE 1.—Iniskin-Tuxedni region.

of the sections measured by Stanton and Martin in 1904. Members of the Geological Survey did not revisit the area until 1920, when Moffit, Herbert Insley, and C. P. McKinley (Moffit, 1922a) made a topographic and geologic reconnaissance in the vicinity of Snug Harbor. This work was continued by Moffit and A. A. Baker (Moffit, 1927, p. 71) in 1921, when the Iniskin Peninsula was mapped.

The 1921 expedition of Moffit and Baker ended the early investigations of the Iniskin-Tuxedni region by the Geological Survey. Private oil companies may have worked in the area at the same time, but the scope and extent of their work are not known.

#### RECENT INVESTIGATIONS

The Iniskin Peninsula was studied in detail by oil company geologists in the period 1934-39, prior to and during the drilling of the Iniskin Bay Association well 1 by the Iniskin Drilling Co. The results of this study have not been published but were made available for review.

In 1944, as part of the war-minerals investigations of the Geological Survey, Lewis B. Kellum and Hel-muth Wedow assisted by Warren Gilman and Spencer Schoonover mapped about 20 square miles along Fitz Creek and the south shore of Chinitna Bay. Some of the results of this investigation were published by Kellum (1945), and some of the material was included in a report on the Iniskin Peninsula by Kirschner and Minard (1949). Kirschner and Minard were assisted in the 1946 survey of the Iniskin Peninsula by D. R. Clark. Most of their work was in the southern part of the Iniskin Peninsula, near Iniskin and Oil Bays.

The investigations of the Iniskin-Tuxedni region that resulted in the present report were started in 1948 by Don J. Miller, Ralph W. Imlay, and John K. Hartsock. Miller and Imlay spent part of the summer at other Jurassic localities on Cook Inlet and the Alaska Peninsula. Hartsock was assisted by J. S. T. Kirkland and D. B. Snodgrass. Arthur Grantz joined Hartsock in 1949 and continued with the project until it was recessed in 1951. They were assisted by R. Werner Juhle, Richard Hoare, William Cunningham, Anthony Fetler, and David Hill. In addition to the present report the investigation has produced reports by Hartsock (1954), Juhle (1955), and Grantz (1956).

Juhle obtained most of the data on the Talkeetna Formation and the intrusive rocks, and Hartsock and Grantz did most of the fieldwork on the sedimentary rocks. Detterman compiled this paper, revised the stratigraphic units, and field-checked the geologic map (pl. 1) in 1957 and 1958.

Several oil companies conducted investigations in the region during the period 1953-58. Most of their

work was confined to the Iniskin Peninsula, where several oil wells had been drilled and oil seeps were known to occur.

#### METHODS OF WORK

The methods of geologic investigation used in the Iniskin-Tuxedni region varied with accessibility of the area, with base maps available, and with the amount of detailed knowledge desired in areas of special interest.

Lack of adequate base maps and vertical aerial photographs complicated the geologic mapping north of Chinitna Bay prior to 1951. In that year the U.S. Geological Survey compiled several quadrangles from trimetrogon aerial photographs. A complete coverage of vertical aerial photographs was not available until 1957, and 1:63,360 quadrangle maps were not available until 1960.

The surface exposures of rocks on Fitz Creek anticline were mapped by planetable methods, as were the rocks on Chisik Island and in the vicinity of Hickerson Lake. Observations in other parts of the region were plotted on aerial photographs at a scale of 1:40,000 and then transferred to base maps.

Travel and transportation of supplies were by skiff and outboard motor along the coast and on foot with packboards in the interior. None of the streams are deep enough to permit the use of an outboard motor. In 1957 and 1958 a truck was available for use on the road from Camp Point to the drilling camp on Fitz Creek, a distance of about 9 miles.

#### ACKNOWLEDGMENTS

The authors are deeply indebted to the late Don J. Miller and to Arthur Grantz, of the Geological Survey, who spent several field seasons in the Iniskin-Tuxedni region, and to the late R. Werner Juhle, who did most of the work on the igneous rocks. Their valuable help and information on many phases of the geology has made the completion of this report possible.

Special thanks are due the Havenstrite Oil Co. and the Alaska Oil and Mineral Co. for courtesies during the investigations and for the valuable information from the oil wells that helped solve many of the geologic problems.

We are grateful to Ralph W. Imlay, of the Geological Survey, for identifying invertebrate fossils collected during the investigation and to Roland W. Brown, also of the Survey, for identifying the plant fossils.

We also express our appreciation to the summer fishermen in Chinitna and Tuxedni Bays for the help and information they gave us about operating a small skiff on the rough waters of Cook Inlet.

We are indebted to many people in Homer and Seldovia who furnished valuable information, helped

in procuring of supplies and equipment, and arranged transportation of equipment and personnel to the west side of Cook Inlet.

The authors express their appreciation to John B. Havenstrite for use of a cabin at the mouth of Fitz Creek from 1948 to 1951 and especially for use of facilities at the drilling camp in 1957 and 1958. A truck was made available to the Geological Survey to transport supplies between the camp and the beach. Special thanks are due also to Eric and Joseph Freibrock, of the Snug Harbor Cannery on Chisik Island, for making the facilities of the cannery available to the Geological Survey from 1948 to 1952.

Gary Brown, a 30-year resident of Chinitna Bay, provided names for many streams previously undesignated on the maps and contributed much of the historical background. Thanks are due Wilbur Morris and Mr. Welsh, of the Red Glacier sawmill, for their hospitality, and for information about the recent activity of Iliamna Volcano.

#### GEOGRAPHY

The Iniskin-Tuxedni region, on the west side of Cook Inlet, is dominated by Iliamna Volcano (alt 10,016 ft.) In 1958 the volcano was sending up four columns of vapor from vents in the precipitous eastern face. The last eruption was in 1867 (Coats, 1950, table 2); since then smoke, and possibly light ash, was ejected in 1876, 1933, 1941, and again in 1947. A reported ejection of smoke and some light ash in the late winter of 1956 or early spring of 1957 has not been confirmed. Gravel cemented by reddish volcanic ash is exposed in the stream banks of Red Glacier River; this ash probably dates from one of the recent eruptions.

The region is mountainous, and land adjacent to the tidal flats is rugged and steep. Mountains within a mile of the coast are 2,000–3,800 feet in altitude. West of the coastal mountains is a valley  $\frac{1}{2}$ –1 mile wide extending northeastward from Iniskin Bay to Chinitna Bay. This valley reflects the structure of the underlying bedrock and continues, with minor interruptions, in a northeasterly direction to Tuxedni Bay. West of this valley the mountains become higher and more rugged as they coalesce with the Chigmit Mountains, a part of the Aleutian Range.

The stream valleys and shorelines have a very dense brush and grass cover that extends up the mountain sides to about 2,000 feet; above this, rock exposures are excellent, having only a thin cover of moss and lichens. Spruce groves and cottonwood trees are common in the valleys and along the shore.

#### RELIEF AND DRAINAGE

##### INISKIN PENINSULA

Chinitna Bay divides the Iniskin-Tuxedni region into two unequal parts that have different geographic characteristics. The Iniskin Peninsula, south of Chinitna Bay, is about half the size of the area between Chinitna and Tuxedni Bays.

The coast mountains rise steeply from Cook Inlet to an altitude of 3,830 feet near Chinitna Bay and 2,410 feet at Mount Pomeroy near Iniskin Bay. The west face of these mountains is in many places a nearly vertical escarpment 500–1,000 feet high cut by numerous small streams. Sea cliffs 100–200 feet high form the shoreline of Cook Inlet between Chinitna and Iniskin Bay, and with the exception of Oil Bay, there is no protected anchorage for small boats.

Bowser and Park Creek valleys lie northwest of the west-facing escarpment and are separated from the Fitz Creek valley by the narrow flat-topped Havenstrite Ridge. A northeast-trending linear belt of hills lies between the Fitz Creek and the Portage Creek valley to the northwest; the highest hill is Tonnie Peak, 2,442 feet in altitude. Northwest of Portage Creek the mountains merge into the Chigmit Mountains and average 3,000–4,000 feet in altitude.

The streams on Iniskin Peninsula are all small, and many have gradients of nearly 1,000 feet per mile. Bowser, Park, Fitz, and Portage Creeks are the principal streams; Fitz Creek, the largest, is about 8 miles long. They meander on flood plains 1,000–5,000 feet wide and have gradients of 75–100 feet per mile. Their general course is parallel to the strike of the rocks. Tributaries of these streams are characterized by steep gradients, V-shaped canyons, and numerous waterfalls. Brown and Bow Creeks are the only large streams in transverse valleys and both flow directly into Cook Inlet.

The transverse valleys of Brown and Bow Creeks and the valley between Bowser Creek and Right Arm are apparently determined by a system of transverse faults that has the same direction as the valleys. The northeast-trending valleys of Bowser, Park, Fitz, and Portage Creeks are dependent on the principal lines of geologic structure in the peninsula.

##### CHINITNA BAY TO TUXEDNI BAY

The area north of Chinitna Bay is dominated by the mass of Iliamna Volcano, whose summit rises 10,016 feet above Chinitna Bay, and by the peaks associated with it, all of which are more than 5,500 feet in altitude. Ten glaciers radiate from the slopes and snowfields

of Iliamna Volcano. Tuxedni Glacier is the longest, extending about 16 miles north to within 3 miles of Tuxedni Bay. End moraines beyond the present ice margin indicate that the glacier entered the bay in the not too distant past. Red Glacier is the next largest, extending 10 miles east toward Cook Inlet. Deep, glacially scoured U-shaped valleys radiating from the snowfields of Iliamna Volcano indicate that all the glaciers reached sea level during at least one stage of glaciation.

The principal streams in this part of the mapped area are Johnson and Red Glacier Rivers and West Glacier, Middle Glacier, East Glacier, Shelter, and Difficult Creeks. All are glacial streams, in contrast to the streams of the Iniskin Peninsula, which are all nonglacial at present. The streams flow in the glacially scoured valleys that are for the most part transverse to the northeast-trending structural pattern of the bedrock. Tributaries of the major streams have V-shaped canyons with steep gradients and numerous waterfalls. Ten waterfalls, ranging in height from 40 to 160 feet, can be seen on streams flowing into Hickerson Lake.

Mountains that correspond to the coastal mountains south of Chinitna Bay are here separated from Cook Inlet by deposits of glacial and fluvial origin 1-3 miles wide. North of Johnson River the mountains reach Cook Inlet and have the same topographic features that characterize the shoreline between Chinitna and Iniskin Bays. The highest peak, Slope Mountain (alt 3,850 ft), is adjacent to Tuxedni Bay. The altitude of the coast mountains decreases gradually southwestward from Tuxedni Bay, the lowest peak being adjacent to Iniskin Bay.

The northeast-trending system of valleys present on the Iniskin Peninsula is not as conspicuous or continuous in this part of the region. The coast mountains are separated from the mountains to the northwest by a discontinuous valley having transverse ridges between segments. These transverse ridges were apparently formed by glacial action and headward erosion of tributary streams from adjoining valleys.

Marsh and Tooie Creeks drain the area at the head of Chinitna Bay. Marsh Creek valley was once glaciated, but at present only a small amount of glacial discharge runs into the valley.

#### ACCESSIBILITY

In 1955 the Iniskin Drilling Co. built a 3,600-foot airstrip at their drilling camp on Fitz Creek that made the Iniskin-Tuxedni region readily accessible to planes

from Anchorage and Homer. The company also constructed a road from Camp Point on Chinitna Bay to the drilling camp, a distance of about 9 miles. The road needs continual maintenance because the heavy rainfall causes numerous washouts and slides. Part of the road is built in Fitz Creek and is washed out with each flood; road damage was particularly extensive during the 1958 field season.

Iniskin, Chinitna, and Tuxedni Bays are natural harbors for boats drawing less than 10 feet of water. Mudflats are exposed at the head of all three bays at low tide, and the only safe anchorage for large ships is in Tuxedni Channel between Chisik Island and the mainland.

All travel into the interior, except on the Fitz Creek road, is by foot and is extremely difficult owing to the dense growth of brush and grass. A trail from Right Arm to Chinitna Bay was originally used by the Indians, and a wagon road from Right Arm to Oil Bay was built in 1903; all traces of the trail and road have since disappeared. Travel by horseback was tried by some of the early Geological Survey parties and some oil-company parties, but owing to dense brush and to bears, this mode of travel was never successful.

The best way to get into the interior is to walk in the streams, but this can be done only during low water. An alternative is to follow bear trails.

#### WILDLIFE

Game, with the exception of bears, is not particularly plentiful in the Iniskin-Tuxedni region. The Kodiak brown bear and the small black bear are abundant, especially when salmon come into the streams to spawn. Hardly a day passed without our sighting one or both of these species of bear. The small black bear is more troublesome, if less dangerous, than the brown bear, owing to its habit of raiding camps.

Beaver, marten, otter, and lynx were seen by members of the Geological Survey, and moose and wolves were reported by Gary Brown on the north side of Chinitna Bay. A few ground squirrels were noted on the rocky slopes but were not abundant.

Birds are plentiful in the tidal marshes and along the streams. Numerous ducks and geese were seen in the spring and fall. A few spruce hens were noted in the timbered areas.

#### VEGETATION

If any single factor were to be considered the greatest deterrent to field investigation in the Iniskin-Tuxedni region, the unanimous choice would be the dense

growth of brush. Brush, especially alder and willow, forms an all but impenetrable wall along streams, shorelines, and hillsides to an altitude of about 2,000 feet. Ferns and ubiquitous devilsclub thrive under the brush.

There is a fairly rigid altitude zonation of the vegetation in this region, as in most of Alaska. Spruce and cottonwood grow to about 750 feet and most of the brush stops at about 2,000 feet. Dwarf birch, blueberry, crowberry, and moss continue to 3,000 feet in favorable locations; above this altitude the rocks are bare except for a few lichens.

Spruce and cottonwood are not uniformly distributed over the area in which they grow, but commonly form small groves or appear as isolated trees. The timbered areas are interspaced with glades of "redtop" grass or thickets of alder and willow. Spruce timber is present in all the larger valleys and along the shoreline. Many fine groves of spruce grow along the beach from Chinitna Bay to Johnson River and at Oil and Iniskin Bays. A sawmill near the mouth of Red Glacier River produces enough lumber for local use. Cottonwood is not as abundant as spruce but grows much larger. It is not uncommon to see trees 4-5 feet in diameter and 100 feet tall. The wood is of little use for lumber because it is soft and punky.

The abundant rainfall contributes to the luxuriant growth of the vegetation. Stalks of grass and fireweed 6 feet tall are not uncommon and make climbing difficult. Wild fruit is present but not as abundant as in the interior of Alaska; this may be due to the excessive rainfall. Blueberries, salmonberries, currants, and crowberries were noted.

#### CLIMATE

The climate of the Iniskin-Tuxedni region is sub-polar marine characterized by abundant precipitation (40-80 in. per year) and strong winds. Rain, fog, and overcast skies occur on about 80 percent of the days during the field season. 1957 was abnormally dry, precipitation falling on only about 20 percent of the days. Rainfall varies from light to extremely heavy; during the 1958 field season it averaged almost 1 inch per day. On the night of August 11, 1958, 7.30 inches of rain fell in 8 hours; the total rainfall for the 24-hour period was 11.21 inches. Wind at times in excess of 60 miles per hour accompanied this storm.

Snowfall is heavy during the winter months, generally starting in late October and continuing to late April on the lowlands. At higher altitudes snow may fall every month of the year. The weather station at the Iniskin drilling camp reported 26 feet of snow during the winter of 1957-58.

This region does not have the extremes of tem-

perature common to much of Alaska. The temperature rarely goes below  $-20^{\circ}\text{F}$  in winter, and then only for a few days; the average summer temperature is about  $50^{\circ}$ - $55^{\circ}\text{F}$ .

#### DESCRIPTIVE GEOLOGY OF THE BEDDED ROCKS

##### REGIONAL SETTING

The Iniskin-Tuxedni region is near the southern margin of a mobile belt of mountain building that borders the northern part of the Pacific Ocean. The floor of the Pacific Ocean is a stable area to the south, and the Arctic Ocean basin and adjacent part of northern Alaska is a stable area to the north.

The region lies within the belt of recent volcanism that borders the Pacific Ocean. Iliamna Volcano, near the center of the region, has been active within historic time and is sending up columns of vapor at present. This activity would suggest that the region is still mobile and undergoing mountain-building movements. The major fault system of the Alaska Peninsula-Cook Inlet area, the Bruin Bay fault, transects the region in a northeasterly direction and in general separates the younger bedded sedimentary rocks from the older volcanic, metamorphic, and intrusive rocks of the Aleutian Range (pl. 2).

The rocks that crop out in the Alaska Peninsula-Cook Inlet part of the mobile continental margin range in age through most of the periods of geologic time since about the middle of the Paleozoic Era. There are at least six successive and contrasting types of bedded rocks: (1) crystalline basement rocks of Paleozoic age, but undetermined system; (2) marine limestone of Permian and Triassic age; (3) chert, siltstone, and limestone containing interbedded volcanic rocks predominantly of marine origin and of Triassic and Early Jurassic age; (4) marine and continental graywacke and siltstone of Jurassic, Cretaceous, and Tertiary age; (5) continental andesitic volcanic rocks of Tertiary and Quaternary age; and (6) Quaternary surficial deposits. Other kinds of rocks, less abundant and less characteristic, are associated with each type.

The mobile continental margin of this part of Alaska was generally a belt of subsidence during the late Paleozoic and early Mesozoic. During this time the bedded rocks of the primary eugeosyncline unconformably overlapped the older crystalline basement complex of rocks. The mobile zone was uplifted at or near the beginning of Middle Jurassic time with accompanying formation of secondary geanticlines and geosynclines that established the present structural framework of the region. The Aleutian Range batholith was emplaced along the core of one of the geanticlines during this Early to Middle Jurassic uplift.

Between the geanticlines are belts of secondary miogeosynclinal deposition in which bedded rocks accumulated unconformably on the older formations. These belts were nearly all marine deposits of graywacke, conglomerate, siltstone, and shale laid down in the Matanuska and Chugach Mountains geosynclines. Early Cenozoic mountain building was followed by subsidence and the formation of the Cook Inlet and Nushagak Basins and Shelikof Trough, in which a great thickness of predominantly continental sandstone, conglomerate, and shale accumulated unconformably on the older bedded rocks.

**GENERAL RELATIONS  
STRATIGRAPHIC UNITS**

Sedimentary rocks underlie about 60 percent of the mapped area. Associated with them are bedded lava flows, agglomerate, and related pyroclastic rocks

that form another 20 percent of the rocks. Granitic rocks of the Aleutian Range batholith form the remaining 20 percent of the bedrock. The major rock types comprise stratigraphic units whose surface distribution is shown on the geologic map (pl. 1). The succession of stratigraphic units is given in table 1 to show how the units fit into the geologic time scale. The geologic nomenclature of these stratigraphic units has undergone a considerable metamorphosis since the first comprehensive report on the area by Martin and Katz (1912, p. 31). The past and present nomenclature of the Jurassic units are given in table 2.

The bedded rocks have a maximum thickness of 29,600 feet, and most of them were deposited in a marine environment. Nearly all of these rocks were laid down in the Matanuska geosyncline and unconformably overlie the metasedimentary and volcanic

TABLE 1.—Stratigraphic units in the Iniskin-Tuxedni region, Alaska

Period	Epoch	Unit	Character	Thickness (feet)	
Quaternary	Recent	Alluvial deposits	Gravel, sand, and silt; may include some talus and glacial outwash.	0-100±	
		Littoral deposits	Boulders, gravel, sand, and silt.	0-50±	
		Colluvial deposits	Rubble, talus, and landslides.	0-400±	
	Pleistocene	Glacial deposits	Drift, moraine, and outwash.	0-100±	
		Iliamna flows	Andesitic flows and fragmental ejecta.	80-400±	
		Residual deposits <sup>1</sup>	Soil, rubble, and talus.	0-20±	
Tertiary	Middle(?) to late(?)	Flows	Andesite to basalt. Angular unconformity	0-300±	
	Oligocene(?) and Miocene	Kenai Formation	Conglomerate, sandstone, and siltstone (terrestrial). Angular unconformity	0-1,085	
Jurassic	Late	Naknek Formation	Pomeroy Arkose Member	Arkosic sandstone, conglomerate, and siltstone. Local unconformity	850-3,300+
			Snug Harbor Siltstone Member	Siltstone, mainly thin bedded, gray to black; interbeds of arkose.	720-860
			Lower sandstone member	Arkosic sandstone, graywacke, and siltstone. Intertonguing	0-840
			Chisik Conglomerate Member	Conglomerate, massive. Local unconformity	0-560
		Chinitna Formation	Paveloff Siltstone Member	Siltstone, massive, gray-weathering; large ellipsoidal limestone concretions; sandstone unit at base.	900-1,370
			Tonnie Siltstone Member	Siltstone, massive, reddish-brown-weathering; small limestone concretions; sandstone unit at base. Local unconformity	820-1,310
	Middle(?) and Late	Tuxedni Group	Bowser Formation	Sandstone, conglomerate, siltstone, and shale. Angular unconformity	1,250-1,830
			Twist Creek Siltstone	Siltstone, massive, gray, rust-brown-weathering; small limestone concretions; ash beds. Local unconformity	0-420
	Cynthia Falls Sandstone		Sandstone, massive; minor conglomerate and siltstone. Local unconformity	600-765	
	Fitz Creek Siltstone		Siltstone, massive, gray; locally arenaceous; small limestone concretions. Local unconformity	640-1,280	
	Gaikema Sandstone		Sandstone, massive, locally conglomeratic; minor siltstone.	500-880	
	Red Glacier Formation		Siltstone, thin-bedded to massive, brown; tan arkosic sandstone; black arenaceous shale. Regional angular unconformity	1,980-4,540	
	Early(?) and Middle	Aleutian Range batholith		Quartz diorite, quartz monzonite, granodiorite, and other granitic rocks; potassium-argon date on biotite 10 mi. west of mapped area gives 159±5 my.	
	Early	Tulkeetna Formation	Horn Mountain Tuff Member	Andesitic tuff, mottled; locally contains andesite flows and arkosic sandstone.	1,800-2,850
Portage Creek Agglomerate Member			Agglomerate, massive, pink; minor green volcanic breccia; locally thick andesitic flows; minor argillite.	2,250-2,850	
Marsh Creek Breccia Member			Volcanic breccia, massive, green; thick andesitic flows; minor agglomerate and argillite. Angular unconformity(?)	1,850-3,350	
Triassic	Late(?)	Metamorphic rocks undivided	Marble, quartzite, metachert, and argillite; locally contains basalt flows; complexly folded.	160-1,300±	

<sup>1</sup> Range in age from Tertiary through Recent.

GEOLOGY, INISKIN-TUXEDNI REGION, ALASKA

TABLE 2.—Comparison of past and present nomenclature of the bedded Jurassic rocks in the Iniskin-Tuxedni region, Alaska

Martin and Katz (1912)	Moffitt (1927)	Kellum (1945)	Kirschner and Minard (1949)	Hartsock (1954)	Detterman (1963)	Detterman and Hartsock (This report)
Upper Jurassic	Naknek Formation Arkose, sandstone, and tuff and tuff Gray shale with sandstone beds Chisik Conglomerate Member	Not examined	Naknek Formation Upper sandstone member Pomeroy Member Siltstone member Chisik Member	Naknek Formation Upper member Lower member Upper member Lower member	Upper Jurassic Not shown	Upper Jurassic Naknek Formation
Middle Jurassic	Chinitna Shale	Upper sandstone member Upper sandy-shale member Cynthia Falls Sandstone Member Lower sandy-shale member	Chinitna Siltstone Tonnie Siltstone Member Bowser Member Cynthia Falls Sandstone Member Lower siltstone member Gaikema Sandstone Member Siltstone member	Chinitna Formation Upper member Lower member Bowser Member Cynthia Falls Member Siltstone member Gaikema Member Lower member	Upper Jurassic Chinitna Formation	Upper Jurassic Chinitna Formation
Middle Jurassic	Tuxedni Sandstone	Middle Jurassic Tuxedni Formation	Middle Jurassic Tuxedni Formation	Middle Jurassic Tuxedni Group	Middle Jurassic Tuxedni Group	Middle Jurassic Tuxedni Group
Lower Jurassic	Volcanic rocks	Lower Jurassic Kiajavik Formation Sandy-shale member	Lower Jurassic Kiajavik Formation Siltstone member	Lower Jurassic Volcanic rocks	Lower Jurassic Talekna Formation	Lower Jurassic Talekna Formation
Lower Jurassic	Porphyries and tuffs	Lower Jurassic	Lower Jurassic	Lower Jurassic	Lower Jurassic	Lower Jurassic Talekna Formation Horn Mountain Tuff Member Portage Creek Agglomerate Member Marsh Creek Breccia Member

rock of the primary geosyncline. Continental deposits of the Cenozoic Cook Inlet Basin unconformably overlie a small area of the older rocks. Crystalline rocks forming the basement complex are not exposed in the Iniskin-Tuxedni region.

"Metamorphic rocks undivided" is the term herein adopted for a sequence of Upper(?) Triassic meta-sedimentary rocks that includes metachert, metalimestone, quartzite, argillite, and low-rank schist. These rocks are exposed at few localities (and the thickness of the unit is therefore uncertain) but is probably no more than 1,300 feet in all.

The Talkeetna Formation consists predominantly of marine volcanic rocks and interbedded sedimentary rocks. Three members are recognized, from oldest to youngest: the Marsh Creek Breccia Member, mainly green volcanic breccia; the Portage Creek Agglomerate Member, mainly a pink agglomerate that is inter-layered with metasedimentary rock and andesitic porphyritic flows; and the Horn Mountain Tuff Member, tuff and tuffaceous sandstone. The clastic sediments are both volcanic and terrigenous. Most of the Talkeetna Formation was probably derived locally by repeated volcanic eruptions.

The Tuxedni Group is a thick sequence of sedimentary rocks made up of mineral grains and rock fragments derived mainly from the underlying Talkeetna Formation. Coarse clastic graywacke and conglomerates are in about equal proportion with fine clastic siltstone and shale. The coarse and fine clastics occur generally only in well-defined units of varying thickness that can be readily mapped. The six formations of the group, from oldest to youngest, are: Red Glacier Formation, Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, Twist Creek Siltstone, and Bowser Formation. The sediments of the Tuxedni Group, believed to have come from terrestrial sources on the nearby Talkeetna geanticline to the northwest, were deposited in the secondary geosynclinal trough of the Matanuska geosyncline. The alternation of rather thick units of coarse and fine clastic rocks suggests a degree of mobility that generally accompanies incipient mountain building. The formations of the Tuxedni Group are subject to considerable lateral variation in both thickness and texture; this variation, too, would confirm the concept of crustal unrest.

The siltstone of the Chinitna Formation is composed of finer grained minerals and rock fragments of the same general composition as the underlying Tuxedni Group. The sediments probably were derived in part from the Tuxedni, but the Talkeetna Formation undoubtedly furnished some of the sediments that were deposited under fairly quiescent conditions in

the geosynclinal trough. The Chinitna was deposited entirely in a marine environment.

The Chisik Conglomerate Member at the base of the Naknek Formation indicates renewed mountain building and uplift of the Talkeetna geanticline. A massive cobble-boulder conglomerate contains granitic rocks from the Aleutian Range batholith, fragments of metamorphic rock from the Triassic, and detritus from the Tuxedni and Chinitna Formations. The Chisik is overlain by the lower sandstone member, Snug Harbor Siltstone Member, and the Pomeroy Arkose Member. The Pomeroy Arkose Member is almost entirely a granitic sheetwash type of rock derived from the batholith. The Matanuska geosyncline, as well as the Talkeetna geanticline, was uplifted during the deposition of the Naknek Formation.

The continental deposits of the Kenai Formation are found at a few localities near the shore of Cook Inlet. The main rock type is a cobble conglomerate composed of constituents representing nearly all the older formations. The conglomerate contains a few interbeds of siltstone and shale and thin lenticular seamlets of coal.

#### STRATIGRAPHIC RELATIONS

The bedded rocks may be divided into at least three major sequences that are separated by regional or angular unconformities. The oldest are the meta-sedimentary and volcanic rocks of the primary geosyncline: metamorphic rocks of Late(?) Triassic age and Talkeetna Formation of Early Jurassic age. The next sequence was formed in the secondary geosyncline: the Tuxedni Group and the Chinitna and Naknek Formations of Middle and Late Jurassic age. The youngest sequence was deposited in the Cenozoic Cook Inlet Basin: the Kenai Formation and the Tertiary and Quaternary lava flows. The unconformities between these major units extend far beyond the mapped area and mark major intervals of crustal movement in southwestern Alaska.

#### TRIASSIC SYSTEM

##### METAMORPHIC ROCKS UNDIFFERENTIATED

Metamorphic rocks, tentatively assigned to the Upper(?) Triassic, are exposed at a few localities in the Iniskin-Tuxedni region. These exposures are in the Chigmit Mountains near the western margin of the mapped area. The metamorphic rocks are the oldest exposed in the region; they are flanked by, and intruded by, the quartz diorite and quartz monzonite of the Aleutian Range batholith. The batholith is primarily responsible for the exomorphic alteration of this dominantly marine sedimentary sequence,

as shown by the well-defined contact aureole adjacent to the pluton. The contact phase generally is pyrometamorphically enriched with base-metal sulfides and magnetite.

#### AREAL DISTRIBUTION

The largest exposures of Triassic metamorphic rocks are between the head of Iniskin Bay and Marsh Creek.<sup>1</sup> Two northeast-trending belts, 1,500–2,000 feet wide, were mapped across this area. The westernmost belt continues along Marsh Creek for several miles before it bends sharply to the east and crosses the mountains into the headwaters of Chinitna River. This belt is in contact with both the quartz diorite of the first intrusive phase and the pink quartz monzonite of the second intrusive phase. Mineralization is markedly increased where the crystalline metalimestone and argillite are in contact with the quartz monzonite. The rocks of this western belt are in their original stratigraphic position, underlying the volcanic rocks of the Lower Jurassic Talkeetna Formation.

The easternmost of the two belts of Triassic metamorphic rock, between Iniskin Bay and Marsh Creek, was thrust faulted into its present position. The metasedimentary rocks are intimately associated with the plutonic rock between the shoreline and the crest of the mountains to the northeast. Two small roof pendants are engulfed in the quartz diorite; they probably represent two blocks of the original country rock that were not quite assimilated in the cooling fluids near the top of the magma chamber. The rocks within these roof pendants are predominantly fine-to coarse-crystalline marble and hornfels. The enclosing rocks have some of the characteristics of migmatite but pass into normal quartz diorite a short distance from the exotic blocks of Triassic rock. Plutonic rocks are absent from the fault block northeast of the crestline of the mountains, and the faults die out a short distance northeast of Marsh Creek. Near Marsh Creek the rocks are crystalline marble, argillite, and quartzite that have all been mineralized slightly. The minerals are chiefly malachite and azurite in a thin vein and pyrite disseminated in the marble. The marble is normally white but is stained in various shades of blue and green from the finely disseminated copper. Magnetite is present also in the mineralized area on Marsh Creek.

Triassic rocks crop out in two small areas between the heads of Chinitna River and Tooie Creek. These areas are remnants of the western Triassic belt that starts on Iniskin Bay. The easternmost, about half a mile

long and 500 feet wide, is completely engulfed in the pink quartz monzonite. The other area, about 2½ miles long by a few hundred feet wide, is irregular in outline; it is on the contact between the diorite and monzonite. The rocks of both areas are highly altered marble, argillite, and hornfels and are probably roof pendants in the pluton.

Triassic metamorphic rocks were observed at several small, widely scattered localities north of Chinitna Bay. One such locality is at about the 3,500-foot level on the southwest slope of Iliamna Volcano. This patch of metamorphic rock, about 3 miles long, is cut by Umbrella Glacier. The eastward-striking beds are in contact with the pluton as well as the Talkeetna Formation. Middle Glacier truncates the east end of the belt, and no other exposures of Triassic rocks were found in the vicinity of Iliamna Volcano, the beds being either covered by Recent lava flows or actually assimilated into the rising magma of the volcano. Assimilation is probably the correct explanation, for the pluton is in thrust-fault contact with the Talkeetna Formation northeast of the volcano, and field evidence indicates that the volcanic neck is about on the contact between the pluton and the Jurassic volcanics. However, the true relationship may never be known, for about 90 percent of the possible Triassic outcrop area is covered by glaciers.

Two other areas of Triassic rock are present in the mountains near the head of Tuxedni Bay. The larger area is about 10 miles northwest of Chisik Island, where about 1,100 feet of crystalline limestone, argillite, and basaltic lava flows is exposed in a mountain along the shore of the bay. A similar, but much thinner section, is exposed about 1 mile north of the limestone mountain. Both areas are on the east side of the Bruin Bay fault zone.

The only other occurrence of known Triassic rocks is a thin sliver along the Bruin Bay fault 3 miles northeast of Johnson Glacier. A maximum of about 160 feet of crystalline limestone and argillite is exposed between the major thrust fault and a high-angle reverse fault east of the thrust. These beds are highly metamorphosed and fractured.

Triassic rocks are not known to be present in the area north of the shoreline of Tuxedni Bay; however, most of this adjoining area has never been mapped by the Geological Survey. The rocks do continue south of Iniskin Bay and have been reported on by Martin and Katz (1912, p. 41–48), Mather (1925, p. 162–63), and Martin (1926, p. 51–65).

#### CHARACTER

All the Triassic rocks have been subjected to varying degrees of contact and (or) dislocation metamorphism,

<sup>1</sup> The name "Marsh Creek" appears on maps of the area published by the Geological Survey prior to 1958, and that name is used in this report. The former "Marsh Creek" is shown as "Clearwater Creek" in later maps.

and though the Triassic was not studied in great detail by the present investigation, certain generalizations concerning this sequence of rocks can be made. The rocks were originally deposited in a marine environment and consisted of limestone, in part dolomitic, sandstone, shale, and basaltic lava flows. The chert characteristic of the Kamishak Formation at Ursus Cove and Bruin Bay (Stanton and Martin, 1905, p. 393-396; Martin and Katz, 1912, p. 47-50), just south of the Iniskin-Tuxedni region, is not present in the mapped area. As suggested by Martin (1926, p. 52), the sequence exposed in the mapped area may be slightly older than the Kamishak Formation.

The first phase of metamorphism occurred during late Early Jurassic or early Middle Jurassic time when the quartz diorite of the Aleutian Range batholith was emplaced. Contact metamorphism produced medium- to coarse-crystalline metalimestone and argillite in which the contact aureole does not extend more than 50-100 feet from the contact; this type of metamorphism is preserved along the north side of the Triassic belt on the southwest slope of Iliamna Volcano. A pink quartz monzonite was injected into both the quartz diorite and the Triassic sedimentary sequence at a later date, forming the second phase of contact metamorphism. The quartz monzonite was apparently more fluid, and at a correspondingly higher temperature, and it produced high-grade contact metamorphic rocks of the pyroxene-hornfels facies. Some of the metalimestone was altered to granoblastic marble; hornfels was formed near Iniskin Bay and quartzite and argillite along Marsh Creek. Some of the rocks were further altered by dislocation metamorphism during movement along the Bruin Bay fault and associated fault systems. This third phase of metamorphism probably took place during middle to late Tertiary, although exact dating is impossible at present. The sliver of Triassic rocks 3 miles northeast of Johnson Glacier shows the effect of dislocation metamorphism very well.

Limestone, metalimestone, and marble are considered together for this discussion, because they are of the same rock unit but have undergone varying degrees of metamorphism. Unaltered limestone is rather uncommon in this region, being confined chiefly to part of the section exposed in the mountain at the head of Tuxedni Bay, where massive light-gray and thin-bedded dark-gray carbonaceous limestone was observed. The limestone is slightly crystalline and metamorphosed near the basaltic sills and flows that are a part of the section but does not appear to have been altered by the quartz diorite with which it is in fault contact. The juxtaposition of the limestone

and quartz diorite occurred at a date much later than the intrusion.

The sliver of Triassic rocks in the mountains 3 miles northeast of the terminus of Johnson Glacier contains a thin sequence of gray crystalline metalimestone and green argillite about 160 feet thick. The beds were subjected to all three phases of metamorphism. A thin section (field sample 52AJu564) of the metalimestone about 100 feet from the contact was examined (pl. 3); it is composed of about 60-65 percent anhedral to subhedral calcite in crystals 0.02-5.0 mm in diameter, most of which show polysynthetic twinning. Carbonaceous material constitutes about 25-30 percent, mostly in finely disseminated flakes and small masses. Euhedral quartz and subhedral dolomite were the only other minerals present and they constitute less than 3 percent of the rock. The rock is not greatly altered, but does show some coarsely crystalline calcite; it has been shattered by faulting and the cracks are sealed by the fine-crystalline calcite. This specimen probably was taken at too great a distance from the intrusive to show maximum effects of metamorphism.

Two samples of marble (50AGz39, 50AGz40) from the westernmost belt of Triassic at the head of Chinitna River were examined in thin section. Sample 39 was taken from near the contact between the Triassic and quartz monzonite and sample 40 from about halfway between the quartz monzonite and quartz diorite. Both samples are typical low-grade contact metamorphic rocks. They are granoblastic, sample 39 more so than 40, having crystals of calcite and dolomite about 5 mm in diameter. Calcite constitutes about 80 percent of both; it is anhedral, polysynthetic twinned, and has many inclusions of accessory minerals that suggest the rock was originally a siliceous dolomitic limestone. Both samples contained 5-8 percent diopside in 0.02-0.05-mm subhedral crystal inclusions in the calcite. In addition, sample 39 contained 3-4 percent forsterite as rounded idiomorphic grains, 2-3 percent long prismatic crystals of tremolite, and 2-3 percent pyrite. Sample 40 did not have forsterite or tremolite, but did contain a little wollastonite and 1-2 percent magnetite in addition to the pyrite. The magnetite was in 0.01-0.02-mm grains. Quartz was not identified in either sample, but the presence of forsterite and diopside indicates that the rock originally contained silica, and chert was found in sample 39.

Argillite is interbedded with the limestone in all sections of the Triassic in this region; it is massive, dark gray, dark green, and blue, and in a few localities is somewhat granular. The argillite has undergone metamorphism similar to the limestone series and now shows increasing grades of metamorphism from well-indurated argillite to pelitic hornfels, slate, and, at

the head of Chinitna River, phyllite. A few thin sections were examined cursorily, more from the point of view of confirming field identification of the rocks rather than doing a detailed analysis. The pelitic hornfels has the typical granoblastic matrix of quartz, orthoclase, biotite, and finely disseminated flakes of graphite; included in this matrix are large porphyroblasts of andalusite. The slate and phyllite show a preferred orientation of the mica and were deficient in feldspar. One specimen was almost a mica schist, as it chiefly contained only quartz and mica in well-defined bands.

Gray quartzite, greenstone, and welded tuff breccia are present locally in parts of the region mapped as Triassic; it cannot be stated definitely that these rocks are Triassic, but because they are metamorphosed more than the Lower Jurassic rocks, it seemed advisable to include them with the Triassic. This group of rocks forms a very minor part of the sequence in the area between Iniskin Bay and the head of Marsh Creek, and may be part of a somewhat similar, but thicker, sequence exposed south of the mapped area (Martin and Katz, 1912, p. 38-40).

#### THICKNESS AND STRATIGRAPHIC RELATIONS

The computed thickness of Triassic rocks ranges from 160 to 1,300 feet (pl. 4). This thickness is probably only a small part of the sequence originally deposited, for in all exposures the lower contact is with intrusive igneous rocks. The figures given are considered as only approximate by the authors; because exomorphic changes in the sedimentary rock have obliterated most of the bedding in some of the area and faulting has further complicated the stratigraphic relationships.

The contact with the overlying beds of the Talkeetna Formation is arbitrarily placed at the point where the beds change from a dominantly volcanic sequence to rocks of dominantly sedimentary origin. Because the rocks in the lower part of the Talkeetna Formation are metamorphosed somewhat, the presence of metamorphism cannot be used as a key in mapping except to the extent that rocks in the Talkeetna show mainly low-grade metamorphism as contrasted to the higher grade metamorphism of rocks in parts of the Triassic.

#### AGE AND CORRELATION

The age of the metamorphic rocks cannot be determined definitely from fossil evidence, for only two meager collections were made. One collection (sample 52AJu402) was from the metalimestone 1.5 miles north of the terminus of Middle Glacier; it contained poorly preserved spongelike fossils that were identified by Helen Duncan, of the U.S. Geological Survey, as *Spongiomorpha (Heptastylopsis) ramosa* Frech of Tri-

assic age. This species was obtained also from a collection made on Iliamna Lake (Martin and Katz, 1912, p. 44-46) that contained other faunal elements of definite Late Triassic age.

The other collection from the Triassic of the mapped area (58ADt53) was from a silicified limestone on Marsh Creek about 3.3 miles from the tidal flats. These rocks contained impressions of fossils resembling corals.

A single specimen of *Monotis* was collected by Arthur Grantz from silicified limestone on the south shore of Iniskin Bay. This limestone is on strike with the Triassic beds on the north shore of the bay and in all probability is a continuation of the limestone that contained the corallike structures of sample 58ADt53. *Monotis* is fairly common in the Kamishak Formation of Late Triassic age.

The metalimestone and associated rocks of this region are part of the Upper(?) Triassic sequence; however, the position within this sequence and the relationship to the Kamishak Formation were not determined.

### JURASSIC SYSTEM

#### LOWER JURASSIC ROCKS

##### TALKEETNA FORMATION

Bedded volcanic rocks consisting of lava flows, tuff, volcanic breccia, agglomerate, and lesser amounts of sandstone and shale have been recognized for many years in the mapped area (Martin, 1905, p. 38; Martin and Katz, 1912, p. 50-59; Martin, 1926, 137-140; Moffit, 1927, p. 11). This thick sequence of rocks has been variously referred to as Lower Jurassic(?) rocks or porphyries and tuffs. The present authors herein propose to extend the Talkeetna Formation of the Talkeetna Mountains and Matanuska Valley to these rocks on the west side of Cook Inlet. The senior author visited many Talkeetna Formation localities in the Talkeetna Mountains with Arthur Grantz in the summer of 1957 and observed the similarity of the rocks in the two areas. Good correlation can be made despite the 225 miles that separate the areas, and it is the authors' opinion that these rocks are of the same stratigraphic unit.

Much new information obtained on these Lower Jurassic rocks during the present investigation of the Iniskin-Tuxedni regions shows that they can be subdivided, broadly, into three stratigraphic units, each having a dominant distinctive lithology. The units are, from oldest to youngest: Marsh Creek Breccia Member, massive dark-green volcanic breccia and argillite; Portage Creek Agglomerate Member, massive red and pink agglomerate, tuff breccia, and argillite; Horn Mountain Tuff Member, thin-bedded to massive tuff and tuffaceous sandstone. Lava flows are common

to all members, but porphyritic flows are largely confined to the Horn Mountain Tuff Member; green aphanitic flows are more common in the older units. The characteristic lithologic features mentioned for the above members are by no means limited to the specific members, but the features are dominant for each member.

#### Marsh Creek Breccia Member

##### AREAL DISTRIBUTION

Rocks making up the Marsh Creek Breccia Member are best exposed in a belt 1-2 miles wide from the head of Iniskin Bay northeastward to the south slope of Iliamna Volcano. The continuity of this belt is broken by numerous faults and by the quartz monzonite intrusive near West Glacier Creek. The member is missing from this northeastward-trending belt for 12 miles starting at a point on the south slope of Iliamna Volcano; it reappears a few miles south of Tuxedni Bay and continues at least as far as the bay, where the rocks are well exposed. Quartz diorite of the Aleutian Range batholith is in fault contact with younger rocks along most of the 12 miles. In the vicinity of Iliamna Volcano the rocks were undoubtedly assimilated into the rising magma chamber under the volcano.

Volcanic rocks of Early Jurassic(?) age occur immediately southwest of the area mapped (Martin and Katz, 1912, p. 50-53), but it is not known if these rocks are equivalent to the Marsh Creek Member. Martin and Katz described the rocks as one unit, and their description (p. 51) indicates to the present authors that at least part of the Marsh Creek Member is present there.

##### CHARACTER

Massive dark-green to green volcanic breccia is the dominant rock type of this member. Much of the breccia has a tuff matrix and is actually a tuff breccia. Bedding is not readily discernible in many of the massive units that range from 40 to as much as 1,100 feet thick. Angular fragments making up the breccia range from about half an inch to nearly 3 feet across. Size sorting is not conspicuous, but in general the constituents become coarser downward in the section. Most of the fragmental constituents are aphanitic green and pink volcanic rocks of the same general composition as the lava flows associated with the breccia.

Lava flows are interbedded with the volcanic tuff breccia throughout the Marsh Creek Breccia Member, but the flows become more abundant and of greater thickness southward across the mapped area. The bedded lava, partly of submarine origin, is dominantly microcrystalline and is mainly andesite and dacite. Phenocrysts,  $\frac{1}{16}$ - $\frac{1}{4}$  inch long, may be abundant or sparse

within short distances in the same flow, and the flows vary in color from light-red to light- to medium-green, the greenish type predominating. Because these lavas are considerably altered near the quartz diorite pluton and are cut by numerous dikes, identification is difficult even in thin section. The holocrystalline to hypocrystalline groundmass was extremely altered in most specimens examined in thin section.

Plagioclase feldspar laths were identified in the felted groundmass of a specimen (51AJu86) taken from one of the green flows at Tuxedni Bay. The plagioclase, extremely corroded, is about andesine. Phenocrysts of andesine are fairly common and orthoclase uncommon, both are altered to sericite along fractures. The mafic mineral phenocrysts were mostly chloritized augite. Magnetite and other opacite crystallites are scattered throughout. A zeolite mineral, probably thomsonite, is present in minor amounts.

A thin section of sample 51AJu296 taken from a red lava flow on the ridge between Middle Glacier and East Glacier Creeks shows a felted texture of albitized plagioclase feldspar microlites. Phenocrysts of andesine and orthoclase are altered to epidote and sericite. Hematite is fairly common and may be partly an oxidation product that imparts the reddish color to the flows. This rock may be dacite but is probably closer to andesite.

Bedded tuff, similar to that described as the matrix in the tuff breccia, is locally an important part of the section of the Marsh Creek Breccia Member. The tuff is present in all parts of the region but is thicker in the southern part and coarser grained in the northern part.

Greenstone was noted at several localities, the thickest unit being about 260 feet near the head of Tuxedni Bay. Although the rocks were not studied in thin section, they were probably derived by alteration of some of the mafic lava flows.

##### THICKNESS AND STRATIGRAPHIC RELATIONS

All thickness values shown on plate 4 were computed from rather meager field information, the primary objective of this project being to study the sedimentary rocks for possible petroleum-resource potential. The study of the Lower Jurassic volcanics and Triassic metamorphic rocks was secondary; consequently, the amount of detail on these older rocks is not as great as it is for the younger sedimentary rocks. Moreover, the character of the older rocks also makes the thickness values less meaningful, inasmuch as they are complexly faulted, and in some places the amount of displacement could not be ascertained.

The estimated thickness for the Marsh Creek Breccia Member probably is more questionable than that for

any other stratigraphic unit in the mapped area. This uncertainty is the result of a combination of such factors as greater faulting, obscure contact relationships with the pluton and Triassic metamorphic rocks, and remoteness of outcrop areas in an extremely rough terrane.

The thickest section, about 3,350 feet, was measured along the south shore of Tuxedni Bay. This section is relatively accessible from the bay and was checked in greater detail than were most other sections of the member; therefore, it is designated the type section, although the member is here named after Marsh Creek (Clearwater Creek). The section starts about 6 miles northwest of Fossil Point and continues along the shoreline for approximately  $2\frac{1}{4}$  miles to the contact with the quartz diorite pluton. The upper contact with the overlying Portage Creek member is a fault, but displacement is considered to be minor. The 3,350 feet of section at this locality does not represent the full sequence of rocks originally deposited, for part was assimilated into the pluton.

Details of the type section are listed below. The section was studied by Arthur Grantz and J. K. Hartsock in 1951 and by R. W. Juhle in 1951 and 1952.

*Type section of Marsh Creek Breccia Member along south shore of Tuxedni Bay*

Fault.	Thickness (feet)
Marsh Creek Breccia Member:	
Volcanic breccia, massive, coarse, green, tuff matrix; green aphanitic lava flow in upper part.....	400
Lava flow, bedded, aphanitic, green; porphyritic sill near middle; unit cut by minor fault.....	250
Volcanic breccia, massive, medium to coarse, green; several dikes and a green aphanitic lava near base..	850
Lava flow, aphanitic, green.....	150
Greenstone.....	250
Lava flow, aphanitic, green.....	150
Covered.....	350
Lava flow, aphanitic, green.....	50
Tuff, coarse, greenish.....	250
Volcanic breccia, massive, coarse, green to dark-green.....	400
Tuff, light-green.....	100
Volcanic breccia, massive, green; increasing metamorphism near contact with pluton.....	150
Total.....	3,350

The section from between Iniskin Bay and Marsh Creek (Clearwater Creek) is nearly as thick, 3,100 feet, as the type section, but is not as well exposed; it contains less coarse breccia and more fine-grained fragmental rocks, most of which are more highly metamorphosed than those elsewhere in the region. Contact relationships with both younger and older rocks are obscure.

Sections of the Marsh Creek Breccia Member are

thinner or missing in the central part of the region. This absence is mainly due to displacement along the Bruin Bay fault and to assimilation of the rocks in the rising magma chamber under Iliamna Volcano.

AGE AND CORRELATION

The age of the Marsh Creek Breccia Member cannot be determined from fossils, because none have yet been found in the mapped area. This apparent lack of fossils probably is due in part to insufficient collecting, for elsewhere—Talkeetna Mountains, Selkovia, and Alaska Peninsula—the Lower Jurassic is fossiliferous. In the Talkeetna Mountains most of the fossils come from the upper part of the Talkeetna Formation, but fossils are present throughout the formation (Arthur Grantz, oral commun., 1953). According to Imlay (written commun., 1961), these fossils from the Talkeetna Mountains represent most of the stages of the Lower Jurassic, some being as old as early Sinemurian, on the basis of the presence of the ammonite *Arnioceras* sp. Correlation of the rocks in the Iniskin-Tuxedni region with the standard zones from northwest Europe is given in table 3.

The stratigraphic sequence in the Talkeetna Mountains is not quite the same as in the Iniskin-Tuxedni region in that Lower Jurassic sedimentary rocks are present below the thick sequence of volcanic rocks. In the Iniskin-Tuxedni region, rocks that are correlated as Upper(?) Triassic may be equivalent to part of these Lower Jurassic rocks in the Talkeetna Mountains but here have been included in the Upper(?) Triassic on the basis of increased metamorphism.

Fossils from the lower sedimentary unit in the Talkeetna Mountains include the ammonites *Arnioceras*, *Cruciloboceras*, *Acanthopleuroceras*, and *Radstockiceras* of Sinemurian and Pliensbachian age. It is impossible to state, at present, if any part of the Marsh Creek Breccia Member is as old; the member may correlate with the upper part of the type Talkeetna Formation and, if so, is of Toarcian age.

The correlation of the Marsh Creek Breccia Member with other Lower Jurassic rocks in the Cook Inlet-Alaska Peninsula region is rather tenuous. Martin and Katz (1912, p. 51) described a sequence from the area just south of the region that seems to correlate in part, but for most of southwestern Alaska the Lower Jurassic volcanic sequence has not been studied in enough detail to permit any direct correlation.

Portage Creek Agglomerate Member

AREAL DISTRIBUTION

Rocks mapped as the Portage Creek Agglomerate Member are exposed in a northeastward-trending belt adjacent to the Marsh Creek Breccia Member in the

Chigmit Mountains. The belt, about 1-2 miles wide, is complexly folded and faulted between Iniskin Bay and Iliamna Volcano. The northward-trending Bruin Bay thrust fault transects the northeastward-striking beds on the southeast slope of Iliamna Volcano, and the member is missing to just north of Johnson River, where it reappears in the east side of the fault zone. The beds continue at least as far as Tuxedni Bay and may continue northeast of the bay for some distance. The segment northeast of Johnson River is less complex structurally than is the part southwest of Iliamna Volcano, probably because the northern segment lies on the east side of the fault zone and was not subjected to the crushing and crumpling that was exerted on the west or upthrown side of the fault.

The abnormally wide outcrop area between Iniskin Bay and Marsh Creek (Clearwater Creek) may be caused by a large anticlinal structure, or possibly by several structural features. Field observations are rather meager for this interval, but they do support the existence of at least one major anticline having steeply dipping flanks and a strong southwesterly plunge. This anticlinal trend was not observed north of Marsh Creek (Clearwater Creek), where the beds have a steep monoclinical dip to the east. Many faults cut the beds on the south slope of Iliamna Volcano. A few of the more conspicuous faults are shown on plate 1; they probably were formed by the rising magma chamber under the volcano, and displacement on them probably is minor.

#### CHARACTER

The Portage Creek Agglomerate Member is composed mainly of fragmental volcanic ejecta somewhat similar to that of the underlying Marsh Creek Member, the main difference being in the form and color of the ejecta. In this member the fragments are mostly rounded volcanic bomb-type detritus, and they form massive beds of agglomerate and lapilli tuff having an overall red or pink color. Some beds contain a preponderance of tuff matrix, others consist almost entirely of coarse fragments having little or no matrix.

The distribution of the coarse volcanic ejecta is just opposite to that of the Marsh Creek Member in that most of the agglomerate and lapilli tuff beds are in the southern rather than the northern part of the region where the rocks grade into fine-grained tuffs, clastic sediments, and lava flows. This distribution seems to indicate a different source area, and could be the reason for the difference in rock types. These rocks are lighter than those of the Marsh Creek Member and are more felsic. Agglomerate and lapilli tuff constitute about 50 percent of the section between Iniskin Bay and Marsh Creek. In the central part of the region these rocks form less than 20 percent of

the section, and at Tuxedni Bay, about 30 percent. Neither the ratio of lapilli tuff to agglomerate nor the rate and direction of change can be determined, because most of the rocks were identified in the field simply as agglomerate and samples are not now available for determination.

The tuffaceous agglomerate and lapilli tuff form thick to massive units in the Portage Creek Member. These units, however, are not quite as massive as are the beds of coarse fragmental ejecta in the underlying Marsh Creek Member, but the interbeds of lava, tuff, and clastic sedimentary rocks are thicker than in the Marsh Creek Member. This change in the lithologic character of the beds would indicate a lessening of the violent volcanic activity in the source area, particularly in the source area adjacent to the central part of the region where thick units of normal sedimentary rock were deposited during this time.

Crystalline to vitric andesitic tuff in thin to medium beds is interlayered with the agglomerate and the lava flows; it is also an important constituent of the clastic sedimentary rocks. Most of the tuff is red to tan, but in a few localities it is basaltic. The bedded tuff is well indurated and brittle, and most beds are laminated.

A specimen of welded lithic tuff agglomerate from the section on the south shore of Tuxedni Bay was examined in thin section. This sample (51AJu119) is from about 1,500 feet below the top of the member. The rock is altered considerably but seems to have a matrix of albite, epidote, and sericite. Devitrified pumice lapilli that have crushed spherulites and lithophysae are present; spherulites are filled with tridymite. Large crystals of orthoclase and andesine are scattered throughout the specimen, as are small crystals of epidote. Numerous lithic fragments of porphyritic volcanic rock are included; these fragments appear less altered than the host rock. Anhedral to subhedral crystals of hematite and ilmenite form 2-3 percent of the specimen. Opacite crystallites are scattered throughout; they are believed to be mostly ilmenite altered to leucoxene.

Lava flows are interbedded with the other rocks in the Portage Creek Member. The flows are generally medium-green andesite porphyry. The thickest sequence of flows is exposed at Tuxedni Bay, where 430 feet of porphyritic andesite underlies a thick unit of agglomerate and breccia and overlies another unit of agglomerate. Sample 51AJu110, from the top of this sequence (600 feet below the top of the member), is probably typical of those examined in thin section. It is a biotite andesite porphyry having a pilotaxitic to felted groundmass of andesine in which large phenocrysts of altered biotite and zoned labradorite are





common and hornblende and andesine less common. Some of the biotite is altered to chlorite, and the feldspars commonly are partly altered to kaolinite. The authors interpret this section as being very close to the vent, because about 75-80 percent of the rock is coarse pyroclastic.

Sedimentary rocks in the Portage Creek Member are mainly argillite, green to dark greenish gray and well indurated. These rocks are found primarily in the central part of the region along with bedded tuff. A massive coarse-grained tuffaceous volcanic sandstone is present at Tuxedni Bay, where it is the only sedimentary rock in the section. Several limestone beds were noted with the argillite on Middle Glacier Ridge.

#### THICKNESS AND STRATIGRAPHIC RELATIONS

The authors qualify all thickness estimates listed for this member as they did for the Marsh Creek Breccia Member, that is, thickness values were computed from rather meager field information and are therefore approximate. The thickness of the Portage Creek Agglomerate Member is believed to be between about 2,250 and 2,850 feet.

The member is here named after Portage Creek, on Iniskin Peninsula, and is fairly well exposed on the east slope of Mount Eleanor, which is just west of the creek. However, the section on the south shore of Tuxedni Bay is better exposed and has more field control; it is therefore designated the type section for the member. It starts about 2.4 miles northwest of Fossil Point and continues along the shoreline to the contact with the underlying Marsh Creek Member. The section was studied by Arthur Grantz and J. K. Hartsock in 1951 and by R. W. Juhle in 1951 and 1952. Details of the type section are listed below.

*Type section of Portage Creek Agglomerate Member from south shore of Tuxedni Bay*

Fault.

Portage Creek Agglomerate:

	<i>Thickness (feet)</i>
Agglomerate, massive, coarse, red to pink, tuff matrix; green volcanic breccia near base; small fault cuts section.....	400
Lava flow, bedded, biotite andesite porphyry; diorite dike and sill cuts lava.....	400
Agglomerate and breccia, coarse, red, tuff matrix....	150
Volcanic breccia, massive, coarse, red; several thick units of hard crystalline tuff; andesite porphyry flow near base.....	550
Lava flow, massive, aphanitic, green.....	150
Sandstone, massive, coarse-grained, tuffaceous.....	450
Fault, probably small.	
Agglomerate and breccia, coarse, red to pink; cut by diorite dike.....	150
Total.....	2, 250

Fault.

Marsh Creek Breccia Member.

The stratigraphic relationship between the Portage Creek Agglomerate and Marsh Creek Breccia Members is not known clearly, because in nearly all parts of the mapped area their contact is a fault. The contact is apparently conformable on the divide between Difficult Creek and Johnson River. The contact with the overlying Horn Mountain Tuff Member is also commonly faulted. Where not faulted, the contacts seem to be conformable. However, inasmuch as the field observations are rather meager and the beds are nearly all massive, the authors hesitate to call any of these contacts conformable.

#### AGE AND CORRELATION

Because the Portage Creek Agglomerate Member is unfossiliferous in this region, the exact position within the Lower Jurassic cannot be determined. The Early Jurassic age assignment is reliable, however, for the member underlies beds that can be correlated with part of the Lower Jurassic (see p. 14) and overlies rocks that rest on Upper Triassic. Additional work in the sedimentary rocks of the central part of the region may demonstrate the presence of fossils usable for more precise dating.

#### Horn Mountain Tuff Member

#### AREAL DISTRIBUTION

On the Iniskin Peninsula, the Horn Mountain Tuff Member is exposed in a narrow belt  $\frac{3}{4}$  to 1 mile wide along the west side of Portage Creek valley. Tertiary lava flows in Range Peak cover several square miles of the member at the Iniskin Bay end of this belt. The area of exposure on the steep eastern slopes of the Chigmit Mountains is sharply defined by fault boundaries. The Bruin Bay fault is the eastern boundary. The western fault boundary with the Portage Creek Agglomerate Member probably has only minor stratigraphic displacement.

The member is not present in the mountains at the head of Chinitna Bay but reappears on the north side of the bay between West Glacier Creek and the Bruin Bay fault along Horn Creek. The best exposures are in Horn Mountain, the type locality for the member. The section is highly faulted north of Chinitna Bay; a few of the more important faults are shown on plate 1. Stratigraphic displacement along Bruin Bay fault reaches a maximum of 12,000-13,000 feet in this area.

A small patch of Horn Mountain Tuff Member is present on a mountain top between the north branch and middle branch of East Glacier Creek. At this point the northward-trending Bruin Bay fault zone transects the northeastward-striking beds. The member reappears east of the fault along the south side of Lateral Glacier and then continues as a belt 1-2 miles wide in a northeasterly direction to Tuxedni Bay.

## CHARACTER

Bedded tuff and tuffaceous feldspathic sandstone are the dominant lithologic types in the Horn Mountain Tuff Member. Porphyritic andesite lava flows are present locally, although they constitute only a minor part of the total thickness. Volcanic breccia, agglomerate, greenstone, and argillite are minor constituents.

Bedded tuff is present in all sections; it is best exposed in Horn Mountain, where it occurs as thin-bedded to massive units that are fine to coarse grained and white, tan, red, green, purple, or mottled. Most of the beds are fine to coarsely crystalline, but a few are lithic tuff; all are well indurated. Some of the beds, at least, were deposited in a continental environment, for tree stumps in an upright position were noted near the top of Horn Mountain. The thin-bedded laminated units may have been deposited in a marine environment, inasmuch as graded bedding is not uncommon and a few belemnite fragments were found.

A sample of coarse red lithic tuff (51AJu9) from about 50 feet below the top of the Tuxedni Bay section was examined in thin section. This rock is a water-laid lithic tuff in which many of the large crystals and rock fragments are distinctly rounded. The matrix is very fine grained to microcryptocrystalline. Several large masses of black vesicular devitrified pumice were noted; the vesicles were filled with kaolinized orthoclase and olivine. Large euhedral crystals of orthoclase, hornblende, plagioclase, and magnetite were common throughout in clasts of volcanic flow rock. The rock was considerably altered, there being kaolinite on the feldspars. This sample was more highly altered than similar tuff from either of the underlying members of the formation. The reason for this alteration is increased weathering due to the proximity of the sample to the overlying major unconformity.

Tuff is present in nearly all the clastic sedimentary rocks of the member, particularly the arkosic sandstone and conglomerate. One such sample (51AJu-102A) from 1,000 to 1,200 feet below the top of the Tuxedni Bay section was examined in thin section under the microscope. The matrix constitutes about 50-60 percent of the rock and is about half silt and half clay, the silt being angular microcrystalline quartz. Large rounded grains of cloudy quartz, orthoclase, and volcanic rock fragments make up about 35-40 percent of the rocks. Minor amounts of garnet and zircon are also present. A specimen of quartz arenite from an overlying bed was 90-95 percent quartz. The quartz is subangular to subround and slightly frosted. Little or no matrix is present, but finely crystalline quartz probably was derived from a silt matrix. Pla-

gioclase, orthoclase, zircon, and magnetite are present in minor amounts.

The quartz arenite at this locality is of minor importance, for the bed is only a few feet thick. Although there is little or no matrix, the rock is well indurated and has negligible pore space. Microcrystalline quartz surrounding larger quartz grains was formed probably from a relic silt matrix. The bed probably does not have much areal extent because arenite is an exotic rock type in a typical eugeosyncline. The quartz probably is merely a well-sorted phase of rock derived from the same source as the arkosic sandstone.

Many of the arkosic sandstone beds have more feldspar than the specimen described above and probably could be accurately termed feldspathic graywacke. Volcanic and other rock fragments as much as a few inches in diameter are commonly included in the arkosic rocks.

Bedded tuff and the tuffaceous content of the clastic sedimentary rock increases southward across the region. A few beds of agglomerate and breccia are present in each of the sections measured south of Tuxedni Bay, but the coarse volcanic ejecta is not an important part of the stratigraphic sequence.

Porphyritic andesite lava flows are present in all sections. Most of the bedded flows are thick, as much as 550 feet thick at Tuxedni Bay.

## THICKNESS AND STRATIGRAPHIC RELATIONS

The Horn Mountain Tuff Member was examined in somewhat greater detail in the field than were the underlying members of the formation, owing chiefly to its accessibility and to its proximity to the sedimentary rocks of the Middle Jurassic. Thickness estimates are therefore believed to be fairly reliable.

The top of all sections is either an angular unconformity or a fault. The unconformity is a major depositional break between the Lower and Middle Jurassic and represents a hiatus of considerable magnitude. The amount of section missing is of course unknown, but the region apparently was reduced to about the same base level, inasmuch as the section from the Beal well correlates fairly closely with the exposed section.

The thickest section measured is 2,850 feet; it is exposed on the south shore of Tuxedni Bay. The type locality is Horn Mountain, after which the member is here named, from the shore of Chinitna Bay to the peak of Horn Mountain and north along the ridge to the contact with the Portage Creek Agglomerate Member; this section is 1,800 feet thick. The Bruin Bay fault cuts off the top of the section, so details of the section

above the lava flow are added from sections exposed farther north.

The type section was examined by Arthur Grantz in 1951 and R. W. Juhle in 1952. Some additional details were added by R. L. Detterman and W. D. Hinckley in 1958.

*Type section of Horn Mountain Tuff Member at Horn Mountain*

Horn Mountain Tuff Member:	<i>Thickness (feet)</i>
Top of exposed section.	
Porphyritic andesite lava flow-----	100
Sandstone, arkosic to feldspathic, thin-bedded, fine- to coarse-grained, tuffaceous; few interbeds of brown to gray siltstone and a few pebble layers; plant and belemnite fragments-----	550
Tuff, bedded, coarse, red and mottled; a few interbeds of tuffaceous sandstone-----	300
Tuff, thin-bedded, fine- to coarse-grained, red, green, purple, and mottled; volcanic breccia near top and a thin unit of green argillite in lower part; few plant fragments-----	550
Sandstone, massive, fine- to coarse-grained, feld- spathic, tuffaceous; few interbeds of red and mot- tled tuff-----	300
Total-----	1,800
Contact Portage Creek Agglomerate Member.	

Sections exposed farther north indicate that about 800 feet was cut from the top of the Horn Mountain section by the fault. Of this amount, 100–150 feet is porphyritic andesite lava; the remainder is mainly bedded tuff and some tuffaceous arkosic sandstone.

#### AGE AND CORRELATION

A few belemnites and plant fragments were found in the bedded tuff near the top of the member. Unfortunately, these fossils were of little value for an age determination because they were poorly preserved and could not be identified specifically. Belemnites are abundant in the overlying beds of Middle Jurassic age, but the Horn Mountain Tuff Member is not considered to be Middle Jurassic, mainly because of the degree of induration, difference in lithology, and the angular unconformity separating the member from the overlying beds. Perhaps the best correlation can be made with beds in the upper part of the Talkeetna Formation from the Talkeetna Mountains area. At that locality the upper part of the formation contains fossils that represent the upper Pleinsbachian and Toarcian stages of Early Jurassic age (Arthur Grantz, oral commun., 1963).

#### MIDDLE JURASSIC ROCKS TUXEDNI GROUP

As a result of the present investigations in the Iniskin-Tuxedni region, the Tuxedni Formation was raised to group status and the former members to formations

(Detterman, 1963). This change in nomenclature is considered the best solution for mapping the thick sequence of Jurassic rocks exposed in southern Alaska and on the Alaska Peninsula. The new formational units are readily mappable everywhere within the region and conform to all requirements of a formation.

The Tuxedni Group was first described as the Tuxedni Sandstone by Martin and Katz (1912, p. 59), and the type section was given as the south shore of Tuxedni Bay, after which it was named. This section on Tuxedni Bay had been visited by Eichwald (1871) and Dall (1896); consequently, it was one of the better known geologic units in Alaska at the time Martin and Katz described the formation. They gave a thickness of 1,128 feet for the unit that starts at Fossil Point and extends 2½ miles northwest along the shoreline. They also recognized the presence of a fault within the section.

The Tuxedni Group, as used in this report, is much thicker than the unit described by Martin and Katz, but the general composition of the included rock units are similar to the beds exposed in the Fossil Point section. Fossil Point is retained as the type locality for the group, but type localities are refined for the six formations. The group has an exposed thickness of 4,970–9,715 feet; some additional section is penetrated by the oil wells in the subsurface under Iniskin Peninsula.

The Tuxedni Group underlies more of the mapped area than any other unit and forms an almost continuous belt 2–6 miles wide from Iniskin Bay to Tuxedni Bay. The group is faulted out for a short distance north of Chinitna Bay, as it is south of Iniskin Bay. The areal extent of the Tuxedni Group immediately north of Tuxedni Bay is not known; however, it probably extends northward from the bay in line with outcrops to the south. Good exposures of nearly all of its formations are present on streams that drain the central part of the mapped region.

Feldspathic graywacke, low-rank graywacke, sandstone, conglomerate composed mainly of volcanic rocks in a graywacke matrix, siltstone, and shale are the chief rock types in the Tuxedni Group. Thick units of one predominant rock type are found within the group and constitute the basis for differentiating the Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, and Twist Creek Siltstone Formations. In all these formations other kinds of rocks are interlayered with the dominant rock type. Conversely, the Red Glacier Formation at the base of the Tuxedni Group and the Bowser Formation at the top are distinguished by the heterogeneous nature of the included rocks.

## Red Glacier Formation

A thick sequence of massive dark-gray arenaceous siltstone and sandstone interbeds, tan arkosic sandstone, and black silty shale at the base of the Tuxedni Group was named the Red Glacier Formation by Detterman (1963). Good exposures are present on both sides of Red Glacier, after which it is named. This unit was formerly named the siltstone member of the Kialagvik Formation by Kirschner and Minard (1949) (table 2). The Kialagvik Formation is exposed at Wide Bay on the Alaska Peninsula some 200 miles southwest of this region. As far as can be determined from present field information, there are no exposures of equivalent beds between the two areas. This sequence of rocks is now part of the Tuxedni Group (Detterman, 1963) for it is genetically related to the Tuxedni and is part of the original Tuxedni Sandstone at Fossil Point; no logical tie can be found with the Kialagvik Formation. The term "siltstone member" used for this unit by Kirschner and Minard (1949) is a misnomer; it resulted from the fact that at the time of their report only the upper silty part of the present formation was known from Iniskin Peninsula. Below the siltstone are thick units of sandstone and shale that are also included in the formation by the present authors.

## AREAL DISTRIBUTION

Part of the type section of the Tuxedni Group as described by Martin and Katz (1912, p. 60, units 21-37) is now mapped as Red Glacier Formation. From the exposures on the south shore of Tuxedni Bay, the formation continues about S. 50° W. in a well-defined belt 1-2½ miles wide to the valley of Boulder Creek. The general structural trend of the rock changes abruptly south of Boulder Creek; this change may be in part due to the upwelling of magma in Iliamna Volcano. The strike becomes more westerly, and the beds are terminated on the east slope of the volcano by the Bruin Bay fault or are covered by lava flows. No other exposures of the member are known for the area north of Chinitna Bay.

Good exposures are found in bluffs on the south shore of Chinitna Bay between the mouth of Gaikema Creek and the Marsh Creek tidal flat. Only the upper part is present where these beds wrap around the end of Tonnie syncline. The beds continue southwest along the flanks of Tonnie syncline as far as Low Creek, where they are terminated by the intersection of the Low Creek cross fault and a branch of the Bruin Bay fault. A thin unit of the formation is exposed at the base of the ridges forming the west wall of the Fitz Creek Valley, between the mouth of Twist Creek and Hardy Creek. A maximum of about 300 feet is

exposed at the mouth of Tonnie Creek, where the formation was faulted to its present position.

## CHARACTER

The Red Glacier Formation is a heterogeneous assemblage of rocks consisting mainly of siltstone, arkosic sandstone, and shale, and minor amounts of subgraywacke, conglomerate, and limestone. The main constituents generally are in units a few hundred to more than a thousand feet thick that contain thin interbeds of other rock types (pl. 5).

Siltstone forms about 40 percent of the exposed rock and is concentrated mainly in the upper part; these features explain why this unit was originally called the siltstone member (Kirschner and Minard, 1949). The siltstone is predominantly coarse grained, thin bedded to massive and dark gray to moderate olive gray; it weathers brownish gray to dark rusty brown. It contains numerous rock fragments and, because it is highly arenaceous, it is not much different from the fine-grained subgraywacke sandstone that forms interbeds in the section. Locally the upper part of this siltstone unit contains lenticular interbeds and ovoid concretions of reddish-gray dense, very hard limestone and a few very thin seamlets of coally material. The sandstone interbeds have a few pebbles locally, generally less than half an inch in diameter.

Arkosic sandstone underlies the siltstone and forms about 25 percent of the total exposed section. Several well-defined units of arkose, 200 to more than 700 feet thick, occur in the sections north of Chinitna Bay. The same units were found in the oil wells on Iniskin Peninsula as well as additional units that probably represent the rocks faulted out in the type section. The arkosic sandstone is massive, fine to medium grained, light tan to buff, and hard. The grains are angular to subangular and contain only a small amount of kaolinitic matrix. Feldspar makes up about 35-40 percent of the component minerals. Contacts between the arkose and the enclosing shale and siltstone are sharp, and there are only a few interbeds of other rock types.

A thick shale sequence is exposed in the type section and is found in the oil wells. The shale is silty to arenaceous, black, very fissile, and soft, and is easily weathered. Many lenticular limestone beds and concretions occur in this unit, as do a few thin silty sandstone interbeds. Locally the shale is in contact with Quaternary lava flows from Iliamna Volcano and has been baked to a slatelike texture. The baked shale is commonly red owing to oxidation of the pyrite during contact with the hot lava. Much of the black shale has a high carbonaceous content.

The lithology of the formation is remarkably uniform throughout the mapped area. Rapid facies changes that are present in the younger formations of the Tuxedni Group are not noticeably present in the Red Glacier, and equivalent beds can be readily recognized at the various localities.

#### THICKNESS AND STRATIGRAPHIC RELATIONS

The exposed parts of the Red Glacier Formation range in thickness from about 2,000 to 4,500 feet; about 2,000 feet of additional section was penetrated in the oil wells. This additional section may represent in part the rocks cut out of the type section by a fault, inasmuch as good correlation above the fault can be maintained between the two areas.

Most exposures of the formation include only the upper part. On Iniskin Peninsula about 1,525 feet of the upper part is exposed in steeply dipping beds on the south shore of Chinitna Bay. The beds wrap around the sharply folded Tonnie syncline with an average dip of about 45°. Southwest along the flanks of the syncline even less of the formation is exposed. The only complete section is exposed along Hungryman Creek and the south shore of Tuxedni Bay. The formation is 1,980 feet thick at this locality and rests unconformably on the older Talkeetna Formation. This 1,980 feet is believed to represent only the upper part of the formation, for it probably was deposited by progressive onlap onto the older rocks.

The thickest section is computed to be 4,540 feet thick from exposures along Red Glacier; this is the type section for the Red Glacier Formation. Part of the type section is exposed on the south side of the glacier and part on the north side. The type locality for the upper 3,310 feet is defined as being the ridge between Red Glacier and Boulder Creek, lat 59°59'45" N., long 152°57' to 152°59' W.; that for the lower 1,230 feet is the ridge between Red Glacier and Lateral Glacier, lat 60°02'30" N., long 152°57' to 152°58' W. The section was measured with planetable and alidade by Arthur Grantz and Richard Hoare in 1951 and rechecked by R. L. Detterman and D. W. Hinckley in 1958.

#### Type section of Red Glacier Formation

Gradational contact.

Red Glacier Formation:

Siltstone, thin-bedded, coarse-grained, brownish-gray; thin interbeds of very fine grained sandstone; large limestone concretions in upper part; porphyritic andesite sill near middle of unit; many thin coquina beds containing <i>Witchellia</i> , <i>Parabigotites</i> , <i>Holcophylloceras</i> , and the pelecypods <i>Meleagrinnella</i> , <i>Trigonia</i> , and <i>Inoceramus</i> .....	750
Siltstone, massive, coarse-grained, gray; weathers grayish brown.....	410

Approximate thickness (feet)

#### Type section of Red Glacier Formation—Continued

	Approximate thickness (feet)
Red Glacier	
Sandstone and siltstone; the sandstone is thin to medium bedded, fine to medium grained, light brown; the siltstone is thin bedded, coarse grained, brownish gray; plant fragments and a few pelecypods and belemnites.....	1,060
Sandstone, arkosic, massive, fine- to medium-grained, buff; 35-40 percent feldspar in kaolinitic matrix; few plant fragments.....	720
Shale, massive, silty to arenaceous, black, very soft and easily weathered, carbonaceous; large concretions and lenticular beds of limestone in upper part; siltstone interbeds in lower parts; many plant fragments; few invertebrate fossils, <i>Tmetoceras</i> ; fault near middle, section below fault measured on ridge north of Red Glacier.....	1,000+
Sandstone, arkosic, massive.....	200
Shale, thin-bedded, silty, banded, black and gray; altered to slate in upper part; few thin sandstone interbeds.....	210
Sandstone, arkosic, massive, tan.....	190
Total section exposed.....	4,540+
Angular unconformity.	

The contact between the Red Glacier Formation and the overlying Gaikema Sandstone is conformable in all exposures. It is not a sharp contact but is gradational through about 50-100 feet of section in which there is a gradual increase in sand constituents and a corresponding decrease in silt. The authors recognize the fact that the contact may not be on the same bed throughout the region, but for convenience they have placed it at the base of the first predominantly sandstone unit.

The depositional contact with the Talkeetna Formation is rarely seen because in most exposures the Red Glacier Formation is in a fault contact relationship with the older rocks. The sections from Hungryman Creek and the north side of Red Glacier show the normal relationship between the two formations, and the contact is an angular unconformity. The strike and dip of the beds change across the contact, and the older rocks appear to be more highly weathered.

The upper and lower contacts of the Red Glacier Formation apparently converge rapidly toward the northeast, for the formation thins from about 6,500 feet at the oil wells on Iniskin Peninsula to 4,540 feet at Red Glacier and finally to 1,980 feet near Tuxedni Bay (fig. 2). Inasmuch as the upper contact with the Gaikema Sandstone is conformable and, fauna of the Tuxedni Bay section of the Red Glacier Formation correlates fairly well with that of the upper part of the thicker sections to the southwest, the change would appear to be mainly at the base of the formation. The formation probably was deposited by progressive onlap

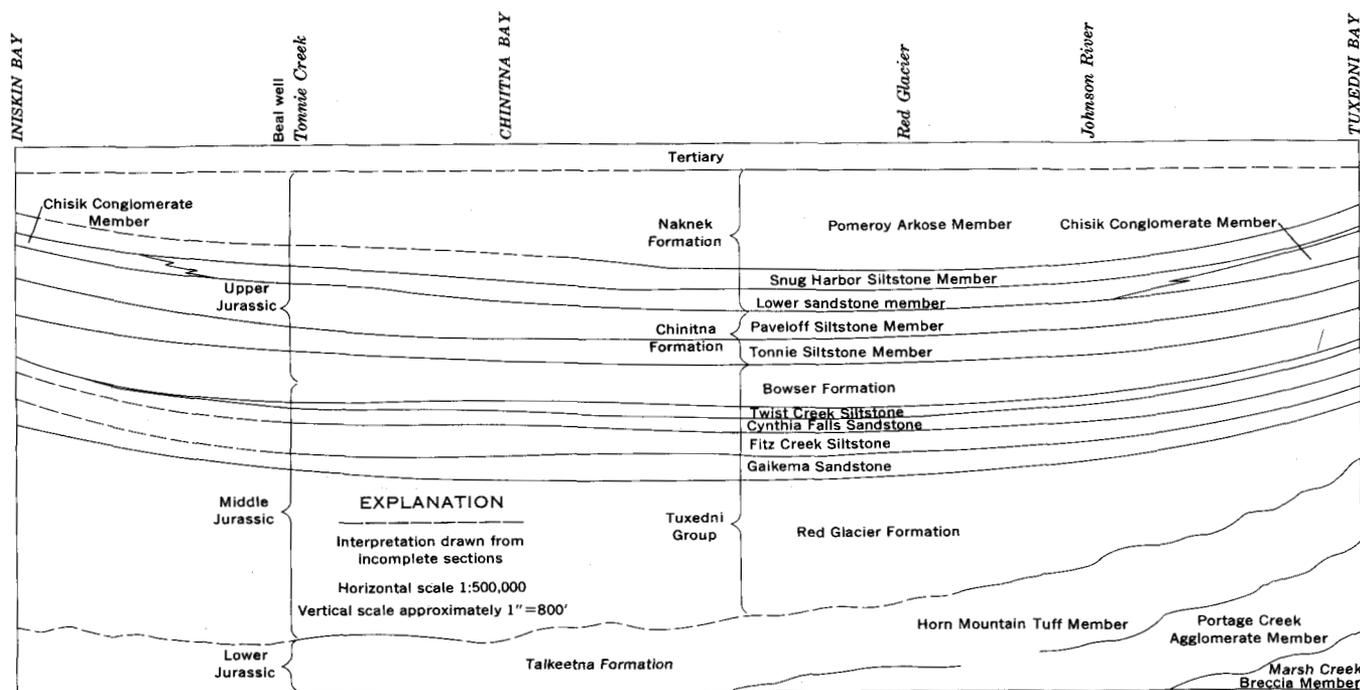


FIGURE 2.—Depositional relationships of the Jurassic stratigraphic units.

onto an irregular south-dipping erosional surface formed on the Talkeetna Formation; some of the increase in section probably is due to subsidence of the basin during deposition.

#### AGE AND CORRELATION

Middle Jurassic sedimentary rocks in the Iniskin-Tuxedni region include some of the most fossiliferous beds discovered in Alaska. Fossils consist mainly of pelecypods and ammonites collected from beds for which there is good stratigraphic control and relatively close spacing of samples (table 4). The ammonites in particular permit a close correlation with the standard stages and zones as set up for northwest Europe by Arkell (1946, 1956). Many new species have been studied and described by R. W. Imlay, of the U.S. Geological Survey, who helped collect and who identified and dated all recently obtained material from the region.

Molluscan faunal remains reported from the Red Glacier Formation are largely from the upper 2,000 feet because that part of the section is exposed more often and in more accessible locations than is the lower part of the formation. The few sections of the lower part studied indicate that the upper few thousand feet are actually more fossiliferous. Numerous thin layers of coquina are recorded in the upper 800–1,000 feet. The coquina is composed mainly of the pelecypods *Meleagrinnella*, *Trigonia*, *Inoceramus*, *Camptonectes*, and *Pleuromya*. Belemnite fragments are also common in the coquina layers, but ammonites are not.

Ammonites in the Red Glacier Formation represent at least two distinct faunal assemblages that can be correlated with the standard zones of northwest Europe. The lower assemblage includes *Erycites*, *Tmetoceras*, and *Pseudolioceras* that correlate closely with the standard zone of *Tmetoceras scissum* of early Bajocian age. The genus *Erycites* in Europe ranges through the early Bajocian (Arkell and others 1957, p. L267; Imlay, 1964, p. B17). In the Iniskin Tuxedni region this faunal assemblage occurs from 1,500 to 4,550 feet below the top of the formation. No fossils have been recorded from the lower 2,000 feet present in the well sections.

The upper faunal assemblage is in the upper 1,300 feet of the formation and with but one exception it does not overlap the lower assemblage. The one exception may be mislocated stratigraphically. The upper assemblage of ammonites includes *Sonninia*, *Emileia*, *Parabigotites*, and in the upper 500 feet, includes also *Papilliceras*, *Strigoceras*, *Lissoceras*, *Stephanoceras*, *Stemmatoceras*, and *Skirroceras*. The abundant *Sonninia* and *Emileia* by themselves indicate a possible correlation with the zone of *Sonninia sowerbyi* of early middle Bajocian age (R. W. Imlay, written commun., 1958). The addition of *Stemmatoceras*, *Stephanoceras*, *Normannites*, and *Witchellia* in the upper 500 feet indicate a good correlation with the lower part of the zone of *Otoites sauzei* of middle Bajocian age, on the basis of the association of *Emileia* and *Normannites* (Imlay, 1964, p. B10–B12).







FIGURE 3.—Vertical stereoscopic view of part of Iniskin Peninsula, giving the locations of type sections for Gaikema Sandstone (Jtg), Fitz Creek Siltstone (Jtf), Cynthia Falls Sandstone (Jtc), Twist Creek Siltstone (Jtt), and Bowser Formation (Jtb) of the Tuxedni Group; the Tonnie Siltstone (Jct) and Paveloff Siltstone (Jcp) Members of Chinitna Formation. Photograph by U.S. Air Force.

#### AREAL DISTRIBUTION

The best exposures of the Gaikema Sandstone are on Gaikema Creek and in the bluffs on the south shore of Chinitna Bay between the mouth of Gaikema Creek and the Marsh Creek tidal flats. At the latter locality the beds are exposed near the tops of the bluffs where they wrap around the northeast end of Tonnie syncline. The formation is present on both limbs of the syncline as a narrow belt, as much as 1,500 feet wide, that extends southwestward from the above-mentioned localities for a distance of 4–5 miles. The rocks exposed on the northwest limb of the syncline are terminated by a normal fault 2 miles southwest of Low Creek. The fault is part of the Bruin Bay fault system. The formation is exposed across the axial zone of the faulted Gaikema Creek anticline as far as the Fitz Creek Valley; from there it continues southwest, at the base of the ridge, to a point just southwest of the Antonio Zappa well 1.

In the northern part of the area the formation is exposed in a southwestward-trending belt from near Fossil Point to Boulder Creek, where the beds attain a more westerly trend and are covered by a lava flow from Iliamna Volcano. The belt of exposures is abnormally wide between Johnson River and Fossil Point; this area is on the southeast slope of the mountains and is nearly a dip slope for the greater part of its width. Within this area are erosional remnants of younger Fitz Creek siltstone and two small exposures of Red Glacier Formation where streams have cut through the Gaikema Sandstone.

#### CHARACTER

Resistant cliff-forming sandstone, in part conglomeratic, is the dominant lithic type in the formation.

Siltstone, shale, and cobble-boulder conglomerate are important but subordinate constituents that are present in varying amounts in some parts of the area. Sections containing a considerable amount of siltstone have few conglomerate interbeds; elsewhere, thick-bedded conglomerate is present with little or no fine clastic shale and siltstone. Thus, a facies change is recognized within the formation, the coarser clastics being confined mainly to the area of Iniskin Peninsula.

The sandstone is massive to thin bedded, most of the beds being 1–10 feet thick. Graded bedding is common, particularly in sections on Iniskin Peninsula where the rocks are somewhat coarser textured than farther north. The grain size varies from very fine to coarse, and the rocks are generally dark to light green and greenish gray in fresh exposures and dark brown to orange red on weathered surfaces. Angular rock fragments and a considerable amount of feldspar in a fine-grained chloritic matrix indicate that most of these sandstone beds are actually high-rank graywacke (Krumbein and Sloss, 1951, p. 121) and feldspathic sandstone.

Conglomerate is confined mainly to the Iniskin Peninsula, where thick-bedded units are present in the type section. The rock fragments are all well rounded and consist of pebbles, cobbles, and boulders of red and green felsitic rocks, aphanitic igneous rocks, and some metasedimentary rocks. The composition of the detrital elements indicates that nearly all were derived from the Talkeetna Formation. A few granitic rock clasts were possibly derived from the pluton forming the core of the Aleutian Range; this occurrence of granitic clasts is the first in the Middle Jurassic rocks. The conglomeratic constituents are generally well sorted as to size within individual beds, and rarely

show the graded bedding feature that is present in the sandstone; however, some beds are graded. The conglomerate becomes thinner and the constituents smaller in a southeasterly direction on Iniskin Peninsula. North of Chinitna Bay the rocks of the formation are generally finer grained, having only a few pebbles in a sandstone matrix to mark the presence of beds that correlate with the massive conglomerate farther south.

Siltstone forms nearly 40 percent of the formation exposed in the ridge between Boulder Creek and Red Glacier; elsewhere it is generally less than 10 percent, occurring mainly as thin interbeds in a section that is otherwise predominantly sandstone. The formation is not exposed between the silty section exposed on Boulder Creek and the predominantly coarse clastic section on the south shore of Chinitna Bay, so the exact nature of the facies change is the subject of much conjecture. The change would have to be rapid, for the two areas are only 11 miles apart.

The siltstone is thin bedded to massive, generally coarse grained to sandy, and gray to olive gray; it weathers brownish to rusty brown. Graded bedding is common. Arenaceous limestone interbeds that weather a bright-rusty orange are found in a few exposures. The siltstone has the same general composition as the sandstone.

Lenticular to slightly irregular bedding surfaces are common in many exposures of the Gaikema Sandstone but not in areas where graded bedding features are abundant. Carbonized plant remains are sometimes localized into lenticular pockets along the irregular surfaces of the beds. Thin coquina layers formed mainly of pelecypods occupy well-defined zones in the lower part of the formation similar to those in the underlying Red Glacier Formation.

THICKNESS AND STRATIGRAPHIC RELATIONS

Exposed sections of Gaikema Sandstone range in thickness from 500 to 870 feet. The type section from Gaikema Creek, measured on the southeast flank of Tonnie syncline in beds having an average dip of 45°, is 850 feet thick. The section thins in a southwesterly direction on Iniskin Peninsula, being only 500 feet thick on Tonnie Creek.

The thickest section is exposed along the north side of Boulder Creek about 1 mile northwest of Hickerson Lake in beds that dip 15°–20° SE. This section also contains the highest percentage of fine clastic rocks. The section from Bear Creek, near Tuxedni Bay, is computed as 600 feet thick; it was measured in the ridge between Bear Creek and Hungryman Creek. This part of the region is cut by many faults, but the section is believed to be complete.

Sections from parts of the area not included on plate 5 range in thickness between the values represented on the plate. One possible exception may be a section on a tributary of Gaikema Creek, where L. B. Kellum and Helmuth Wedow measured 970 feet. The stream follows the faulted axis of the Gaikema creek anticline, and the present authors believe the 970 feet represents some duplication of section by faulting, particularly inasmuch as the unfaulted type section a quarter of a mile northwest is 850 feet thick.

The type section for the Gaikema Sandstone is along the north bank of Gaikema Creek, lat 59°48' 35'' N., long 153°10'50'' to 153°11'30'' W. (pl. 3; fig. 3). This section is about 1 mile from the shore of Chinitna Bay and is readily accessible from the bay. The section was measured with plane table and alidade by L. B. Kellum and Helmuth Wedow in 1944 and was rechecked several times between 1948 and 1958.

Type section of Gaikema Sandstone

Contact.	Thickness (feet)
Gaikema Sandstone:	
Sandstone, medium-bedded, medium-grained, dark-olive-green; weathers dark brown; cobble conglomerate near middle of unit, mainly well-rounded volcanic rock.....	120
Sandstone, thin- to medium-bedded, medium-grained, olive-green to gray; mottled by many light-gray angular feldspar fragments; few silty shale interbeds containing fossils; <i>Witchellia</i> .....	220
Sandstone, medium-bedded, medium- to coarse-grained, arkosic; numerous thick beds of cobble-boulder conglomerate, mainly green and red felsitic rocks; numerous thin coquina beds, mainly <i>Meleagrinnella</i> and <i>Trigonia</i> .....	110
Covered interval.....	50
Sandstone, medium-bedded, medium- to coarse-grained, arkosic, greenish-gray; well-rounded felsic and aphanitic igneous cobble conglomerate; thin coquina beds, mainly pelecypods as above.....	130
Covered interval.....	40
Sandstone, medium-bedded to massive, medium- to coarse-grained, olive-gray to dusky-yellow-green; weathers dark brown; lenticular beds of pebble-cobble conglomerate; silty shale and siltstone in lower part of unit; one thin bed of chocolate-brown friable sandstone near base of unit; many coquina beds, <i>Witchellia</i> , <i>Trigonia</i> , and <i>Inoceramus</i> .....	180
Total section measured.....	850

The contact between the Gaikema Sandstone and the underlying Red Glacier Formation is exposed at many localities on Iniskin Peninsula and in the area north of Chinitna Bay. In all exposures the contact appears to be gradational through about 50–100 feet of section. The authors have placed the contact at the base of the first predominant sandstone unit for convenience in field mapping.



fauna may necessitate some change in the age determinations as given above.

#### Fitz Creek Siltstone

The name Fitz Creek Siltstone was introduced by Detterman (1963) for a thick sequence of dark-gray arenaceous siltstone that overlies the Gaikema Sandstone in the Iniskin-Tuxedni region. This unit was called the lower siltstone member of the Tuxedni Formation by Kirschner and Minard (1949) and the siltstone member of the Tuxedni Formation by Imlay (1953). There are many thick siltstone units in this region; therefore, to avoid confusion, this unit is herein named after the principal stream on the Iniskin Peninsula. The formation is exposed at many localities along the upper course of Fitz Creek and on nearly all tributaries that drain the high ridge to the northwest. The type locality is along Tonnie Creek, 2,000–3,400 feet northwest of Iniskin Bay Association well 1 (fig. 3).

#### AREAL DISTRIBUTION

On Iniskin Peninsula, outcrops of the Fitz Creek Siltstone are mainly confined to two belts along the flanks of Tonnie syncline. These belts, 1,000–1,500 feet wide, lie between two prominent hogback ridges on the lower slopes of the mountain mass formed by Tonnie syncline. The hogback ridges are formed by sandstone and conglomerate of the Gaikema and Cynthia Falls Sandstones. The Fitz Creek Siltstone is less resistant than the underlying and overlying beds and forms a trough between them in which the rocks are less well exposed than are the adjacent beds.

The belt along the northwest flank of Tonnie syncline is terminated by a normal fault that roughly follows the base of the mountain mass along the southeast side of Portage Creek. The section is repeated in Portage Creek valley between this fault and the Bruin Bay fault along the west side of the valley.

The belt on the southeast flank of the syncline continues southwest as far as the pass between Right Arm and Oil Bay; its disappearance here is due partly to faulting and partly to the southwest plunge on the Fitz Creek anticline.

The Fitz Creek Siltstone is the lowest formation of the Tuxedni Group to be exposed in the southeast flank of Fitz Creek anticline. The main exposures here are in the general vicinity of the oil wells, where the formation is present at the base of Havenstrite Ridge. A thin belt is present across the anticlinal

axis from the point where the anticline enters Havenstrite Ridge to the cross fault about 2,000 feet southwest of Cliff Creek. Between Cliff Creek and the south shore of Chinitna Bay, the Fitz Creek Siltstone is exposed at a few scattered localities where streams have cut through the overlying Cynthia Falls Sandstone. The formation occupies the core of the anticline in the bluffs on the south shore of the bay, as well as the small plunging anticlines that lie west of the main anticline as exposed in the bluffs.

In the area north of Chinitna Bay, the Fitz Creek Siltstone is present in a poorly defined belt 1,000–1,500 feet wide from near Tuxedni Bay to Boulder Creek. The soft nonresistant character of the member has aided the growth of streams that occupy the same position as the member, notably Bear Creek and Red Creek. The best exposures north of Chinitna Bay are in the ridge between Boulder Creek and Red Glacier.

#### CHARACTER

Massive bluish-gray arenaceous siltstone that commonly weathers a rusty orange and contains many small ovoid fossiliferous limestone concretions is the dominant lithic type of the Fitz Creek Siltstone. Interbedded with the siltstone are fine-grained sandstone and, locally, conglomerate.

The siltstone is coarse to fine grained and in the upper part it is actually more of a silty shale than a siltstone. The shaly part is somewhat banded in appearance with an alternation of light and dark bands  $\frac{1}{16}$  to  $\frac{1}{4}$  inch thick; coarser grained siltstone interbeds in this shaly section are banded also. Minuscule specks of finely disseminated limonitic material give the shaly parts a rusty-red-brown appearance on a weathered surface. A concretionary weathering feature is also common to the more shaly parts. This part of the section is not seen often in outcrops because the rocks are soft and easily eroded, the best exposures being in some of the roadcuts along the shore of Chinitna Bay and along Fitz Creek. The medium- to coarse-grained siltstone is generally well indurated and weathers brownish gray. It is composed of rock fragments and subrounded grains of feldspar set in a chloritic matrix. Intercalated with the coarser grained siltstone are thin beds of fine-grained sandstone of the same general composition and arenaceous limestone concretions.

Sandstone and conglomerate are not common constituents of the Fitz Creek Siltstone but form an important part in the Gaikema Creek section, where a 75-foot

unit of conglomerate and sandstone occur near the middle of the formation. The constituents are mainly well-rounded pebbles and cobbles of light-green to dark-gray volcanic rock in a very coarse grained dark-green sandstone matrix consisting of angular fragments of volcanic rocks, chloritic material, and feldspar. Most of these constituents probably were derived from the Lower Jurassic Talkeetna Formation. The thin sandstone beds intercalated in the siltstone section are generally very fine to fine grained, dark gray on fresh surface, and light brown on the weathered surface. Feldspar is the most abundant mineral.

Exposures of the Fitz Creek Siltstone in the northern part of Iniskin Peninsula contain a higher percentage of coarse clastic fragments than do exposures elsewhere in the region. This part of the region must have been very near the source area or at the mouth of a large stream that drained the source area to the northwest. The facies change is rapid and fairly consistent in all directions away from the present Gaikema Creek; therefore, sections exposed at points equidistant from Gaikema Creek have about the same proportion of coarse to fine clastics. Sections to the northeast may have a slightly higher percentage of sand.

#### THICKNESS AND STRATIGRAPHIC RELATIONS

Exposed sections of the Fitz Creek Siltstone range in thickness from about 650 to 1,280 feet. As might be expected, the thickest section is from Gaikema Creek and the formation becomes progressively thinner away from this locality. The section from Tonnie Creek is 1,090 feet thick; it was designated the type section because the rocks are more typical of the formation throughout the area than are the rocks in the Gaikema Creek section.

North of Chinitna Bay the maximum exposed thickness is 825 feet in the ridge between Boulder Creek and Red Glacier. Thinning in a northeastward direction further reduces the section to about 650 feet in the vicinity of Tuxedni Bay. Thus, the formation becomes thinner at a rate of about 25 feet per mile northeast of Gaikema Creek and nearly 50 feet per mile southwest of Gaikema Creek.

The type section for the Fitz Creek Siltstone is designated as the section exposed along Tonnie Creek between 2,000 and 3,400 feet N. 55° W. of the Iniskin Bay Association well 1. This is in the southeast flank of Tonnie Syncline in rocks that dip 38°-45° NW (fig. 3). The section was measured with planetable and alidade by L. B. Kellum and Helmuth Wedow in 1944 and rechecked several times between 1948 and 1958.

#### Type section Fitz Creek Siltstone

Contact.	Thickness (feet)
Fitz Creek Siltstone:	
Siltstone, arenaceous, massive, gray; weathers rusty yellow brown and nodular; numerous small limestone concretions and a few beds of nodular limestone and silty sandstone; contains <i>Normannites</i> and <i>Chondroceras</i> .....	530
Sandstone, medium-bedded, very fine grained, silty, gray; weathers brown.....	70
Siltstone, platy, blue-gray; thin beds of silty greenish-gray sandstone; few small limestone concretions; contains abundant <i>Chondroceras</i> , <i>Holcophylloceras</i> , and <i>Zemistephanus</i> .....	340
Covered interval; approximate thickness.....	70
Siltstone, platy, blue-gray; few limestone concretions; <i>Sonninia</i> .....	80
Total section measured.....	1,090

The contact between beds of the Fitz Creek Siltstone and the underlying Gaikema Sandstone appears to be conformable in all exposures. In most places it is a sharp siltstone-on-sandstone contact, but in the vicinity of Gaikema Creek the contact is between two sandstone units and is a little harder to locate. Fortunately the two sandstone units are lithologically dissimilar and the contact can be picked with a fair degree of accuracy. The general area of the contact is expressed topographically by a pronounced break in slope. The relatively incompetent siltstone of the Fitz Creek forms low saddles adjacent to the hogback ridges formed by the resistant Gaikema Sandstone.

The upper contact with the Cynthia Falls Sandstone is sharp and easily recognized. The massive resistant sandstone of the Cynthia Falls forms hogback ridges and many waterfalls on the streams draining the mountains formed by Tonnie syncline. The contact is conformable except in the area just north of Hickerson Lake, where the two formations are locally unconformable. At this locality the top of the Fitz Creek Siltstone is an erosional surface. The authors believe that only a small amount of the Fitz Creek was stripped off here prior to deposition of the Cynthia Falls Sandstone.

The considerable variation in thickness of the Fitz Creek Siltstone suggests the presence of minor depositional unconformities within the formation. These features are undoubtedly present, but they cannot be identified within the limits of a single outcrop.

#### AGE AND CORRELATION

The Fitz Creek Siltstone is abundantly fossiliferous, having a large and varied ammonite fauna that surpasses any present in the older rocks, both in size of individual specimens and in number of species (table 6). Many pelecypods are found, but for the first time

in the Jurassic of this region the pelecypods are less numerous than are the ammonites. This sudden burst in the ammonite population probably represents a change in the ecological conditions of deposition as shown by the change from a general sandstone to siltstone facies. A few brachiopods are present but are nondiagnostic.

Ammonites present in the Fitz Creek Siltstone indicate that the lower fourth correlates with the standard European zone of *Otoites sauzei* and the upper three-fourths correlates with the zone of *Stephanoceras humphriesianum* (Imlay, 1964, p. B12-B14). Correlation with the *S. humphriesianum* zone is indicated by the association of *Normannites (Itinsaites)*, *Teloceras*, and *Chondroceras*. Correlation of the lower fourth of the formation with the *O. sauzei* zone is suggested by the presence of *Sonninia* and the absence of *Teloceras* in that part.

The correlation chart (table 3) shows an overlapping of zones between the formations in the lower part of the Tuxedni Group. The chart is based on ammonites that have a restricted range, and thus demonstrates a period of rapid deposition without any major breaks for most of Red Glacier time and all of Gaikema, Fitz Creek, and Cynthia Falls time.

The common pelecypods in this formation are *Inoceramus* and *Pleuromya*. The *Inoceramus* has been identified specifically as *I. ambiguus* Eichwald and is different from the common *Inoceramus* in the older rocks. The *Pleuromya* is a smooth type in contrast to the coarsely ribbed forms in the older beds; as yet the *Pleuromya* has not been identified specifically. Other abundant but less common pelecypods include *Trigonia*, *Parallelodon*, *Pecten*, *Camptonectes*, and *Astarte*.

The Fitz Creek fauna is Middle Jurassic, and can be restricted to the *Otoites sauzei* and *Stephanoceras humphriesianum* zones of middle Bajocian age. All recent collections are given in table 6. The identifications and age assignments were made by R. W. Imlay, who has examined all recent material.

#### Cynthia Falls Sandstone

Massively bedded sandstone and conglomerate that overlies the Fitz Creek Siltstone was named the Cynthia Falls Sandstone by Kellum (1945) after a prominent waterfall on Hardy Creek. The rocks are exposed a little better on Tonnie Creek, and this section is designated the type locality (fig. 3).

#### AREAL DISTRIBUTION

The narrow linear belt of hogback ridges on the flanks of Tonnie syncline, formed by the resistant sandstone and conglomerate of this formation, are no more than 1,000–1,500 feet wide. The belt on the northwest flank of the syncline is cut by the normal fault that follows the east side of Portage Creek Valley, and the section is repeated in the valley. The Bruin Bay fault places the Lower Jurassic Talkeetna Formation in contact with the Cynthia Falls Sandstone along the west side of the valley.

Beds that dip steeply northwest in the belt on the southeast flank of the syncline continue to a point about 1 mile southwest of the pass between Right Arm and Oil Bay. A reversal in dip occurs at this point and the beds cross over the nose of the southwest-plunging Fitz Creek anticline. Havenstrite Ridge and the other ridges forming the east wall of Fitz Creek valley are composed almost entirely of rocks of the Cynthia Falls Sandstone. This easternmost belt of Cynthia Falls is as much as 3,500 feet wide.

North of Chinitna Bay the formation is exposed in a discontinuous belt from Fossil Point to southwest of Boulder Creek, where it disappears under a Quaternary lava flow from Iliamna Volcano. The continuity of this belt is broken by Red Glacier and the transverse-flowing Johnson River. This part of the region does not have the conspicuous hogback ridges that are characteristic of the formation on Iniskin Peninsula.

#### CHARACTER

Massive to thick-bedded graywacke-type sandstone and layers of pebble-cobble conglomerate are the main constituents of the Cynthia Falls Sandstone. Minor amounts of arenaceous siltstone, containing a few small limestone concretions, are interbedded with the sandstone at a few localities. Graded bedding features are present in the sandstone.

The sandstone is predominantly medium to coarse grained and greenish gray to dark green; it weathers to light gray, and is commonly mottled on the weathered surface. The mottled appearance is caused by small light-green to gray spots rich in zeolite minerals. The sandstone is composed mainly of angular fragments of feldspar and volcanic rocks in a matrix of silt-size grains of the same general composition. Quartz, biotite, chlorite, and magnetite are present in minor amounts. Thin lenticular beds of pebble conglomerate are present in most sections except at the extreme





Type section of *Cynthia Falls Sandstone*

Local unconformity.	
Cynthia Falls Sandstone:	<i>Thickness (feet)</i>
Sandstone, massive, coarse-grained, gray-green; weathers light gray; mottled by light-green; splotches of minerals rich in zeolite; few lenticular beds of small pebbles, mainly volcanic rocks.....	280
Siltstone, thin-bedded, coarse-grained, arenaceous, brownish-gray.....	50
Sandstone, similar to top unit except fewer pebbles..	270
Total section measured.....	600
Contact.	

The upper contact with the Twist Creek Siltstone is conformable throughout most of the area. An exception to this conformity occurs in the southwestern part of Iniskin Peninsula, near the pass between Right Arm and Oil Bay. At this locality an unconformity that exists between the Twist Creek Siltstone and the Bowser Formation becomes more pronounced, with the result that all of the Twist Creek is removed and the Bowser rests unconformably on Cynthia Falls Sandstone. Exposures are very poor at this locality, but the available field evidence seems to indicate that very little of the Cynthia Falls was removed prior to deposition of the overlying rocks. The same situation may be present in parts of the area north of Chinitna Bay, but in general the exposures are too poor to be certain of the contact relationships.

The lower contact with the Fitz Creek Siltstone is conformable and sharp except for a small area near Hickerson Lake, where a slight angularity exists between the two units and the top of the Fitz Creek exhibits some features common to an erosional surface.

AGE AND CORRELATION

The environment under which the massive sandstone was deposited apparently was not conducive to a diversified fauna, for this member is practically destitute of all molluscan remains. The beds are believed to represent a marine nearshore deposit rather than a nonmarine one, but they were either deposited very rapidly or else under some condition such as a change in sea temperature or circulation that effectively restricted the growth of marine life.

The meager fauna collected from the Cynthia Falls Sandstone is given in table 7. Four collections contained identifiable ammonite remains consisting of *Chondroceras* and *Stephanoceras* that are correlative with specimens from the European standard zone of *Stephanoceras humphriesianum* (Imlay, 1964, p. B14). The correlation of the entire formation with the *S. humphriesianum* zone may be evidence of rapid deposition, particularly inasmuch as the underlying Fitz Creek Siltstone also occupies part of this zone. The

faunal evidence indicates that deposition must have been virtually continuous, and an unconformity would not be expected between these two formations. The unconformity present in the vicinity of Hickerson Lake must be only a very localized feature. The few pelecypods collected contain elements that link them specifically with those from the underlying Fitz Creek Siltstone.

TABLE 7.—*Geographic and stratigraphic distribution of fossils in the Cynthia Falls Sandstone*

(Identified by R. W. Imlay. Collections made by Arthur Grantz, R. W. Imlay, D. J. Miller, and Helmuth Wedow)

Geographic location.....	Bowser Creek-Fitz Creek area				Fossil Point area		
	117	119	120	123	118	121	122
Map reference (pl. 3).....							
Stratigraphic position above base of formation (ft).....	0-150	100-150	200	600	70-80	400-500	550-650
USGS Mesozoic loc.....	21771	21307	20004	22444	21280	22707	22708
Rhynchonellid brachiopod.....	X						
<i>Grammatodon</i> sp.....	X						
<i>Inoceramus</i> sp.....			X				
<i>Mytilus</i> sp.....			X				
<i>Chondroceras defonti</i> (McLearn) Sp.....	X					X	
<i>Stephanoceras</i> sp.....		X			X	X	
Ammonite fragment (undet.).....				X			X

Twist Creek Siltstone

The rocks herein described and mapped as the Twist Creek Siltstone were formerly included in the lower part of the Bowser Member by Kirschner and Minard (1949) and Imlay (1953, 1961) and as the Twist Creek Siltstone by Dettnerman (1963). The primary reason for formational status is that the distinctive characteristics of the siltstone make it one of the most readily recognized units in the region; furthermore, an angular unconformity exists between the siltstone sequence and the overlying beds of the Bowser Formation. The unit was named after the Twist Creek, a tributary of Fitz Creek, and the type locality is on Tonnie Creek.

AREAL DISTRIBUTION

Outcrops of the Twist Creek Siltstone on Iniskin Peninsula are confined to three narrow northeast-trending belts. The best exposures are in the hills along the flanks of Tonnie syncline, where the non-resistant siltstone is preserved between the resistant sandstone of the underlying and overlying formations. The maximum outcrop width is about 1,000 feet near the northeast end of the syncline where the beds cross the axis of the structure. Southwest of this point the belts became narrower as the unconformity between Twist Creek Siltstone and the Bowser Formation cuts out part of the section. The formation is missing southwest of the pass between Right Arm and Oil Bay.

The belt of Twist Creek Siltstone along the east

flank of Havenstrite Ridge is somewhat wider than the ones along the hills northwest of Fitz Creek because the beds are exposed on a dip slope. The only good exposures of the formation in this eastern belt are along Cliff Creek and a few of the small streams tributary to Park Creek.

The formation is seen next in the vicinity of Hickerson Lake, where the siltstone emerges from beneath a lava flow on the south side of Boulder Creek. From this point the formation continues northeast to Bear Creek, near Tuxedni Bay. The best exposures of the siltstone north of Chinitna Bay are in the ridge forming the divide between Boulder Creek and Red Glacier.

CHARACTER

The formation is remarkably uniform throughout the entire region. It consists of soft, poorly consolidated siltstone and silty shale interbedded with a few thin beds of graywacke-type sandstone. The siltstone is thin bedded to massive, arenaceous, and dark gray, and weathers to dark rusty brown. Many thin beds of volcanic ash are intercalated with the siltstone, and small discoidal limestone concretions, as much as 6 inches across, occur abundantly throughout.

The soft nonresistant character of the siltstone, the numerous thin ash layers, and the overall rusty-brown-weathering color make the formation one of the easiest units to recognize in the region. The ash layers are commonly oxidized to a bright orange color that further increases the distinctiveness of the unit. The poorly indurated siltstone does not form good exposures except in stream cuts or where protected by resistant sandstone of the underlying and overlying formations. The numerous small limestone concretions are commonly fossiliferous.

THICKNESS AND STRATIGRAPHIC RELATIONS

An angular unconformity exists between the Twist Creek Siltstone and the Bowser Formation. This unconformity is very apparent on Iniskin Peninsula, where the Twist Creek Siltstone is 420 feet thick on Gaikema Creek, 400 feet on Cliff Creek, 240 feet on Tonnie Creek, and 100 feet in the headwaters of Fitz Creek. The formation continues to become thinner in a southwesterly direction and is missing entirely southwest of the pass between Right Arm and Oil Bay, where the Bowser Formation rests directly on the Cynthia Falls Sandstone. The 410 feet present north of Hickerson Lake compares favorably with the Gaikema Creek section, but a northeasterly thinning reduces this thickness to about 300 feet near Tuxedni Bay. The unconformity apparently is present in this part of the area too, but it cannot be mapped from field evidence.

The type section for the Twist Creek Siltstone is designated as being on Tonnie Creek, starting at a

point about 5,000 feet S. 47° E. of Tonnie Peak and continuing upstream for about 500 feet. The section is well exposed along the stream and was measured by planetable and alidade by L. B. Kellum and Helmuth Wedow in 1944; it was rechecked numerous times between 1948 and 1958.

Type section of Twist Creek Siltstone

Unconformity.	
Twist Creek Siltstone:	Thickness (feet)
Siltstone, thin-bedded to massive, arenaceous, brownish-gray; weathers dark-rusty brown; numerous volcanic ash layers ¼ to ½ inch thick; many small, yellow-weathering discoidal limestone concretions containing <i>Liroxites</i> , <i>Megasphaeroceras</i> , and <i>Leptosphinctes</i> -----	240
Total section exposed -----	240

The lower contact of the formation with the Cynthia Falls Sandstone appears to be conformable in most exposures. A considerable difference in time is suggested by the ammonites for the rocks on opposite sides of the contact, but there is no field evidence for an unconformity except in the southwestern part of Iniskin Peninsula. The contact is sharp, being the boundary between a soft incompetent siltstone and a resistant sandstone.

AGE AND CORRELATION

The Twist Creek Siltstone has an abundant ammonite fauna that is for the most part restricted to the limestone concretions. A few pelecypods are associated with the ammonites, which were identified, dated, and discussed by R. W. Imlay (1961, 1962a). The fossils are listed in table 8.

The main elements of this fauna include *Oppelia* (*Liroxites*), *Megasphaeroceras*, *Leptosphinctes*, *Lissoceras*, and *Normannites* (*Dettermanites*). (Imlay, 1962a, p. A-6; 1964, p. B6). Of these, *Leptosphinctes* is typical of the zone of *Strenoceras subfurcatum* of late Bajocian of Europe and the presence of *Normannites* indicates an age not younger than early late Bajocian (Imlay, 1964, p. B17).

MIDDLE(?) AND UPPER JURASSIC ROCKS

TUXEDNI GROUP  
Bowser Formation

The rocks herein mapped and described as the Bowser Formation of the Tuxedni Group are virtually the same sequence of rocks mapped as Bowser Member by Kirschner and Minard (1949). However, Kirschner and Minard included the Twist Creek Siltstone and an overlying siltstone. The present authors believe that the overlying siltstone beds are more closely related to the Chinitna Formation and have designated the Bowser Formation as the uppermost unit of the

TABLE 8.—*Geographic and stratigraphic distribution of fossils in the Twist Creek Siltstone*

(Identified by R. W. Imlay. Collections made by R. L. Detterman, Arthur Grantz, R. W. Imlay, C. E. Kirschner, and Helmuth Wedow)

Geographic location.....	Tonnie Creek area			Cliff Creek-Gaikema Creek				Bear Creek						
	126	129	130	125	124	127	131	134	128	132	133			
Map reference (pl. 3).....	50-125	76-100	100	0-100	0-176	125-176	125-176	85	200	300	100	280-275	300	
Stratigraphic position above base of formation (ft).....	21315	27069	20001	20764	21314	21315	21313	19943	19934	26593	21310	22709	22710	21282
USGS Mesozoic loc.....														
Crustacean fragments.....	X	X			X									
Brachiopods undet.....	X	X			X									
<i>Grammatodon</i> sp.....	X	X			X									
<i>Paralleodon</i> sp.....	X	X			X									
<i>Amberleya</i> cf. <i>A. densinodosa</i> Huddleston.....	X	X			X									
<i>Inoceramus ambiguus</i> Eichwald.....	X	X			X									
<i>Trigonia</i> sp.....	X	X			X									
<i>Modiolus</i> sp.....	X	X			X									
<i>Entolium</i> sp.....	X	X			X									
<i>Lucina</i> sp.....	X	X			X									
<i>Isocyprina?</i> sp.....	X	X			X									
<i>Pleuromya</i> sp.....	X	X			X									
<i>Macrophylloceras</i> cf. <i>M. grossicostatum</i> Imlay.....	X	X			X									
<i>Calliphylloceras</i> sp.....	X	X			X									
<i>Lytoceras</i> sp.....	X	X			X									
<i>Spiroceras</i> sp.....	X	X			X									
<i>Lisoceras bakeri</i> Imlay.....	X	X			X									
<i>Oppelia</i> ( <i>Lirozyites</i> ) <i>kellumi</i> Imlay.....	X	X			X									
<i>Megasphaeroceras rotundum</i> Imlay cf. <i>M. rotundum</i> Imlay.....	X	X			X									
sp.....	X	X			X									
<i>Dettermanites vigorousus</i> Imlay.....	X	X			X									
<i>Leptosphinctes cliffensis</i> Imlay.....	X	X			X									
( <i>Frostaphinctes?</i> ) <i>delicatus</i> Imlay sp.....	X	X			X									
Belemnite fragments.....	X	X			X									

Tuxedni Group (Detterman, 1963). Kirschner and Minard further suggested the possibility that the Bowser is both Middle and Late Jurassic in age; recent field evidence has confirmed this suggestion. For the purpose of this report, the Bowser is informally divided into two parts on plate 5; this division is based primarily on faunal evidence and is made at the break between the Middle(?) and Late Jurassic.

The Bowser Formation was named after Bowser Creek, which drains the southeastern part of Iniskin Peninsula. The formation crops out over a large part of the peninsula in many good exposures in stream valleys tributary to Bowser Creek. The section exposed on Tonnie Creek has been studied in more detail than other sections and was designated the type locality for the formation; it starts 4,500 feet S. 47° E. of Tonnie Peak and continues upstream for about 1,500 feet (fig. 3).

## AREAL DISTRIBUTION

The Bowser Formation crops out over a wide part of Iniskin Peninsula, underlying more of the area than all other formations of the Tuxedni Group combined. The main outcrop areas are in general confined to three belts. The widest occupies a low saddle and the low western slopes of the coastal mountains; it is on the east flank of Fitz Creek anticline and lies between

ridges formed by the resistant Cynthia Falls Sandstone and the coastal mountains. This eastern belt, 4,000–14,000 feet wide, extends southwest from Chinitna Bay to Iniskin Bay, where it underlies a broad area over the nose of Fitz Creek anticline and across the southwest-plunging Tonnie syncline. The formation is exposed along the eastern shore of Iniskin Bay from Portage Creek to the base of Mount Pomeroy. The other two belts occur along the flanks of Tonnie syncline, where the formation occupies the upper slopes of the mountainous mass formed by the steeply dipping beds of the syncline. The Bruin Bay fault system cuts the section near Right Arm and the sequence is repeated in the valley of Portage Creek.

The Bowser is the only formation of the Tuxedni Group to be exposed on the north shore of Chinitna Bay. A few hundred feet are present in the lower part of Horn Creek Valley, where it was brought to the surface between two faults. The westernmost fault is a continuation of the Bruin Bay fault and brings up Lower Jurassic beds against the Middle(?) and Upper Jurassic. The Bowser occupies a triangular-shaped area about 1 mile long in which the beds are vertical to steeply dipping. The formation is next seen in the upper part of the valley of East Glacier Creek, 5 miles to the northeast, where it partly underlies a quaternary lava flow. The beds are terminated near the base of Iliamna Volcano by the Bruin Bay fault. The lava flow caps the ridge between East Glacier Creek and Boulder Creek, and the Bowser is next seen under the flow in the valley of Boulder Creek. From Hickerson Lake, the Bowser Formation continues N. 40° E. as a narrow belt on the lower northwest-facing slopes of the coastal mountains. The continuity of this belt is broken by Red Glacier and Johnson River. A few feet of Bowser Formation is exposed at low tide on the extreme northwestern tip of Chisik Island.

## CHARACTER

The heterogenous assemblage of rocks assigned to the Bowser Formation includes massive units of cliff-forming graywacke-type sandstone and pebble-cobble conglomerate, thin-bedded, poorly consolidated shale, and massive siltstone. The character is further confused by rapid facies changes.

Massive sandstone and conglomerate units several hundreds of feet thick are the dominant lithic types on the Iniskin Peninsula. The sandstone and the matrix of the conglomerate beds are coarse grained, consisting mainly of angular fragments of feldspar and quartz; silt-sized feldspar and chlorite occur in minor amounts. Biotite, augite, and magnetite are common accessory minerals. The sandstone is light gray to dark gray

and greenish gray. The light-gray sandstone is commonly calcareous and is interbedded with the darker sandstone, which is generally spotted; it resembles the sandstone of the Cynthia Falls. The conglomeratic constituents include well-rounded small pebbles to large boulders of felsite and basalt and about 10 percent granitic rock types. The coarser clastic components of the sandstone and conglomerate are concentrated in the vicinity of Tonnie Peak, which is a little farther south than such components of the underlying units. Elsewhere the sandstone becomes finer grained and thinner bedded. Units that are equivalent to the massive sandstone near Tonnie Peak are thin-bedded sandstone and siltstone near Tuxedni Bay.

Siltstone units several hundred feet thick occur with the coarser clastic rocks on Iniskin Peninsula. North of Chinitna Bay the units are as much as 700-800 feet thick and are the dominant lithic type in the Bowser Formation. The siltstone is massive to thin bedded, medium to coarse grained, dark-brownish gray, light gray where calcareous, and weathers to light brown. Some parts are quite arenaceous and grade into sandstone. Much of the siltstone is well indurated and fractures into small angular fragments. Large, lenticular laminated yellow-weathering fossiliferous limestone concretions are abundant in the exposures north of Chinitna Bay.

The best exposures of the Bowser Formation are in the two belts on the flanks of Tonnie syncline. This is the area that contains most of the coarse clastic material. The eastern belt on Iniskin Peninsula has more siltstone, as does the area north of Chinitna Bay, and the exposures are confined to stream-cut banks. The facies change suggests a northwest source area for the member similar to the source areas for the older units. Close similarity of texture and structure of the included rocks to that of some of the older units indicates that very little change occurred in the source area during the entire period of Tuxedni Group deposition.

An important feature of the Bowser are the numerous coquina beds in the calcareous light-gray sandstone. The beds are 1-3 feet thick and are similar to the ones in the Gaikema and Red Glacier Formations. These beds appear to be confined to the coarser clastic parts of the formation on Iniskin Peninsula; they were not seen north of Chinitna Bay, where the beds contain abundant ammonite-bearing concretions. The coquina beds are composed almost entirely of the pelecypods *Inoceramus* and *Trigonia*.

THICKNESS AND STRATIGRAPHIC RELATION

Exposed sections of the Bowser Formation range in thickness from about 1,250 feet to as much as

1,850 feet. The thicker sections are on Iniskin Peninsula at the localities that contain the coarse clastic material.

The section exposed in the ridge between Hickerson Lake and Red Glacier is the thickest single section of the formation. The clastic constituents are somewhat finer grained than the rocks on Iniskin Peninsula, but this area apparently was close enough to the source to receive abundant detritus. The predominantly siltstone sections are considerably thinner near Tuxedni Bay than elsewhere in the area; the Bear Creek section is only 1,250 feet thick.

The type section on Tonnie Creek, starting 4,500 feet S. 47° E. of Tonnie Peak, is on the southeast flank of the syncline in beds that dip 30°-35° NW. It is well exposed with numerous waterfalls where the stream flows over the more resistant sandstone and conglomerate beds. The type section was measured with planetable and alidade by L. B. Kellum and Helmuth Wedow in 1944 and rechecked numerous times between 1948 and 1958.

Type section of Bowser Formation

Contact.	Thickness (feet)
Bowser Formation:	
Sandstone, massive, medium- to coarse-grained, dark-gray; interbeds of calcareous light-gray sandstone containing numerous coquina layers; thin to thick irregularly bedded layers of small-pebble-to-cobble conglomerate, mainly felsitic rocks.....	180
Siltstone, massive, arenaceous, olive-gray; weathers light brown; thin interbeds of fine-grained gray-wacke sandstone; contains the ammonites <i>Keplerites</i> and <i>Kheraicerias</i> .....	250
Conglomerate, massive, irregular bedded, cobble to small boulder, mainly felsite and porphyry but some basalt and granitic rock types; matrix is coarse-grained feldspathic sandstone.....	170
Sandstone, thin- to shaly bedded, fine- to medium-grained, light-gray; few interbeds of medium-grained dark-gray mottled sandstone and lenticular beds of pebble conglomerate; abundant pelecypods...	170
Siltstone, thin-bedded to massive, arenaceous, dark-gray; contains pelecypods.....	130
Sandstone, medium-bedded to massive, medium- to fine-grained, light olive-gray; contains numerous interbeds of coarse-grained sandstone and pebble conglomerate.....	250
Siltstone, massive, sandy, gray.....	260
Conglomerate, massive; cobbles mostly volcanic rock types and some intraformational sandstone; lenticular interbeds of coarse-grained sandstone.....	70
Siltstone, massive, coarse-grained, arenaceous; few small pebbles.....	50
Siltstone, massive, coarse-grained, arenaceous, dark-gray; contains <i>Cranoccephalites</i> .....	230
Sandstone, thin- to shaly bedded, fine- to medium-grained, dark-gray; few pebbles.....	70
Total section exposed.....	1,830
Unconformity.	





On Iniskin Peninsula the contact at the top of the Bowser, which is the contact between the Tuxedni Group and Chinitna Formation, appears to be conformable, and a massive sandstone unit 100–180 feet thick underlies the basal siltstone beds of the Chinitna Formation. North of Chinitna Bay the sandstone unit is missing and the contact is marked by an unconformity.

#### AGE AND CORRELATION

The Bowser Formation is probably the most fossiliferous unit in the Tuxedni Group; it has a diversified molluscan fauna that includes abundant ammonites and pelecypods (table 9). Most of the pelecypods have not been identified specifically, but the ammonites are identified and discussed by R. W. Imlay (1962). A few of the more important features of the ammonite fauna are germane to this report and will be discussed.

Present evidence shows that two faunal zones are present in the Bowser Formation.

The lowest fauna occupies an interval 400–750 feet thick immediately overlying the Twist Creek Siltstone. The interval is mainly siltstone, but contains several massive sandstone and conglomerate units. Representatives of the fauna are present throughout from within 25 feet of the base to 50 feet of the top. This fauna includes *Cranocephalites*, *Arctocephalites*, *Siemiradzkaia*, *Cobbanites*, and *Parareineckia*. The age of this fauna is somewhat in doubt, but Imlay (1962b) believes the evidence suggests a late Bathonian age for these fossils and further correlates them with the zones of *Clydoniceras discus* and *Oppelia aspidoides*. However, certain important elements characteristic of these zones are missing in the collections from this region, and it is therefore possible that this sequence of beds may be Callovian rather than Bathonian.

The remaining beds at the top of the Bowser contain a fauna that is definitely of Callovian age. Many of the species from this part are also in the overlying beds of the Chinitna Formation, and no faunal break exists between the top of the Tuxedni Group and the base of the Chinitna Formation. A lithologic break is present, however.

The ammonites from the upper 800–1,200 feet of the Bowser include such typical Callovian forms as *Xenocephalites*, *Kheraceras*, and *Kepplerites* (Imlay, 1962b, p. C3). These genera can be correlated with the zone of *Proplanulites koenigi* and possibly the lower part of the zone of *Sigaloceras calloviense*, all of early Callovian age. The zone of *Macrocephalites macrocephalus* may not be present, inasmuch as *Arcticoceras*

has never been found in Alaska. The correlation of the fauna with the *P. koenigi* and *S. calloviense* zones definitely establishes a Late Jurassic age for the upper part of the Bowser Formation.

The unconformity between the Bowser and the Twist Creek Siltstone is the most important hiatus within the Tuxedni Group. The age of the lower fauna in the Bowser is somewhat questionable. It possibly is lower Callovian; if so, this unconformity is the break between Middle and Upper Jurassic. Lithologically, however, the Bowser is more closely related to the Tuxedni Group than it is to the overlying Chinitna Formation of known Late Jurassic age.

#### UPPER JURASSIC ROCKS

##### CHINITNA FORMATION

The massive arenaceous siltstone mapped as Chinitna Formation has long been recognized as one of the more distinctive units in the Cook Inlet area. The formation was originally designated the Chinitna Shale by Martin and Katz (1912, p. 65–68), and the type section was given as the north shore of Chinitna Bay. This section was visited by Stanton and Martin in 1904 and was described by them in 1905. Moffit (1927, p. 23–26) continued to use the term Chinitna Shale, but Kirschner and Minard (1949) redefined the unit as the Chinitna Siltstone. Imlay (1953, table 5) called the same sequence of beds the Chinitna Formation, and the present authors retain this term but subdivide the formation into a lower unit called Tonnie Siltstone Member and an upper unit called Paveloff Siltstone Member. The section in the bluffs along the north shore of Chinitna Bay is retained as the type locality for the formation.

##### Tonnie Siltstone Member

The name Tonnie Siltstone Member is herein redefined as the lower part of the Chinitna Formation. The name was used originally by Kirschner and Minard (1949) for the uppermost member of the Tuxedni Formation. Recent fieldwork has shown that this sequence of rocks is lithologically and faunally part of the Chinitna Formation. The name is retained because the type section is along Tonnie Creek. Imlay (1953), in a paleontologic investigation of the formation, subdivided the Chinitna into thirds, designating the Tonnie Siltstone Member as the lowest third and the section exposed along the western flank of the coast mountains as the upper two-thirds. The present authors believe the lower and middle thirds of Imlay's classification are one group of rocks.

## AREAL DISTRIBUTION

Good exposures of the Tonnie Siltstone Member are found at the tops of the mountains along the Tonnie syncline, where this member occupies the center of the structure. The Tonnie Member is the youngest unit exposed along the greater part of the syncline, but the complete section is present at only two localities. Other exposures of the member on Iniskin Peninsula are largely confined to a belt 2,000–4,000 feet wide along the western flanks of the coast mountains. Excellent exposures are seen on Iniskin, Oil, and Chinitna Bays and in the many streams that drain the precipitous west slopes of these mountains, particularly the tributaries of Bowser Creek.

North of Chinitna Bay the member is present as a narrow belt, 1,500–2,000 feet wide. From Hickerson Lake to the northeast end of Chisik Island the belt is confined to the lower western slopes of the coast mountains. The continuity of this belt is broken between Hickerson Lake and the north shore of Chinitna Bay.

## CHARACTER

Massive arenaceous dark-gray to brownish-gray siltstone constitutes most of the Tonnie Siltstone Member. The siltstone weathers brownish gray to red brown and contains numerous small yellowish-brown-weathering limestone concretions that occur in parallel bands and at random throughout the section. Sandstone is present as thin interbeds in the siltstone, generally being fine grained and greenish gray. A more massive sandstone unit is present at the base of most sections. An unusual feature of the section on Chisik Island is a basal channel conglomerate of cobbles and boulders, mainly volcanic rock types. The Chisik Island section also contains numerous thin beds of volcanic ash.

The arenaceous siltstone common to the member is a fine-textured rock similar in composition to the graywacke of the Tuxedni Group. Rock fragments are present but not common, and moderately abundant feldspar grains make the rock almost a feldspathic siltstone. The massively bedded units are highly fractured, and in most outcrops the attitude of the beds can be determined only when layers of sandstone or concretions are present. The rock is well indurated and forms nearly vertical exposures on the steep western slopes of the coast mountains. The coloration of the rocks, particularly the brownish gray of the weathered surfaces, is one of the main criteria for differentiating the Tonnie Member from the Paveloff Member. This coloration is probably due to a greater abundance of

pyrite crystals in the lower part of the Chinitna Formation.

Limestone is a minor but important constituent of the siltstone sequence, occurring mainly as small concretions and as lenticular beds intercalated with the siltstone. The concretions are generally ovoid and 6 inches or less in maximum diameter. They are extremely hard, yellowish brown to almost white on weathered surfaces, and commonly fossiliferous. These autochthonous concretions generally contain a single large ammonite that is nearly the size of the inclosing concretion. The lenticularly bedded limestone is normally dark, dense, and siliceous.

Graywacke-type sandstone is present as thin beds at intervals throughout the section; it has the same general composition as the siltstone but is slightly coarser grained. The sections from Tonnie syncline have slightly more sandstone than those from the belt in the coastal mountains because they are nearer the source area. A sandstone unit, 20–100 feet thick, is present at the base of the Tonnie Member in nearly all exposures. This rock is medium-bedded to massive, fine- to medium-grained, grayish-brown. The few pebbles in exposures on the Iniskin Peninsula are probably correlative with the 215-foot-thick cobble-boulder channel conglomerate that is present on the northwest side of Chisik Island. A channel conglomerate that is similar, but only a few feet thick, was seen near Hickerson Lake. These channel deposits probably mark submerged stream channels and indicate a nearby source area for the deposits. The basal sandstone beds contain many shell layers.

## THICKNESS AND STRATIGRAPHIC RELATIONS

Sections of the Tonnie Siltstone Member range in thickness from about 800 to 1,300 feet. North of Chinitna Bay the member is of fairly uniform thickness, being about 800–900 feet. South of the bay the unit becomes progressively thicker southward at a more or less uniform rate.

The type section is along the upper part of Tonnie Creek, starting 2,300 feet southeast of Tonnie Peak at an altitude of 1,500 feet and continuing upstream for 1,200 feet (fig. 3). The section is well exposed along both sides of the creek; it may have slightly more sandstone than the more easterly sections but is believed to be representative of this member. The section was measured with tape and Brunton by L. B. Kellum and Helmuth Wedow in 1944. Additional details were added by D. J. Miller and R. W. Imlay in 1948 and rechecked several times between 1948 and 1958.

## Type section of Tonnie Siltstone Member

## Gradational Contact.

## Tonnie Siltstone Member:

	Thickness (feet)
Siltstone, massive; becomes more massive and arenaceous toward the top; brown on fresh and weathered surfaces; fewer concretions than underlying units-----	340
Siltstone, massive, dark-gray; weathers brown to dark brown; small light-yellowish-brown limestone concretions scattered at random and in parallel bands; <i>Lilloettia buckmani</i> , <i>L. milleri</i> -----	240
Sandstone, thin-bedded, fine-grained, silty, greenish-gray; <i>Paracadoceras tonniense</i> -----	25
Siltstone, massive, fine-grained, gray; weathers brown; small brown-weathering concretions and a few large lenticular limestone beds; contains <i>Xenocephalites vicarius</i> -----	135
Sandstone, medium-bedded, fine-grained, greenish-gray; siltstone interbeds-----	40
Siltstone, similar to above unit; thin sandstone interbeds near base-----	140
Siltstone, massive, arenaceous, dark-gray, weathers brownish-gray; many small buff- to brown-weathering limestone concretions in parallel bands; fossiliferous, <i>Kepplerites abruptus</i> , <i>Paracadoceras tonniense</i> -----	80
Sandstone, massive, fine- to medium-grained, greenish-gray; few pebbles, mostly volcanic rock types.--	20
Total sections measured-----	1,020

## Contact.

The lower contact with the underlying Bowser Formation of the Tuxedni Group appears to be conformable and sharp in all exposures on Iniskin Peninsula. Between Chinitna Bay and Tuxedni Bay this same contact is an unconformity, and most sections show channel conglomerate deposits at or near the contact. Thus, the southern part of the area was receiving sediments while the northern part was undergoing erosion and accompanying deposition of the channel conglomerates. This relationship, and the thicker sections present on Iniskin Peninsula, seem to indicate that the basal beds on Iniskin Peninsula are older than beds in a similar position north of Chinitna Bay.

The upper contact with the Paveloff Member has been placed at the base of a predominantly sandy section. This contact is gradational through about 50-75 feet of section. The authors fully realize that the bed picked as the contact in one part of the region may not be the same bed that is picked in another part, but they believe the breakdown into two members is fully justified on the basis of lithology. The sandstone is present in all sections and clearly indicates a depositional change that must have affected the entire region at approximately the same time. Consequently, the fact that a single sandstone bed may pass laterally into siltstone is not really germane. The

important thing is the presence of a sandstone interval that separates two dissimilar siltstone sequences.

The Tonnie Member is in fault contact with older rocks at several localities between the north shore of Chinitna Bay and the North Fork of East Glacier Creek. The Bruin Bay fault has placed rocks of the Talkeetna Formation in juxtaposition to the Tonnie Member at several places along this 6-mile interval. This relation indicates a stratigraphic displacement of about 9,000-10,000 feet for part of this fault.

## AGE AND CORRELATION

Many collections of molluscan fossils were obtained from the Tonnie Siltstone Member during the fieldwork. Ammonites from all collections through the 1950 field season were discussed by Imlay (1953). He used a threefold breakdown of the Chinitna Formation, whereas the present authors use only two; in order to place the collections in their proper stratigraphic position relative to the new subdivision, all collections for the member since 1944 are given in table 10.

The Tonnie Member can be correlated on the basis of ammonites with the upper part of the European standard zone of *Proplanulites koenigi*, all of the *Sigaloceras calloviense* zone, and at least the lower part of the zone of *Cosmoceras jason*. This correlation is based on the presence of *Cadoceras*, *Paracadoceras*, *Kepplerites*, *Lilloettia*, *Kheraicerias*, *Xenocephalites*, and, at the top, *Pseudocadoceras*. Imlay (1953, p. 51) states:

An early Callovian age is clearly shown by the abundance of *Paracadoceras*, which includes such European forms as *C. elatmae* (Nikitin) and *C. breve* Blake. The presence of *Gulielmiceras* only a few hundred feet above the base of the Chinitna Formation indicates an age not older than the *Sigaloceras calloviense* zone of northwest Europe for most of the lower third. The presence of *Gowericeras* near the base of the Chinitna Formation in Chisik Island suggests that the lower 200 to 300 feet represent the *Proplanulites koenigi* zone.

Inasmuch as *Pseudocadoceras* has been found associated with *Cadoceras comma* and *C. catostoma* in the upper part of the Tonnie Member, the present authors feel that at least part of the zone of *Cosmoceras jason* is represented by these beds.

Faunal elements other than ammonites are not common in the Tonnie Member. Pelecypods are localized in some of the more sandy intervals and consist mainly of *Pleuromya*, *Camptonectes*, *Trigonia*, *Inoceramus*, *Tancredia*, and *Quenstedtia*. Belemnites are found only rarely, as are gastropods and brachiopods. Crustaceans and plant fragments occur in some of the concretions.

## Paveloff Siltstone Member

The Paveloff Siltstone Member is herein named for the upper part of the Chinitna Formation. This is virtually the same siltstone unit that was included as

the upper third of the Chinitna Formation by Imlay (1953, p. 49-51). The member is named after Paveloff Creek, an easterly tributary of Bowser Creek, along which the member is exposed in nearly vertical cliffs on the west face of Front Mountain.

#### AREAL DISTRIBUTION

On Iniskin Peninsula, the Paveloff Member is chiefly confined to a narrow sinuous belt on the upper western slopes of the coast mountains. Here it forms nearly vertical exposures that are capped by the resistant beds at the base of the Naknek Formation. The member is probably one of the best exposed units in the region, but owing to the nature of the exposures is also one of the most difficult to study. Excellent exposures are also present on the shores of Iniskin, Oil, and Chinitna Bays.

Two small exposures of the member occur along the axis of Tonnie syncline. The upper few hundred feet of Tonnie Peak is composed of sandstone and siltstone at the base of the Paveloff Member. The rocks cover an area about 1,000 feet across. A smaller area is present along the axis about 4,000 feet south of Tonnie Peak. These two small outcrops represent the youngest strata along the syncline and also the youngest beds west of the coast mountains.

North of Chinitna Bay, the 1,000- to 1,500-foot belt continues along the upper west-facing slopes of the coast mountains between Hickerson Lake and the north end of Chisik Island. South of Hickerson Lake the member is exposed over a somewhat wider area along East Glacier Creek and along the north shore of Chinitna Bay.

#### CHARACTER

Massive arenaceous dark-gray siltstone constitutes the major part of the member. A thick sandstone interval is present at the base of nearly all sections, and large ellipsoidal limestone concretions and lenticular beds of limestone occur throughout. Thin beds of sandstone are interlayered with the siltstone above the massive basal sandstone.

The massive arenaceous siltstone is quite similar to the siltstone of the Tonnie Member except that it is gray on both the fresh and weathered surfaces. The fact that the fine-textured rock contains considerably less pyrite than does the Tonnie, is probably the reason for the difference in coloration; however, a few of the siltstone beds contain abundant finely disseminated pyrite crystals that cause the beds to weather rusty brown. The siltstone is well indurated and is fractured into many large angular fragments. The upper part of the siltstone sequence is thin bedded, in places

almost shaly bedded, and fractures into small angular fragments.

Graywacke sandstone, thin bedded to massive, locally lenticularly bedded, fine to coarse grained, gray to greenish gray, forms the basal part of the member. Other thin interbeds of graywacke are found at irregular intervals throughout the section, being more common south of Chinitna Bay. A few of the sandstone units are calcareous. Locally the coarser grained sandstone may contain small well-rounded pebbles of volcanic rock types. The basal sandstone is about 100 feet thick in most sections but ranges from 30 to 200 feet thick on Chisik Island. Siltstone of the same general composition as the feldspathic graywacke sandstone is interbedded with the basal sandstone unit, being somewhat more abundant in the thicker intervals.

Limestone is present in appreciable quantities in most sections, generally as large ellipsoidal concretions and lenticular beds. The limestone is very dark gray on fresh surface and weathers to buff and cream yellow; it is extremely hard and dense. Locally, both beds and concretions are bioclastic, but in general the section is not abundantly fossiliferous. Most of the concretions are 8-12 inches thick and 5-6 feet long. The lenticular beds may be as much as 2-3 feet thick and 50 feet long.

Marcasite lentils  $\frac{1}{2}$  inch thick and 2 feet long were noted in the upper part of the section along the west shore of Chisik Island. Elsewhere, marcasite usually occurs as small irregularly rounded concretions as much as 1 inch in maximum diameter but is not common in any of the sections.

#### THICKNESS AND STRATIGRAPHIC RELATIONS

Measured sections of the Paveloff Siltstone Member range from 900 to 1,350 feet thick. The thicker sections are near the central part of the area and the thinner sequences are at both north and south ends of the mapped area. The thinner sections are unconformably overlain by the Naknek Formation and probably do not represent the maximum thickness of the Paveloff Member. The thickest measured sections for the member are on the west-flowing tributaries of Bowser Creek, particularly between Paveloff and Edelman Creeks, on the west face of Front Mountain.

The member is named after Paveloff Creek, but the type locality is from an unnamed tributary of Bowser Creek that starts near the top of Front Mountain and flows northwestward between Paveloff and Edelman Creeks. The type section starts about 1,800 feet N. 40° W. of Front Mountain and continues upstream for 750 feet in strata that dip 20°-25° SE. (fig. 3).



TABLE 10.—Geographic and stratigraphic distribution of fossils in the Tonnie Siltstone Member of the Chinina Formation—Continued

Geographic location.....	Bowser Creek area						Brown Creek-Park Creek										Tonnie Creek																				
	255	260	262	263	266	267	268	271	272	205	206	207	214	219	226	237	252	258	265	212			215	228	233	243	256										
Map reference (pl. 3) .....	750-800	850-900	850-950	850-950	1000-1050	1000-1100	1000-1100	1050-1100	Top	Top	25-100	30-40	50	50-75	125-175	200-250	300-400	450-500	700-750	800-850	900-1000	70	70	90-100	90-100	100	130-150	350	350	400	425	575	760				
Stratigraphic position above base of member (ft) ..	22425	22423	20734	20762	22452	22429	20757	22430	22451	20759	22442	22438	21341	22437	21277	22420	22421	21348	21340	22556	22541	21327	70	21330	21328	21332	21326	21329	21325	21321	21324	21331	21322	21323			
USGS Mesozoic loc.....																																					
<i>Echinotites</i> sp.....																																					
Brachiopod (undet.).....					X	X										X						X															
<i>Grammatodon</i> sp.....																																					
<i>Nuculana</i> sp.....																																					
<i>Pinna</i> sp.....																																					
<i>Inoceramus ambiguus</i> Eichwald.....																																					
sp.....																																					
<i>Ozytoma</i> sp.....			X	X												X																					
<i>Ostrea</i> sp.....																																					
<i>Trigonia doroschina</i> Eichwald.....				X																			X														
sp.....																																					
<i>Chlamys</i> sp.....																																					
<i>Camptonectes</i> sp.....		X									X																										
<i>Entolium</i> sp.....																																					
<i>Lima</i> sp.....																																					
<i>Pleuromya</i> sp.....						X					X	X										X															
<i>Modiolus</i> sp.....																																					
<i>Mytilus</i> sp.....																																					
<i>Goniomya</i> sp.....																																					
<i>Astarte</i> sp.....															X	X																					
<i>Tancredia</i> sp.....																																					
<i>Protocardia</i> sp.....																																					
<i>Garvillia</i> sp.....																																					
<i>Isocryprina</i> sp.....																																					
<i>Quenstedtia</i> sp.....					X																																
Gastropods (undet.).....																																					
<i>Phylloceras</i> sp.....							X		X																												
( <i>Partschiceras</i> ) <i>subobtusiforme</i> Imlay.....																																					
( <i>Partschiceras</i> ) <i>granzi</i> Imlay.....																																					
<i>Macrophylloceras grossicostatum</i> Imlay.....											X																										
<i>Calliphylloceras freibrocki</i> Imlay.....																																					
sp.....																																					
<i>Oppelia</i> ( <i>Ozycerites</i> ) sp.....																																					
<i>Lilloettia buckmani</i> (Crickmay).....								X																													
<i>milleri</i> Imlay.....																																					
<i>mertoniarwoodi</i> Crickmay.....																																					
<i>lilloetensis</i> Crickmay.....											X																										
sp.....																																					
<i>Kheratoceras magniforme</i> Imlay.....																																					
<i>martini</i> Imlay.....																																					
<i>abruptum</i> Imlay.....																																					
<i>paricostatum</i> Imlay.....																																					
<i>intermedium</i> Imlay.....																																					
? <i>pariforme</i> Imlay.....																																					
sp.....																																					
<i>Cadoceras catostoma</i> Imlay.....																																					
<i>comma</i> Imlay.....		X																																			
<i>glabrum</i> Imlay.....																																					
<i>doroschina</i> (Eichwald).....																																					
<i>wosnessenskii</i> (Grewingk).....																																					
( <i>Paracadoceras</i> ) <i>multiforme</i> Imlay.....																																					
( <i>Paracadoceras</i> ) <i>tonniense</i> Imlay.....																																					
( <i>Stenocadoceras</i> ) <i>multicostatum</i> Imlay.....																																					



*Type section of the Paveloff Siltstone Member*

[Measured with tape and Brunton by Kirschner and Minard in 1946]

Contact.	<i>Thickness (feet)</i>
Paveloff Siltstone Member:	
Siltstone, massive, fine-grained, gray to greenish-gray; weathers dark gray; thin irregularly spaced fine-grained dark-greenish-gray calcareous sandstone interbeds; few concretions.....	700
Siltstone, massive, gray; weathers gray in upper part and brownish gray in lower part; regularly spaced fine-grained gray to buff sandstone interbeds; many lenticular beds and ellipsoidal concretions of dark dense limestone; pelecypods and belemnites...	640
Sandstone, thin- to medium-bedded, fine- to medium-grained, gray.....	30
Total section measured.....	1, 370

Gradational contact.

The lower contact with the Tonnie Siltstone Member is placed at the base of the sandstone that forms the lowest unit of the member. This contact is gradational, as was discussed on page 42, but the authors believe it marks a significant break in lithology that can be mapped.

The upper contact with the Naknek Formation is conformable over most of the region but is locally an unconformity at the northeast and southwest ends of the mapped area. These are the sections that are overlain by the massive cobble-boulder conglomerate facies of the Chisik Member; from all indications, some of the Chinitna must have been eroded prior to deposition of the conglomerate.

The Paveloff Member is in fault contact with the Talkeetna Formation at two localities north of Chinitna Bay. The lower 50-100 feet of the member is in fault contact in the pass between Horn Creek and East Glacier Creek, and the lower 150-200 feet is in similar contact on the ridge between the middle and north forks of East Glacier Creek. These are the youngest rocks exposed in fault contact with the Lower Jurassic volcanics along the Bruin Bay fault, and a stratigraphic displacement of about 10,000 feet is indicated for this segment of the fault.

AGE AND CORRELATION

Shell beds in the basal sandstone unit of the Paveloff Member have yielded many pelecypods and belemnites along with a few brachiopods and gastropods. The pelecypods include *Inoceramus*, *Chlamys*, *Camptonectes*, *Grammatodon*, *Tancredia*, and a few other genera. They have not been identified specifically, and it is doubtful if any identification of species would aid in the correlation of the member with other Jurassic beds.

Many ammonites were collected from the siltstone and limestone concretions above the basal sandstone. Collections made through the 1950 field season were

discussed by Imlay (1953), and all collections made since 1944 are included in table 11 of this report, which is based on a twofold subdivision of the Chinitna Formation rather than the threefold used by Imlay.

The Paveloff Siltstone Member can be correlated on the basis of ammonites with the upper part of the European standard zone of *Sigaloceras calloviense* and all of the zones of *Cosmoceras jason* and *Erymnoceras coronatum*. The presence of *Lilloettia* and *Xenoccephalites* with *Phylloceras* in the lower part of the member on Iniskin Bay would indicate that at least part of the member was as old as the zone of *S. calloviense*. Abundant *Pseudocadoceras*, *Stenocadoceras*, *Cadoceras*, and *Phylloceras* in the upper part of the member show that it correlates with at least the zone of *E. coronatum*, as *Pseudocadoceras* is not known to range higher (Imlay, 1953, p. 53).

The upper two zones of the Callovian, *Peltoceras athleta* and *Quenstedtoceras lamberti*, cannot be identified positively from this region. A specimen of *Cosmoceras* from Chinitna Bay may be some indication of these beds, but it was found in float. Probably the hiatus indicated by the local unconformity at the top of the Chinitna Formation at Iniskin Bay represents at least part of the two upper zones of the Callovian.

NAKNEK FORMATION

The Naknek Formation was first described 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. Martin (1905, p. 52-53) first used the term in the Iniskin-Tuxedni area to describe a sequence of sandy shale, andesite flows, and agglomerate exposed at Iniskin Bay. In 1912, Martin and Katz defined the Chisik Conglomerate Member at the base of the formation from the section that Martin had called agglomerate in the 1905 report. Moffit (1927, p. 31-38) retained the nomenclature used by Martin and Katz, but recognized the fact that the Naknek Formation above the Chisik Conglomerate Member could be divided into a lower unit that is predominantly "shale and arkosic sandstone" and an upper unit of "light-gray sandstone with abundant igneous material." Kirschner and Minard (1949) divided the Naknek into four members: Chisik Member, siltstone member, Pomeroy Member, and upper sandstone member.

A fourfold division of the Naknek Formation is used for this report. This division is based on practically the same breakdown as that suggested by Moffit in 1927 except that a sandstone facies of the Chisik is recognized and mapped. The Chisik Conglomerate Member is retained for the lowest unit, and the sand-

TABLE 11.—*Geographic and stratigraphic distribution of fossils in the Paveloff Siltstone Member of the Chinitna Formation*  
 [Identified by R. W. Imlay. Collections made by R. L. Detterman, Arthur Grantz, J. K. Hartsock, R. W. Imlay, R. Werner Juhle, and C. E. Kirschner]

Geographic location.....	Oil Bay—Iniskin Bay area					Chinitna Bay area										Hickerson Lake area				Chisik Island																	
	273	280	284	285	289	292	274	276	278	288	293	296	297	298	299	300	301	295	279	282	286	290	275	277	281	283	287	291	294	302							
Map reference (pl. 3).....																																					
Stratigraphic position below top of member (ft).....	Top	160-200	280-300	280-300	450-500	500-550	0-100	70	100-150	100-150	400-425	400-450	550-575	800-900	850	1,100-1,200	1,125-1,175	1,150-1,200	Base	Base	700-800	100-150	200-300	300-350	500	20-40	60-80	100	200-225	220	350-400	380-375	500	600	Base		
USGS Mesozoic loc.....	22551	22435	22415	22417	22484	20763	26590	21342	21346	26691	21776	21347	21778	21339	21777	22526	22624	22525	52A Ju483	22453	21775	22704	52A Ju539	22702	22703	22668	22669	21289	22554	22670	22671	21290	22672	22673	22675		
<i>Grammatodon</i> sp.....	X						X	X	X			X	X								X																X
<i>Inoceramus</i> sp.....		X																																			
<i>Ozytoma</i> sp.....					X			X	X																												
<i>Pteria</i> sp.....																																					
<i>Chlamys</i> sp.....																																					
<i>Camptonectes</i> sp.....																																					
<i>Pleuromya</i> sp.....				X																																	
<i>Goniomya</i> sp.....					X																																
<i>Thracia</i> (?) sp.....																																					
<i>Astarte</i> sp.....			X																																		
<i>Tancredia</i> sp.....																																					
<i>Aloidia</i> (?) sp.....																																					
Gastropods (undet.).....								X						X																							
<i>Phylloceras bakeri</i> Imlay.....																																					
( <i>Partschiceras</i> ) <i>subobtusiforme</i> Imlay.....																																					
sp.....																																					
<i>Calliphylloceras freibrocki</i> Imlay.....																																					
<i>Lilloettia stantoni</i> Imlay.....																																					
(?) sp.....																																					
<i>Kheraia</i> sp.....	X																																				
<i>Cadoceras comma</i> Imlay.....		X	X																																		
<i>tenuicostatum</i> Imlay.....																																					
<i>doroschini</i> (Eichwald).....			XX																																		
<i>woenessenskii</i> (Grewingk).....					X																																
<i>kialagvikense</i> Imlay.....																																					
( <i>Paracadoceras</i> ) sp.....																																					
( <i>Stenocadoceras</i> ) <i>multicostatum</i> Imlay.....							X																														
( <i>Stenocadoceras</i> ) <i>stenoloboides</i> Pompeckj.....								XX																													
( <i>Stenocadoceras</i> ) <i>pomeroyense</i> Imlay.....				X																																	
sp.....																																					
<i>Pseudocadoceras grewingki</i> (Pompeckj).....		X																																			
<i>chinitnense</i> Imlay.....																																					
sp.....																																					
<i>Kepplerites</i> ( <i>Seymourites</i> ) <i>multus</i> (McLern).....																																					
( <i>Seymourites</i> ) <i>ingrahami</i> (McLern).....																																					
( <i>Seymourites</i> ) <i>mcevoyi</i> (McLern).....							XXX																														
<i>Xenoccephalites hebetus</i> Imlay.....					X																																
<i>Cosmoceras</i> (?) sp.....																																					
Belemnite fragments.....							X																														

stone equivalent of the conglomerate is informally named lower sandstone member. The siltstone sequence overlying the Chisik is herein named the Snug Harbor Siltstone, and the upper member is called Pomeroy Arkose Member.

The present authors recognize the fact that the Naknek Formation as mapped in the Iniskin-Tuxedni region may not be exactly the same sequence of rocks that is exposed throughout much of the Alaska Peninsula. However, gross lithologic features are similar; faunal elements are similar in some respects and dissimilar in others. The dissimilarities of faunas suggest a possible solution to the correlation problems in that the sequence exposed in the Iniskin-Tuxedni region may be equivalent to only part of the lower Naknek on the Alaska Peninsula. This possibility will be discussed more fully in the succeeding pages.

Chisik Conglomerate Member

The Chisik Conglomerate Member is used in this report in the restricted usage of the earlier reports and

not in the broad sense that Kirschner and Minard applied to it. In restricted usage, Chisik was applied to a massive cobble-boulder conglomerate that was found locally at the base of the Naknek Formation. Kirschner and Minard recognized an arkose and graywacke present at the base of the formation in most localities as being a facies of the conglomerate and use the name to include both facies. The present authors have designated the lower sandstone member as this lateral equivalent of the Chisik Conglomerate Member.

The Chisik Conglomerate was first described by Martin (1905, p. 44) from the exposures along the northwest side of Chisik Island, after which it is named. Stanton and Martin (1905, p. 406) and Moffit (1922, p. 141-142; 1927, p. 31-32) also mention and describe the Chisik Conglomerate from the Iniskin-Tuxedni region, but none of these early workers actually established and described a type section. Therefore, this paper will refine the type section as being along the northwest side of Chisik Island, starting just north of

the Snug Harbor Cannery and continuing northwest along the shore for 2,500 feet.

AREAL DISTRIBUTION

The Chisik Conglomerate Member is restricted to the north and south ends of the mapped area, the best exposures being on Chisik Island and on the east shore of Iniskin Bay. The massive conglomerate forms nearly vertical cliffs at both localities. Southward from Chisik Island the conglomerate interfingers with the lower sandstone member, and wedges out completely on the south side of the Johnson River. The thick section of conglomerate present at Iniskin Bay exhibits a similar "wedge-out" to the north. The member cannot be recognized as such north of Brown Creek; however, a few small pebbles are present in parts of the lower sandstone member at Chinitna Bay and Hickerson Lake.

CHARACTER

Massive cobble-boulder conglomerate is characteristic of the Chisik Conglomerate Member. About 40 percent of the constituents are intrusive rocks, diorite and other granitic rock types; an equal amount is volcanic and metasedimentary rocks, chiefly red and green lava and gray quartzite. The remaining 20 percent are mostly cobbles of intraformational sandstone and siltstone. The percentages are based on a physical count of the constituents in a small area averaged with the results of counts from other nearby localities. The percentage of intraformational constituents counted may be a little low owing to the tendency of these softer rocks to crumble before the volcanic and igneous rocks do.

Lenticular beds of coarse-grained arkosic sandstone and grit-to-pebble conglomerate occur throughout the massive conglomerate. The clastic sediments in the lenticular beds and the matrix of the massive conglomerate are similar in composition to constituents of the conglomerate. All clastic elements show a high degree of sphericity. The massive conglomerate passes laterally into sandstone; where transition occurs, the coarse constituents gradually become smaller and less numerous until only a few pebbles are present in the sandstone.

The rapid facies changes indicate that this period was one of crustal unrest that was probably accompanied by mountain building. The high percentage of granite and diorite in the conglomerate indicates that the Aleutian Range batholith was being actively eroded. Intrusive rock constituents are present in only very minor quantities in beds older than basal Naknek.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the Chisik Conglomerate Member is highly variable, attaining a maximum of 560 feet at the type locality; it is 300 feet thick at Iniskin Bay and is absent between Brown Creek and Johnson River.

The contact with the underlying Chinitna Formation is locally an unconformity, as is well illustrated at Iniskin Bay, where the uppermost beds of the Chinitna Formation are missing. The upper contact with the Snug Harbor Siltstone Member was seen only in the vicinity of Iniskin Bay, where it is conformable and sharp. Elsewhere the upper contact is with the lower sandstone member and is gradational.

The section herein described from the type locality was measured with planetable and alidade by Arthur Grantz and J. K. Hartsock in 1951.

Type section Chisik Member

Gradational Contact.

Chisik Conglomerate Member:	<i>Thickness (feet)</i>
Conglomerate, massive, pebble-to-boulder; cobbles and boulders near base; becomes less coarse toward top; lenticular and irregular beds of coarse-grained sandstone and grit scattered throughout; conglomeratic constituents 40 percent intrusive rock, 40 percent volcanic and metamorphic rock, 20 percent intraformational rock.....	560
Total section measured.....	560
Unconformity.	

AGE AND CORRELATION

The massive conglomerate beds have not furnished any fossils, but the age of the Chisik Conglomerate Member can be determined fairly closely by association with beds that contain a good ammonite fauna. The conglomerate interfingers with and passes laterally into the lower sandstone member of the Naknek Formation; therefore, these two units must be time equivalents. The lower sandstone member contains several species of the genus *Cardioceras* which can be correlated with the European standard zone of *Quenstedtoceras lamberti* through the zone of *C. cordatum*. These zones are correlated with uppermost Callovian and lower Oxfordian stages of Late Jurassic age.

Lower Sandstone Member

The lower sandstone member is the lateral equivalent of the Chisik Conglomerate Member; it interfingers with and grades into the Chisik near Tuxedni and Iniskin Bays and replaces the Chisik Conglomerate Member in the area between Brown Creek and Johnson River.

Kirschner and Minard (1949) mapped these beds as part of their Chisik Member, but by original definition the Chisik was restricted to the massive conglomerate

and is so restricted in this paper. The present authors believe that the lower sandstone member is only a local feature and that even though it can be mapped throughout the Iniskin-Tuxedni region, it does not warrant a formal name.

#### AREAL DISTRIBUTION

The lower sandstone member is mapped from the east shore of Oil Bay to Chisik Island; it is missing on Iniskin Bay where the Chisik Conglomerate Member is in contact with both the underlying Chinitna Formation and the overlying Snug Harbor Siltstone Member of the Naknek Formation. Along most of its area of exposure the lower sandstone member forms the upper nearly vertical cliffs of the coast mountains.

#### CHARACTER

Arkosic sandstone and high-rank graywacke characteristic of the lower sandstone member attain their maximum thickness in the central part of the area. The rocks are thin bedded to massive, fine to coarse grained, and light gray; some beds have a tuffaceous matrix. Zones of small pebbles may be present, and thin beds of arenaceous siltstone are not uncommon between thick sandstone units. The sandstone near the base of the member has a banded appearance that results from the alternation of light-gray beds with darker gray and brown beds. The appearance of these beds is very distinctive, and they form a good horizon marker.

#### THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the lower sandstone member is highly variable, owing to intertonguing with the Chisik Conglomerate Member; the sandstone attains a maximum thickness of 840 feet at Chinitna Bay and is missing at Iniskin Bay. About 500 feet of arkosic sandstone is present at Chisik Island; this sandstone includes some thick conglomerate lenses that are actually part of the Chisik but cannot be defined at the scale of the map.

The lower sandstone member is in contact with the overlying Snug Harbor Siltstone Member throughout most of the area; the contact is in a gradational zone a few tens of feet thick in which sandstone is replaced by siltstone.

#### AGE AND CORRELATION

Fossils are not as numerous in the Naknek Formation as they are in the underlying Chinitna Formation and Tuxedni Group. The Chisik Conglomerate Member has furnished no fossils, but beds in the lower sandstone member have a limited ammonite fauna. The ammo-

nites are usually in thin-bedded sandstone or siltstone that probably reflect a depositional environment that was a little more conducive to preservation of the fossils than were the conditions under which the massive sandstone and conglomerate was deposited. The fossils collected are listed in table 12.

Ammonites from the lower sandstone member are restricted to three genera, *Cardioceras*, *Phylloceras*, and *Lytoceras*. *Cardioceras* is by far the most abundant, having two subgenera, several described species, and possibly one or more new species represented. Two of the species, *Cardioceras martini* and *C. distans*, can be correlated with species from northwest Europe. *C. martini* is found in the basal few hundred feet of the member; near the top of its range it is associated with *C. distans*, which then continues to the top of the member. *C. martini* is correlated with the top of the European standard zone of *Quenstedtoceras lamberti* through the lower part of the zone of *Q. mariae* (Imlay, 1953, chart opposite p. 60). The range of *C. distans* is through the upper part of the zone of *Q. mariae*, and the succeeding zones of *C. cordatum* and *Perisphinctes plicatilis* (Imlay, 1953, and written commun., 1958). These European zones are correlative with uppermost Callovian and lower Oxfordian stages of Late Jurassic age.

A few pelecypods are found associated with the ammonites in the lower sandstone member. The more common ones include *Pleuromya*, *Quenstedtia*, *Oxytoma*, *Thracia*, and *Astarte*. Pelecypods are not common but may be found locally in large numbers. Other faunal elements present in the member are a few gastropods, echinoids, and belemnites.

The fauna from the lower sandstone member may furnish a clue to the correlation problems that seem to exist in the Naknek Formation between the Cook Inlet area and the Alaska Peninsula. Martin (1926, p. 211) recognized this problem when he stated, "It should be noted that the fauna of the Naknek Formation of most places on the Alaska Peninsula differs from that of the supposed equivalent beds on Cook Inlet in not containing *Cardioceras*. Specimens of this genus, which is characteristic of the lower (sandstone member of this report) beds that have been referred to the Naknek Formation on Cook Inlet, have been found at only one locality on the Alaska Peninsula." The pelecypod *Buchia* (= *Aucella*), which is common in the Snug Harbor Siltstone Member overlying the lower sandstone member, is also abundant in beds that overlie the basal conglomerate on the Alaska Peninsula (Keller and Reiser, 1959, p. 269-273) (Martin, 1926, p. 209-218). There are several possible explanations for this apparent discrepancy of the faunas: difference in age of the basal part of the formation in the two areas;

TABLE 12.—Geographic and stratigraphic distribution of fossils in the Naknek Formation  
[Identified by R. W. Imlay. Collections made by R. L. Detterman, Arthur Grantz, J. K. Hartsock, R. W. Imlay, and C. E. Kirschner]

Member.....	Lower sandstone								Snug Harbor Siltstone Member							
	Oil Bay		Chinitna Bay area				Hickerson Lake area		Iniskin Bay-Oil Bay			Chinitna Bay			Chisik Island	
Geographic location.....	303	307	304	308	309		310	305	306	311	312	314	313			315
Map reference (pl. 3).....																
Stratigraphic position above base of members (ft).....	50	150	50-150	200-250	450	450	800	100-175	100-200	200-225	550-600	650-675	600	600	600	700-750
USGS Mesozoic loc.....	22418	22426	21350	21782	21351	21784	21783	22701	27095	22450	20723	22449	21785	21786	21352	22667
<i>Echinotis</i> sp.....		X														
<i>Melagrinea</i> .....		X														
<i>Grammatodon</i> sp.....		X														
<i>Oryzoma</i> sp.....		X			X	X					X					
<i>Buchia</i> cf. <i>B. concentrica</i> (Sowerby).....										X	X					X
aff. <i>B. concentrica</i> (Sowerby).....															X	
sp.....																
<i>Pleuromya</i> sp.....	X	X			X			X	X		X	X			X	
<i>Goniomya</i> sp.....											X				X	
<i>Pholadomya</i> sp.....						X										
<i>Thracia</i> sp.....		X				X		X	X							
<i>Astarte</i> sp.....					X	X					X	X				
<i>Cyprina?</i> sp.....		X														
<i>Isocyprina</i> sp.....	X										X					
<i>Tancredia</i> sp.....											X					
<i>Quenstedtia</i> sp.....		X				X					X					X
<i>Isognomen</i> sp.....					X						X					
Gastropod (undet.).....											X					
<i>Phylloceras</i> sp.....			X		X		X			X	X		X	X	X	
<i>Lytoceras</i> sp.....	X										X					
<i>Cardioceras distans</i> (Whitfield).....					X						X					
<i>distans</i> var. <i>depressum</i> Reeside.....											X					
<i>martini</i> Reeside.....				X		X		X								
(Scarburgiceras) <i>martini</i> Reeside.....	X	X	X					X								
(Scoticardioceras) <i>alaskense</i> Reeside.....					X											
(Scoticardioceras) sp.....					X			X								
<i>Perisphinctes</i> sp.....											X	X				X
Belemnite fragments.....											X					X

difference in depositional environment, including such factors as temperature of the water; a barrier between the areas; or merely a failure in collecting. The present authors believe that the most logical explanation is that the basal part of the Naknek Formation in the Cook Inlet area is actually older than the basal part on the Alaska Peninsula.

Snug Harbor Siltstone Member

Snug Harbor Siltstone Member is herein named to supersede the term siltstone member of the Naknek Formation used by Kirschner and Minard (1949). The member is well exposed in the sea cliffs at Snug Harbor on the southwest end of Chisik Island and is named for that locality. The massive arenaceous dark-gray siltstone forms a conspicuous unit in the Naknek Formation that can be readily mapped.

AREAL DISTRIBUTION

The Snug Harbor Siltstone Member is present as a continuous band in the coast mountains from Iniskin Bay to Chisik Island. Between Iniskin and Oil Bays the siltstone crops out near the summit of the steep west-facing escarpment of the coast mountains and is found in a similar position between Brown Creek and Chinitna Bay. Between Oil Bay and Brown Creek

the siltstone is on the southeast-facing dip slope of the mountains between peaks formed by resistant beds of the lower sandstone member and the overlying Pomeroy Arkose Member.

The Snug Harbor Siltstone Member is exposed north of Hickerson Lake in a belt 2,000-3,000 feet wide on the southeast-facing slopes of the coast mountains. These slopes are in part dip slopes. Between Chinitna Bay and Hickerson Lake the member occurs in low saddles between the more resistant members of the Naknek Formation.

CHARACTER

Massive to thin-bedded, dark-gray to black siltstone is the dominant constituent of the Snug Harbor Member. The siltstone is hard and usually fractures into small angular fragments; locally it has a concentric fracture. The concentrically fractured rock is very fine grained, almost a claystone, while the angularly fractured siltstone is arenaceous. Concretions and lenticular beds of hard gray limestone and small nodules of marcasite are present but not conspicuous, for they are commonly oriented parallel to the bedding and have about the same hardness as the enclosing siltstone. Calcareous thin-bedded gray sandstone is a

minor constituent of the section; locally a few small pebbles are found in these sandstone interbeds. Thin layers of volcanic ash and tuffaceous material are found in a few localities but are not abundant.

The siltstone near the base of the section is commonly laminated with alternating light-gray and dark-gray layers similar to the banding that is conspicuous in the lower sandstone member. The laminae are thin, generally about  $\frac{1}{8}$  to  $\frac{1}{4}$  inch thick, and the rock is very fine grained. An increase in light-gray clay-sized particles probably explains the light bands. The dark bands have the same general mineral composition as the bulk of the siltstone in the Snug Harbor Member.

The lithology of the member is remarkably uniform throughout the region. Rapid lateral facies changes that are common to most of the stratigraphic units of the Middle and Upper Jurassic of this region are not present in the Snug Harbor Siltstone Member. Limestone concretions are somewhat more numerous in the northern part, and sandstone interbeds are thicker in the southern part but, except for these minor fluctuations, the member appears to have been deposited under similar conditions throughout the region. The source area for the sediments was still to the northwest, for the mineral constituents of the siltstone are generally the same as for the underlying rocks. It is impossible to determine the amount or type of any transverse facies change that might have been present because only the one linear belt of outcrops is now preserved.

#### THICKNESS AND STRATIGRAPHIC RELATIONS

Sections of the Snug Harbor Siltstone Member range from 720 to 860 feet thick. This uniformity of thickness seems to match the uniform lithology of the rocks and makes the member an unusual stratigraphic unit for this part of Alaska. The thickest section is at the type locality on Chisik Island.

The type section is exposed in the sea cliffs along the southwest shore of Chisik Island. The rocks of this member are less resistant to erosion than the underlying Chisik Conglomerate Member or the overlying Pomeroy Arkose Member; consequently, a small indentation of the coastline known for many years as Snug Harbor, has formed. The type section starts about 1,000 feet north of the extreme southern tip of the island and continues north along the shore for about 3,200 feet in strata that dip  $19^{\circ}$ - $20^{\circ}$  SE. Details of the type section were measured with planetable and alidade by Arthur Grantz and J. K. Hartsock in 1951.

#### Type Section of Snug Harbor Siltstone Member

Local unconformity.	
Snug Harbor Siltstone Member:	Thickness (feet)
Siltstone and shale, thin- to medium-bedded, gray, calcareous; interbeds of fine-grained calcareous sandstone; beds become thinner and more lenticular toward the top.....	280
Siltstone, massive, gray, hard; few limestone concretions scattered throughout; rare interbeds of sandstone.....	260
Siltstone and claystone, massive to medium-bedded, gray; few thin interbeds of shale; large limestone and small marcasite concretions.....	230
Siltstone, laminated with dark- and light-gray bands; interbeds of fine-grained sandstone.....	90
Total section exposed.....	860
Gradational contact.	

The lower contact of the Snug Harbor Siltstone Member with the Chisik Conglomerate Member and the lower sandstone member appears to be conformable in all exposures; it is placed at the top of the massive sandstone throughout most of the area and is somewhat gradational. At Iniskin and Oil Bays the siltstone is in contact with the massive conglomerate of the Chisik Member; this contact also appears to be conformable, but the massiveness and irregularities of bedding in the conglomerate make this uncertain.

The upper contact is placed at the base of the lowest massive arkosic sandstone of the overlying Pomeroy Arkose Member. This contact is sharp and conformable throughout most of the region mapped with the exception of the type locality on Chisik Island, where a slightly irregular erosional surface is present between the two members.

#### AGE AND CORRELATION

The siltstone of the Snug Harbor Member is the most fossiliferous unit of the Naknek Formation. Most of the fauna consists of the pelecypod *Buchia* (*Aucella*), of which there are many species. A few ammonites have been collected, but the large ammonite population characteristic of the underlying Chinitna Formation and Tuxedni Group is missing. The ammonites collected belong to the genera *Amoeboceras*, *Phylloceras*, and *Perisphinctes*. The genus *Cardioceras*, which is moderately abundant in the lower sandstone member, has been found associated with *Buchia* in only the lower few feet of the Snug Harbor Siltstone Member; this association is based on two collections from Oil Bay.

Correlation of the Snug Harbor Siltstone Member with the European standard zones is based on the association of a few faunal elements and is not as definitive as the correlation of the underlying beds

based on large faunal assemblages. The presence of *Cardioceras distans* var. *depressum* Reeside in association with *Buchia* cf. *B. concentrica* (Sowerby) suggests that the base of the siltstone can be correlated with the top of the zone of *Perisphinctes plicatilis* of middle Oxfordian age. A single specimen of *Amoeboceras* was obtained by Stanton in 1904 from about the middle of the siltstone unit on Oil Bay. This specimen was associated with *Buchia* cf. *B. concentrica*, which is the common form of *Buchia* in the siltstone beds. The top of the range of *Amoeboceras* is correlated with the zone of *Rasenia mutabilis* (Imlay, 1953) of early Kimmeridgian age but the genus is more characteristic of the zone of *Decipia decipiens* of late Oxfordian age (Imlay, written commun. 1958). *Buchia* has a range similar to *Amoeboceras* (Imlay, 1959).

The age of the Snug Harbor Siltstone Member cannot be determined exactly; it is at least as old as late Oxfordian and may be as young as middle Kimmeridgian, all of Late Jurassic age. A similar assemblage of fossils has been found at many places on the Alaska Peninsula, as reported by Keller and Reiser (1959, p. 269-273), Martin (1926, p. 207-218), Smith (1925, p. 198-201), Smith and Baker (1924, p. 181-183), Capps (1922, p. 101-105), Martin and Katz (1912, p. 72-74) and Stanton and Martin (1905, p. 402-407). On the Alaska Peninsula this faunal assemblage overlies an unfossiliferous conglomerate that is correlated with the Chisik Conglomerate Member.

#### Pomeroy Arkose Member

Pomeroy Arkose Member is herein redefined as the uppermost unit of the Naknek Formation in the Iniskin-Tuxedni region. This unit includes the Pomeroy Member and upper sandstone member of Kirschner and Minard (1949). The present writers believe it is impracticable to subdivide this unit into two members because arkosic sandstone is the dominant constituent of both members and a contact based on lithology cannot be drawn with any certainty between them.

#### AREAL DISTRIBUTION

The Pomeroy Arkose Member is conspicuous wherever it is exposed because of its light-gray color and its resistance to erosion. The massive resistant arkose forms the southeastward-facing dip slopes of the coast mountains and the spectacular white sea cliffs between Iniskin and Chinitna Bays. The light-colored escarpment along the crest of most of the coast mountains, as seen from the landward side, is also formed by these same beds.

Rocks of this member are the youngest consolidated sedimentary rocks on Iniskin Peninsula and are present along the entire Cook Inlet shoreline except where

cut by Oil Bay and Dry Bay. The arcuate belt formed by these beds is about 1-2½ miles wide. The greater width of this belt as compared to that of some older rock units is due to its being a dip slope. The many islands and reefs in the vicinity of Iniskin Bay and Oil Bay and Gull Island at the mouth of Chinitna Bay are all remnants of still younger beds that have been removed by erosion.

North of Chinitna Bay the massive arkosic beds form southeastward-facing dip slopes on most of the coast mountains and light-colored landward-facing escarpments along the crests, but the conspicuous white sea cliffs are missing except north of Johnson River. Between Chinitna Bay and Johnson River the Pomeroy Arkose Member is separated from the shoreline by a belt of Tertiary and Quaternary deposits ½-3½ miles wide.

#### CHARACTER

Massive medium- to coarse-grained light-gray arkose is the main constituent of the member. The sea cliffs and the escarpment along the crest of the coast mountains tend to overemphasize the massiveness of the beds. Closer inspection shows many thin beds of siltstone and pebble conglomerate interlayered with the arkose. This lithology is characteristic of the sandstone facies of the member. A conglomerate facies is present at one locality on Iniskin Peninsula.

Rocks that are believed to be typical of the ones classified as arkose or arkosic sandstone in this report were examined in thin section. They are rich in quartz, 40-45 percent, and contain almost as much feldspar, 30-35 percent; the feldspar is almost entirely sodic plagioclase. Dark minerals, mainly hornblende and tourmaline, constitute about 15-20 percent of the rock and give it a distinct salt-and-pepper appearance. Other minerals in minor amounts include garnet, sphene, magnetite, and biotite, the biotite being more abundant than the other minor minerals. Volcanic rock fragments make up about 2-3 percent of the rock. The matrix of the specimens is quite variable. Most have a fine clay matrix, but locally the rock is tuffaceous or chloritic and in some specimens the grains are cemented by silica. The individual grains in the specimens are subangular to subround. The more destructible minerals are distinctly more angular than is quartz. The character of the grains led the present authors to conclude that these rocks are epiclastic sediments and not pyroclastic as they were defined originally by Martin and Katz (1912, p. 72). The authors further believe that even the rocks having a tuffaceous matrix are epiclastic sediments, inasmuch as the grains in the one specimen examined were distinctly rounded.

The general composition of the arkose suggests that the source was the quartz diorite exposed along the eastern margin of the Aleutian Range batholith, which is about 10 miles west of the present position of the arkose beds. The high percentage of destructible minerals and their angular character tend to support the idea of short transport and quick burial.

The massive arkose commonly contains small pebbles of volcanic rock or intraformational sedimentary rocks. The pebbles may be in thin lenticular beds or scattered at random and may correlate in part with the massive conglomerate facies that is present on the east shore of Iniskin Bay, where it forms spectacular sea cliffs. Mount Pomeroy is composed of this conglomerate. The massive conglomerate becomes thinner a mile east of the mountain and grades laterally into sandstone; hence only a thin section of conglomerate is present at Oil Bay. The only occurrence of the massive conglomerate facies in the mapped area is that near Iniskin Bay; how far this facies extends south of the Iniskin-Tuxedni region is not known.

The constituents of the conglomerate are mainly large well-rounded pebbles and cobbles in a matrix of coarse-grained arkosic sandstone. About 40 percent of the pebbles and cobbles are intrusive rocks, mainly diorite and other granitic rocks; 30 percent are volcanic rocks; and about 30 percent are intraformational sandstone and siltstone. The composition is very similar to that of the conglomeratic facies of the Chisik Member. Lenticular beds of arkosic sandstone similar to the matrix of the conglomerate occur at intervals throughout the section.

Dark-gray to brownish-gray siltstone is present throughout the section, mainly as thin interbeds between massive beds of arkose. The mineral constituents of the siltstone are quite different from the arkose and more closely resemble the graywacke of the older formations. Most sections of the Pomeroy Arkose Member have at least one 70-350-foot siltstone unit in which the rock is medium bedded to massive, arenaceous, and gray, and weathers brownish gray to olive gray. This siltstone sequence is usually in the lower part of the member.

A few thin beds of water-laid tuff are present in sections from the vicinity of Hickerson Lake and Red Glacier. These beds are probably the only pyroclastic sediments in the Pomeroy Arkose Member. In this area the arkose has a tuffaceous matrix.

#### THICKNESS AND STRATIGRAPHIC RELATIONS

Exposed sections of the Pomeroy Arkose Member show a wide range in thickness. This extreme variability is more a function of erosion than of deposition. Erosion is continuing at the present time to remove

beds exposed in the sea cliffs along the shore of Cook Inlet. Sections shown in plate 5 represent the approximate maximum and minimum thicknesses for the member. The thinnest section, about 850 feet thick, was measured on the south end of Chisik Island. The thickest section, along the south side of Red Glacier, was measured and computed to be about 3,300 feet; the upper 1,500 feet is poorly exposed, however, and this thickness may be slightly in error.

The type section is a composite of the sections exposed on the north and south sides of Chinitna Bay. The section on the north side was first measured by G. C. Martin and T. W. Stanton in 1904 and has been rechecked many times since then. The section on the south side was measured by J. K. Hartsock and Arthur Grantz in 1949 and was checked several times between 1949 and 1958; this section does not have the large concealed intervals that are present on the north side and it is used for the type section except for the upper 700 feet. The upper 700 feet on the north side represents beds that are missing from the south shore of the bay.

*Type section of the Pomeroy Arkose Member from Chinitna Bay*  
[Units 1-83 of section by Martin and Katz (1912, p. 69-71) rechecked by J. K. Hartsock and Arthur Grantz in 1949]

Unconformity.	<i>Thickness (feet)</i>
<b>Pomeroy Arkose Member:</b>	
Arkose, thin- to medium-bedded, coarse-grained, light-gray; pebbles and cobbles mainly granite and volcanic rocks; thin interbeds of siltstone; belemnites near base.....	110
Siltstone, arenaceous, dark-gray; <i>Buchia</i> near top..	20
Arkose, medium-bedded, coarse-grained, conglomeratic; large-scale cut-and-fill channels.....	80
Siltstone, arenaceous; thin interbeds of arkose.....	80
Covered interval.....	400
Arkose, massive, coarse-grained, light-gray, cross-bedded; few lenticular beds of pebbles; thin interbeds of dark-gray siltstone.....	360
Siltstone, thin-bedded, dark-gray; thin sandstone interbeds.....	50
Sandstone, thin-bedded to massive.....	160
Arkose, thick-bedded to massive, medium- to coarse-grained; conglomeratic; siltstone interbeds.....	470
Siltstone, medium-bedded, dark-gray; weathers brown hard; thin interbeds of fine-grained sandstone....	280
Arkose, massive, coarse-grained, gray-brown; few pebbles.....	200
Siltstone, massive, gray, hard.....	80
Arkose, massive, coarse-grained, gray-brown; conglomeratic zones.....	110
Total section exposed.....	2,400
Contact.	

The lower contact with the Snug Harbor Siltstone Member is conformable and sharp in all exposures except on Chisik Island, where a slightly irregular

erosional surface separates the two units. The contact is placed at the base of a massive conglomeratic arkose bed and can be picked without difficulty in all exposures.

The upper contact is a regional angular unconformity. The Pomeroy Arkose Member is the youngest Mesozoic unit present in the Iniskin-Tuxedni region. From the north shore of Chinitna Bay to Johnson River the Pomeroy is unconformably overlain by Tertiary deposits. The angular discordance between the Naknek and Kenai (Tertiary) Formations is small, about 5°-8°.

#### AGE AND CORRELATION

The age of the Pomeroy Arkose Member is only imperfectly determined by the meager fauna. Three collections have been reported; all are from siltstone interbeds in the massive arkose. *Lytoceras*, *Phylloceras*, and the pelecypod *Buchia concentrica* are the only forms of value for age determinations. The fauna is not definitive as to European standard zones but does suggest an age similar to that of the upper part of the Snug Harbor Siltstone Member. The stratigraphic succession of beds clearly indicates that most of the Pomeroy is younger than the Snug Harbor; this relation means that the arkose cannot be older than the late Oxfordian. The *Buchia* collected from beds in the middle of the member suggest an age for those beds not younger than middle Kimmeridgian, and in all probability no part of the Pomeroy Arkose Member is younger than early Kimmeridgian.

### TERTIARY SYSTEM

#### KENAI FORMATION

##### AREAL DISTRIBUTION

Sedimentary rocks of Tertiary age mapped as the Kenai Formation are present between Chinitna Bay and Johnson River. The rocks are exposed in a narrow belt along the southeast slopes of the coast mountains. The southeast-dipping beds extend from sea level at Chinitna Bay to about 2,800 feet on the mountain between Hickerson Lake and Red Glacier. The exposure on the north shore of Chinitna Bay was examined as early as 1909 by Martin and Katz (1912, p. 77-78).

The area of exposed Kenai Formation is less than 10 square miles, most of which is on the southeast slope of the mountain between Hickerson Lake and Red Glacier. Till and outwash deposits mantle the lower slopes of the coast mountains and probably cover large areas underlain by the formation.

#### CHARACTER

The Kenai Formation in the Iniskin-Tuxedni region consists chiefly of cobble conglomerate, with which are interbedded smaller amounts of sandstone, laminated siltstone, and silty shale. Coal beds a few inches thick are interbedded with the siltstone and shale. A thin lenticular bed of carbonaceous ashstone breccia was noted in the exposure on the north shore of Chinitna Bay; this bed is apparently the one referred to as obsidian by Martin and Katz (1912, p. 78). The bed contains some quartz and feldspar grains and probably some glass shards but also contains plant fragments and is clearly of sedimentary origin.

The conglomerate, which is similar to that in the underlying Naknek Formation except that it is less well indurated and a slightly different color, is composed chiefly of round to subround cobbles of quartz diorite, flow rock, argillite, sandstone, siltstone, quartzite, tuff, and coal fragments. Intrusive and volcanic rock fragments, in about equal amounts, form about 70 percent of the conglomerate. The remainder is primarily sedimentary rock.

The matrix for some of the conglomerate is a dusky-brown siltstone. In other beds the matrix is a medium-to coarse-grained arkosic sandstone that contains much feldspar and mica and can be broken easily in the hands. The arkosic sandstone is present also as lenticular beds in the conglomerate. Some of the conglomerate contains very little matrix and is poorly indurated.

The sandstone is arkosic to subarkosic, massive, irregularly to lenticularly bedded, medium to coarse grained, and light olive gray to light olive brown; it contains abundant mica and feldspar grains. The grains are subround to subangular, the feldspar and mica grains being a little larger than the quartz grains. The matrix seems to be a fine-grained variety of the same lithologic composition.

The siltstone and shale interbedded with the conglomerate and sandstone is a very fine grained variety of the subarkosic sandstone set in a poorly defined matrix of silt- and clay-sized particles. Most of the siltstone is thin bedded to finely laminated, but other units are massive and have no discernible bedding. The rock is moderate yellowish brown and weathers to lighter shades of yellowish brown. This coloration is typical of Tertiary sedimentary rocks in the Cook Inlet area and is distinctly different from that of the older sedimentary rocks.

Coal associated with the siltstone is a shaly sub-bituminous-rank coal that burns imperfectly and leaves a volume of ash almost equal to the original volume of coal.

## THICKNESS AND STRATIGRAPHIC RELATIONS

The Kenai Formation in this region is about 1,100 feet thick. The thickest section is on the southeast slope of the mountain between Hickerson Lake and Red Glacier. Small streams have cut into the formation, and a nearly complete section can be obtained by checking these stream cuts. The most accessible exposures are on the north shore of Chinitna Bay, near the point where East Glacier Creek enters the bay. About 450 feet of section is exposed at this locality.

The formation has a gentle southeast dip of about 15°-16° in the lowermost beds and about 7°-8° in beds near the top. The exposed sections are not complicated by faulting insofar as can be determined by field observation. The contact with the underlying Naknek Formation, of Late Jurassic age, is an angular unconformity. The angular discordance is small, about 5°-8°. The upper contact is also an angular unconformity with surficial deposits of Pleistocene age overlying the formation.

The areal extent of the Kenai Formation is too small to determine facies changes or directional thinning of beds. The rocks were apparently deposited rapidly, as attested by the extremely lenticular bedding, large-scale crossbedding, cut-and-fill features, and the poorly sorted conglomerate and sandstone.

## AGE AND CORRELATION

Sedimentary rocks herein mapped as the Kenai Formation are probably of late Oligocene(?) and Miocene age. This age designation is based on a correlation with similar beds assigned to the Kenai Formation on the east side of Cook Inlet and on the fossil plants found at USGS Paleobotany locality 3505. The Kenai Formation in other parts of the Cook Inlet region ranges in age from late Oligocene(?) through Pliocene. The plants from locality 3505 originally identified by F. H. Knowlton (in Martin and Katz, 1912, p. 78) have been reidentified by J. A. Wolfe as *Metasequoia glyptostroboides* Hu and Cheng and *Ginkgo biloba* L.; the dicotyledonous fragments determined by Knowlton are not considered to be determined to genus. In the Kenai Formation, *Ginkgo biloba* is known only from the lower part, which is of late Oligocene(?) and Miocene age. Arthur Grantz recollected plant fossils from this locality in 1950, but the material was not identifiable.

The exposed Tertiary rocks in this region are presumably equivalent to part of the Kenai Formation on the east side of Cook Inlet. The section is much thinner than any known section on the Kenai Peninsula; consequently, no direct correlation can be made between the two areas. The texture, composition, and coloration are similar; any minor differences are prob-

ably due to different source areas for the sediments. The relationship between the Kenai Formation in the Iniskin-Tuxedni region and the Tertiary rocks on the Alaska Peninsula is not known, but they may be in part equivalent.

## TERTIARY LAVA FLOWS

## AREAL DISTRIBUTION

Remnants of Tertiary lava flows occur in small isolated patches from Iniskin Bay to Tuxedni Bay. The largest flow covers the southeast side of Range Peak, northwest of Right Arm, from sea level to the top of the peak. This flow is 2½ miles long and ¾ mile wide; it is exposed at many places along the west side of Portage Creek. Another exposure of Tertiary flow rock is at the northwest end of Portage Creek valley, where it caps some of the hills between the valley and Marsh Creek. This patch is about 1 square mile in areal extent. A patch of similar size is near the mouth of West Glacier Creek at the head of Chinitna Bay.

Three outcrops mapped as Tertiary flows are very small, being no more than a few hundred yards in areal extent. One is a small islandlike body on the flood plain of West Glacier Creek opposite the mouth of Right Fork. Another is on the north side of Marsh Creek, where it enters the salt marsh at the head of Chinitna Bay. The last exposure is on the south shore of Tuxedni Bay, 2 miles northwest of Fossil Point.

## CHARACTER

The lava is dark-blue-gray to black cryptocrystalline to vesicular basalt and andesite that is slightly altered. Thin irregular veins of hematite and malachite are present in the altered zones that are largely confined to shear planes and fault zones and rarely extend more than 5 feet into undisturbed rock. Some iron staining was noted as much as 30-50 feet from the fractures. Chlorite and calcite are fairly common near the larger fractures where the alteration was most severe.

The vesicular phase of the lava flows contains abundant amygdules of chalcedony and calcite and rare ones of chlorite and zeolites. The dense massive lava, typical of the flow remnants along the west side of Portage Creek valley, is commonly porphyritic, containing phenocrysts of andesine. Basal flow breccia 20-50 feet thick consisting of angular blocks in a vesicular matrix was seen at Tuxedni Bay. Columnar jointing is common through most of the lava.

## THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the Tertiary lava flows is not known but is probably several hundreds of feet in the larger masses west of Portage Creek. In the small remnants the thickness is probably no more than a few tens of feet.

The flows unconformably overlies the upturned edges of Lower Jurassic bedded pyroclastics and Middle Jurassic graywacke and siltstone. The discordant nature of the contact is probably best exposed at the base of the flow on the south shore of Tuxedni Bay. At that locality the flow moved across the eroded edges of Middle Jurassic siltstone and graywacke.

#### AGE AND CORRELATION

The age of the flows cannot be directly determined, but they are younger than Middle Jurassic, for they overlies upturned beds of that age. The surface of the lava is severely dissected as compared to the surface of the Quaternary lava flows near Iliamna Volcano. The degree of weathering suggests an early to middle Tertiary age. However, the flows in this region are probably in part equivalent to the Tertiary flows in the Iliamna Lake region, which overlies sandstone that contains a Tertiary flora (Martin and Katz, 1912, p. 81-82) and are considered to be late Tertiary. Consequently, the best estimate that can be made for the age of the flows in the Iniskin-Tuxedni region is middle(?) to late(?) Tertiary.

### QUATERNARY SYSTEM

#### ILLIAMNA LAVA FLOWS

##### AREAL DISTRIBUTION

Quaternary lava flows radiate from Iliamna Volcano, 11 miles north of Chinitna Bay. The exposed flows cover an area of about 10 square miles, but the total area covered by lava is probably much larger, for snow and ice largely obscure bedrock on the upper slopes of the volcano.

The longest flow extends 3.5 miles down the valley formed by Umbrella Glacier. Two flows down East Glacier Creek are almost as long. The younger is separated from the older flow by a basal breccia zone that includes blocks broken from the lower flow. The East Glacier flow is a flat-topped mesalike ridge bounded by deep gorges of the South and Middle Forks of East Glacier Creek.

A flow near the head of Boulder Creek is nearly as large as the East Glacier Creek flow; it is a shieldlike mass on the side of the volcano. The remaining patches of rock mapped as Iliamna lava flows occur at random through the ice and snow covering the sides of the volcano.

##### CHARACTER

For the purpose of this report, rock mapped as Iliamna lava flows (pl. 1) may include a variety of lithologic types other than actual lava flows; thus, crater fillings and basal flow breccia are included. Juhle (1955, p. 13-33) gives a detailed description of the geology of Iliamna Volcano and its basement.

The lava is a light-gray hypersthene-augite andesite. Phenocrysts of zoned plagioclase as well as hypersthene and augite are embedded in a pilotaxitic groundmass of andesine microlites. Minor amounts of olivine, hematite, and glass are included in the flows. Hematite and its hydration products caused red and light-orange staining of the andesite that is especially common on the rock debris covering Red Glacier. Fragments of native sulphur in the surficial deposits indicate the presence of solfataric deposits. Columnar joints are not particularly numerous in the flows, but a platy jointing having an irregular surface is common. North Twin is composed of yellow-gray opalized-tuff crater fillings, as is part of Iliamna Volcano. South Twin is a lava flow.

##### THICKNESS AND STRATIGRAPHIC RELATIONS

The lava flows have a maximum thickness of about 400 feet near the head of Boulder Creek. The East Glacier flow is about 200 feet thick; it overlies 20-40 feet of blocky breccia that includes fragments of lava and the underlying Jurassic and Triassic bedrock.

The flows were extruded onto the weathered upturned edges of the Triassic and Jurassic basement rocks and cover the Bruin Bay Fault and other fault systems. The flows are in sharp angular discordance with the older rock.

##### AGE AND CORRELATION

Little is known concerning the exact age of the lava flows except that they are probable late Quaternary. Only minor activity is recorded for Iliamna Volcano in historic time (Coats, 1950). At present the volcano is sending up several plumes of steam from its precipitous eastern face (fig. 4). The flows cover several major faults and some minor ones; there is no indication of movement along the faults after the flows were deposited. The main period of faulting is believed to be late Tertiary. The oldest glacial deposits recognized in the area contain abundant fragments of lava, so it can be assumed that the major flows predate the oldest glaciation, which is correlated with the Naptowne Glaciation (Karlstrom, 1957). The Iliamna lava flows were probably formed contemporaneously with some of the numerous Quaternary lava flows in the Cook Inlet-Alaska Peninsula area.

##### SURFICIAL DEPOSITS

##### GENERAL RELATIONS

Unconsolidated deposits of Pleistocene and Recent age mantle about 140 square miles of the Iniskin-Tuxedni region, exclusive of the mudflats. It is not within the scope of this report to give a detailed analysis of these deposits and the factors causing their deposition, but rather to give a brief description of

their size, location, and composition. Most of the field observation consisted of a rather cursory inspection of the more spectacular deposits.

In general, most of the mapped surficial deposits originated through the agencies of Pleistocene and Recent glaciers with subsequent modification by stream and tidal action. The thickness of surficial deposits can only be estimated because depths to bedrock have not been determined except for the oil wells on Fitz Creek; the wells penetrated 20–30 feet of unconsolidated alluvium. Some of the surficial deposits may be much more than 100 feet thick.

The succession of surficial deposits has not been established definitely, but is probably as follows, from oldest to youngest: (1) The residual deposits, which cover most of the bedrock areas below 2,500 feet, are composed of soil and rubble produced by weathering

of bedrock; (2) glacial deposits, which are confined primarily to the area between Chinitna and Tuxedni Bays, include moraine and moraine on ice or superglacial till; (3) colluvial deposits, which occur along the steep northwest-facing escarpment of the coast mountains and where glaciers or streams have cut steep-walled canyons, are made up of rubble that has slid down the hill sides; (4) alluvial deposits, which are present along all the streams, include stream gravel, alluvial fans and cones, and glacial outwash; and (5) littoral deposits, which occur along the shoreline of the bays and along the coast between Chinitna Bay and Johnson River, consist of sand and small gravel and some large blocks.

All but the residual deposits are shown on the geologic map (pl. 1). The residual deposits reflect the character of the bedrock, from which they were derived,



FIGURE 4.—Oblique view of the eastern face of Iliamna Volcano showing type of activity, 1954. Photograph by U.S. Air Force.

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FIGURE 4.—Oblique view of the eastern face of Iliamna Volcano showing type of activity, 1954. Photograph by U.S. Air Force.

and have therefore been used in mapping the bedrock. The surficial deposits lie unconformably on bedrock and are probably all of Pleistocene and Recent age.

#### RESIDUAL DEPOSITS

A layer of soil and rubble covers the hills below 2,500 feet. Hills higher than 2,500 feet are generally too steep to support residual deposits, being composed mainly of bare rock. The residual deposits above 2,000 feet are mainly large rock fragments, because most of the soil-forming vegetation grows below 2,000 feet.

The deposits vary considerably in thickness, depending on bedrock source. Many of the formations are composed of shale and siltstone that rapidly break down to soil owing to the abundant rainfall and vegetation of the region. Stone rings and stone streams, which are characteristic results of frost acting on residual deposits, are not common in this region because the ground surface is covered with a thick layer of snow during the months when frost action would be most severe.

Most of the residual deposits in this region post-date the Pleistocene, inasmuch as glaciers probably covered all land areas below about 1,500 feet, and the movement of the ice would have removed most of the deposits. Because the general character of the topography probably has not changed much since late Tertiary, except for surficial modification by glaciers, any residual deposits not removed by the movement of ice would date from late Tertiary. A thin zone of residual soil beneath the East Glacier lava flow is probably Tertiary in age.

#### GLACIAL DEPOSITS

Glacial deposits in the Iniskin-Tuxedni region are the result of alpine valley glaciers and are probably no older than late Wisconsin. At least three advances are indicated by the position and character of the moraine, and they are correlated with similar deposition on the east side of Cook Inlet (Karlstrom, 1957). The oldest moraine, correlated with the upper part of the Naptowne Glaciation, extends as much as 10 miles beyond the present glaciers. Well-defined moraine 1.5-3 miles beyond the outer margin of present glaciers is correlated with the Tustumena Stade of the Alaskan Glaciation. Small morainic ridges at the threshold of most of the cirques and end moraines just beyond the outer margin of present glaciers were probably formed by a small advance within the past 1,000 years and are correlated with the Tunnel Stade of the Alaskan glaciation. Small remnants of glacial deposits and erratics on the Iniskin Peninsula may indicate a fourth advance. This part of Cook Inlet was undoubtedly

glaciated by several more extensive glaciations than the ones indicated by deposits at the present, but evidence of the older deposits has been removed or covered.

Deposits of the Naptowne Glaciation form part of the shoreline of Cook Inlet from about a mile west of the mouth of East Glacier Creek to Johnson River. This belt of morainic ridges has a maximum width of about 2½ miles but is completely obscured by outwash and alluvium near the mouth of Red Glacier River. A small remnant of moraine on the north side of Tuxedni Bay is also correlated with this glaciation. Deposits of this advance are missing from the valleys of West Glacier and Middle Glacier Creeks and all narrow valleys where the streams probably flushed out or buried the deposits. Several recessional moraines and sinuous eskers are present on the point between East Glacier and Shelter Creeks and along the abandoned lower course of Johnson River.

Rock fragments in the boulder clay of the Naptowne Glaciation are about 85 percent light-gray lava from Iliamna Volcano and 15 percent intrusive, volcanic, and sedimentary rock of Jurassic and Triassic age. Most of the fragments are 6 inches to 2 feet across, although a few are as much as 6 feet across. Silt, sand, and gravel compose the smaller fractions. The knob-and-kettle topography is considerably modified, but there are many undrained kettle lakes. The knobs are covered by spruce forests and brush but still retain their sharp outline.

Deposits correlated with the Tustumena Stade are present in nearly all valleys. Where these valleys still contain glaciers, the deposits are generally 1.5-3 miles beyond the present terminus. Knob and kettle topography is fresh, there being many undrained lakes. Lateral, terminal, and recessional moraines are well defined and sharp; most are arcuate in outline. The deposits are particularly well defined downstream from the termini of Lateral, Tuxedni, and Red Glaciers. Modification of the moraine is mainly through breaching by melt-water streams and burial by outwash. Most of the deposits are brush covered, but only a few trees are present.

Karlstrom (1957) recognized three distinct advances within the Tustumena on the east side of Cook Inlet. In the Iniskin-Tuxedni region there is good evidence for two minor advances in the Tustumena. Tuxedni Glacier has five arcuate moraines that are correlated with this glaciation (fig. 5); at least two of these, however, are believed to be recessional moraines. The outwash plain from Tuxedni Glacier has nearly buried the Tustumena moraine; only the upper 5-10 feet are still unburied on the youngest deposits and 2-5 feet on the oldest.

Moraine of the Tunnel Stade is relatively unaltered. Knob-and-kettle topography is fresh, and many kettle lakes formed by melting blocks of ice are present between the terminal moraines. Brush covers some of the deposits, but most are brush free and little different from the ablation moraines being formed along existing glaciers.

Small morainic deposits formed during the Tunnel Stade are present as threshold dams across many ice-free cirques; some of these dams impounded small lakes. The cirque deposits are common on the mountains near the coast, where the accumulation area was insufficient for formation of large glaciers. The deposits are largely free of vegetation and consist of large blocks of arkosic sandstone from the Naknek Formation.

Rock fragments in till produced by the major glaciers around Iliamna volcano during the Tunnel Stade are about 95 percent Quaternary lava from Iliamna Volcano and were probably transported as superglacial and englacial till. The present surface of the glaciers, below 3,000 feet, is almost completely covered with ablation moraine and probably represents the zone of maximum ablation in the current retreat of the glaciers. The fragments are as much as 15 feet in diameter, the average being 2-4 feet. Silt, sand, and gravel form a considerable part of the till.

#### MODERN GLACIERS

The glaciers between Chinitna and Tuxedni Bays are probably remnants of the last advance of Tunnel Stade (1700-1800, Karlstrom, 1957). These glaciers are now retreating, as is shown by recessional and ablation moraines near the ice margin. The rate of retreat is not known, but it has amounted to about 200 yards in the very recent past, for the deposits near the present ice margins are fresh and unaltered. Perched lateral moraines 50-100 feet above the surface of the ice indicate the amount of recent thinning.

Iniskin Peninsula has no glaciers at present except for two small cirque glaciers in the mountains near the head of Iniskin Bay. Deposits at the front of these cirque glaciers and the morainic dams in the ice-free cirques of the coast mountains probably date from the Tunnel Stade. A small patch of boulder clay (too small to show on pl. 1) on the east side of Fitz Creek near Iniskin Bay Association well 1 appears to be different from any of the other glacial deposits. Granite and diorite boulders form as much as 30 percent of the boulder clay. Granite and diorite are present also in many of the streams on the peninsula. However, the relative abundance of these intrusive rocks may reflect a source in the mountains at the head of Chinitna

or Iniskin Bays, if so, their presence on Iniskin Peninsula then indicates a more extensive glaciation than any for which deposits were mapped north of Chinitna Bay.

#### COLLUVIAL DEPOSITS

Colluvium, or rock detritus transported by the action of gravity, is abundant in the mountainous area forming the Iniskin-Tuxedni region. Many of the colluvial deposits are too small to map at the scale used on plate 1, and some are included with the alluvium; all large deposits are included on the geologic map.

Most of the colluvial deposits are in areas underlain by siltstone and shale of the Chinitna Formation, possibly because the formation is exposed in the steep northwest-facing escarpment of the coast mountains and in many of the deep stream gorges. The formation is less competent than most of the other rock units exposed in the region and is readily eroded into near-vertical cliffs.

The largest landslide is the one forming the dam at the lower end of Hickerson Lake (fig. 6). A mass of rock nearly 8,000 feet long, 7,000 feet wide, and 300-500 feet thick slid out of the mountain on the southwest side of the valley. The slide is composed almost entirely of blocks of massive arkosic sandstone of the Pomeroy Arkose Member of the Naknek Formation. The lake is in a deep U-shaped glacial valley having bare, almost-vertical bedrock walls near the lower end. The walls extend 200-500 feet above the lake and at least another 100 feet below the surface. The side of the valley collapsed sometime after the withdrawal of the glacier at the end of the Naptowne glaciation, as shown by the fact that the landslide is in part resting on top of the moraine of this glaciation. The slide could have been caused by a severe earthquake accompanying an eruption of Iliamna Volcano. Debris bordering the lake was pushed into ridges 150 feet high by a readvance of ice during the Tustumena Stade or by ice of the Tunnel Stade. The dam is not glacial in origin, inasmuch as the debris does not contain any volcanic rock that is characteristic of the glacial deposits in this region. A thin stand of brush now covers part of the landslide debris as well as the actual slide area. The lake does not have a stream outlet; the water seeps through the coarse debris forming the dam.

A second large landslide is at the entrance to Right Arm of Iniskin Bay. The mass of debris is about 1 mile long,  $\frac{1}{4}$  mile wide, and 500 feet thick; it consists of rock of the Chinitna and Bowser Formations. Glaciers probably were the prime factor causing this slide. Other slides of even greater dimension, but less spectacular, occur along the northwest side of the coast mountains, particularly near Johnson River.

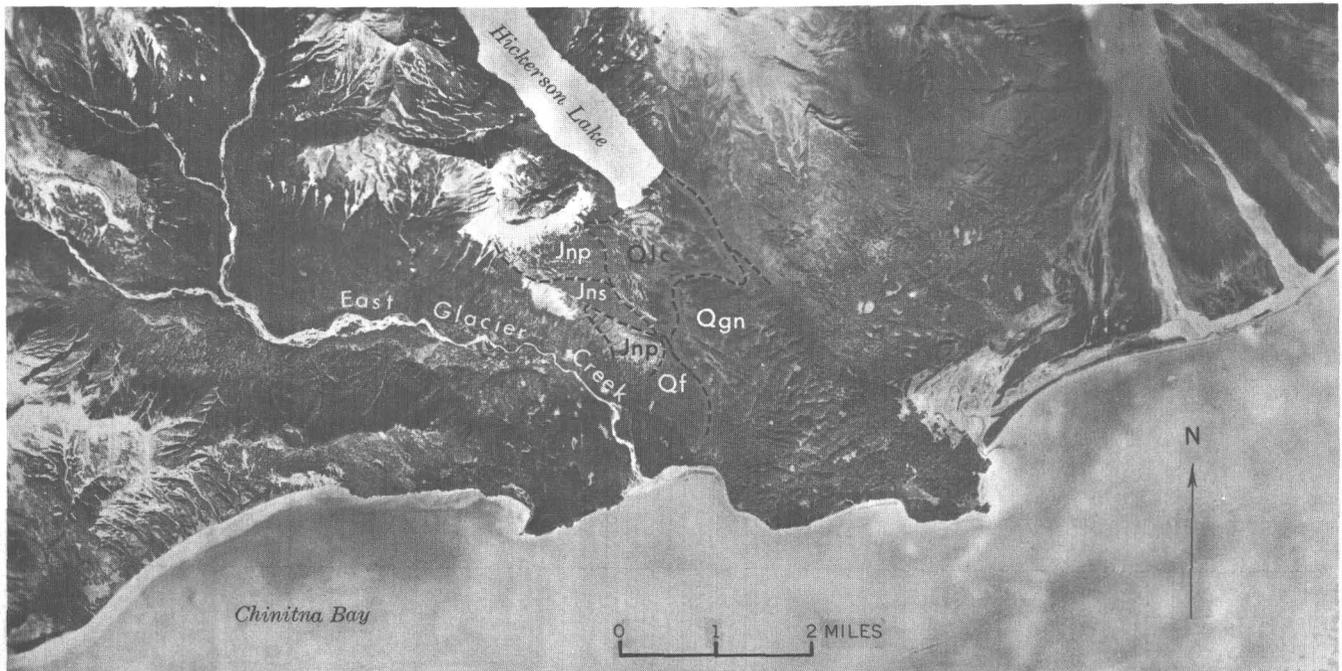


FIGURE 6.—Mosaic of the Hickerson Lake area. The lake was formed when a landslide (Qlc) dammed the valley. The slide debris is composed chiefly of blocks of arkosic sandstone from the Pomeroy Arkose Member of the Naknek Formation (Jnp); it overlies moraine of the Naptowne Glaciation (Qgn). Also indicated are the Snug Harbor Siltstone Member of the Naknek Formation (Jns), and an alluvial fan (Qf). Photograph by U.S. Air Force.

#### ALLUVIAL DEPOSITS

Stream gravel, glacial outwash, and alluvial fans and cones are included under the general heading of alluvial deposits. Alluvium is by far the most abundant of the surficial deposits. The thickness of alluvium in the streams is not known except at the oil wells on Fitz Creek, where the Iniskin Bay Association well 1 penetrated 20–30 feet of unconsolidated gravel overlying bedrock. The rivers between Chinitna and Tuxedni Bays probably contain a much greater thickness of alluvium.

The composition of the unconsolidated deposits forming the alluvium is quite varied. The streams are short and the alluvium reflects the limited source area to the extent that the deposits on some streams may consist almost entirely of one lithologic type. The gradient of the streams is also highly variable, from less than 100 feet per mile to more than 1,000 feet per mile; the size of the constituents may therefore range from pea-gravel to boulders 15 feet across.

Streams in this region do not have large flood plains. West Glacier Creek and Johnson River have flood plains about  $1\frac{1}{2}$ –2 miles wide, much wider than the average. The fact that most of the streams are entrenched 5–10 feet in the alluvium on the flood plains may reflect recent uplift.

Glacial outwash is largely confined to the area between Chinitna and Tuxedni Bays, more specifically

to areas immediately adjacent to the present-day glaciers. Red Glacier and Tuxedni Glacier have broad, gently sloping outwash plains as much as 5 miles wide at their outer margin at tidewater. These outwash fans have obscured most of the morainal deposits of the Naptowne Glaciation and Tustumena Stade. The other glaciers have smaller outwash plains that are confined to the valleys. Most of the deposits mapped as glacial outwash date from the Tunnel Stade. The mass of superglacial and englacial till forming the ablation moraines at the margin of the glaciers is being eroded by melt water to form outwash plains. These deposits are small now but are beginning to cover some of the moraine of the Tunnel Stade.

Alluvial fans and cones are very common in this mountainous region, especially along the valley walls of the larger streams. Small tributary streams having gradients as much as 1,000 feet per mile dump great masses of loose rock material on the relatively flat flood plains of the larger streams. These deposits build fans where the tributaries emerge onto the flood plains. The brush and spruce that cover most of the fans indicate that the tributaries are not eroding their valleys as rapidly as in the past. In many places streams entering Cook Inlet have built alluvial fans that are exposed only at low tide. These fans are indicated on the geologic map as submerged fans.

Small alluvial cones are mostly confined to streams

cutting into the northwest-facing escarpment of the coast mountains. These streams commonly have gradients of 1,500 feet per mile and are intermittent, flowing only after rainstorms and while snow is melting. Consequently, the surface of the cones is much steeper than the surface of the fans. The alluvial cones are included with fans.

#### LITTORAL DEPOSITS

Elevated beach deposits and salt marshes are included with littoral deposits. The mapped beach deposits are now above high-tide line but were formed in the littoral zone in the very recent past and elevated to their present position. Sand and small gravel are the most common constituents but beach shingle and boulders occur on some of the beaches. At the present time, beach shingle is more common in the littoral zone than in the older beach deposits above high-tide line. One reason for this feature is Recent uplift which caused the streams to dump more coarse rock fragments into Cook Inlet, where they form beach shingle on the shoreline.

A tombolo just east of the mouth of Middle Glacier Creek ties an island of Talkeetna Formation rocks to the mainland. Tombolos also connect some of the wave-cut stacks to the main part of Gull Island.

A series of elevated beach ridges are present at Oil and Dry Bays 800–1,500 feet from the present shoreline. At the mouth of Johnson River the oldest beach ridge is 2,500 feet from the present shoreline. These beach ridges are 20–30 feet above the high-tide mark and probably indicate that much uplift of the shoreline in the recent past. Spruce forest now grows on the ridges. The size of the spruce trees indicates an age of not less than 50 years.

The top of a wave-cut terrace on Gull Island is 25 feet above the present beach. This height is about the same as the beach ridges and is further evidence of uplift along the shoreline. Both of these features could have been formed when the water was higher than it is at present; however, sea level is higher now than it has been since the last interglacial stage, and these features obviously are not that old.

Large areas of mudflats are exposed in all of the bays at low tide, and at times of minus tides as much as 50 square miles is exposed. The silt forming the mudflats is laminated with much small-scale crossbedding and occasional layers of small pebbles that were probably deposited during severe storms. Streams entering the bays have cut meandering channels 4–6 feet deep across the mudflats.

#### IGNEOUS ROCKS

Igneous rocks crop out in the western part of the Iniskin-Tuxedni region; they form about 25 percent of the total mapped area. South of Red Glacier the igneous rocks are largely restricted to the area west of the Bruin Bay fault. The fault strikes nearly due north from Lateral Glacier to Tuxedni Bay; it transects the northeasterly regional structural trend of the rocks and causes a thick sequence of igneous rocks to crop out east of the fault near Tuxedni Bay. Small isolated areas of igneous rock are present east of the fault on Iniskin Peninsula.

Both intrusive and extrusive rocks are represented. The extrusive rocks are part of the thick sequence of bedded rocks and are discussed in that connection. They include basaltic lava flows of Late(?) Triassic age; andesitic to dacitic lava flows, tuff, volcanic breccia, and agglomerate of Early Jurassic age; andesitic to basaltic lava flows of Tertiary age; and andesitic lava and volcanic ash of Quaternary to Recent age.

The intrusive rocks are part of the Aleutian Range batholith that is 20–40 miles wide and at least 120 miles long. A strip 2–12 miles wide along part of the eastern border of the batholith is included in the map of the Iniskin-Tuxedni region (pl. 1). Dike and sill offshoots of the pluton are shown where large enough to be depicted at the scale of the geologic map. The dikes and sills associated with the batholith do not extend more than half a mile into the country rock; most are confined to within a few hundred yards of the border. They include granite pegmatite, aplite, quartz diorite, quartz monzonite, lamprophyre, and basalt. The few dikes in the sedimentary rocks east of the Bruin Bay fault are believed to be associated with Iliamna Volcano or the Tertiary flows.

The age of the batholith cannot be determined exactly from the rather limited part exposed in the mapped area. Field evidence suggests, however, that it was emplaced during late Early Jurassic or early Middle Jurassic. A potassium-argon age date on biotite from the batholith at Pile Bay, 15 miles west of the mapped area, gave an age of  $160 \pm 5$  million years; this age would be Middle Jurassic. A lower time limit for the emplacement of the batholith can be established by the intrusive contact with the basal beds of the Lower Jurassic sequence. Mather (1925, p. 166–167) noted that intrusive rocks probably cut the Tuxedni Formation of Middle Jurassic age in the Kamishak Bay region. The present authors found no evidence of such a relation in the Iniskin-Tuxedni region. There are dikes cutting the Tuxedni and younger formations, but most are associated with Iliamna Volcano.

TABLE 13.—*Succession of igneous rocks exposed in the Iniskin-Tuxedni region*

Unit	Age	Character	Stratigraphic relationship
Ash deposits	Recent	Volcanic ash in unconsolidated deposits.	Thin interbeds in alluvial gravel.
Iliamna lava flows	Quaternary	Hypersthene-augite andesite lava, breccia, and associated pyroclastics.	Lie unconformably on folded Talkeetna, Tuxedni, and Chinitna Formations, and the quartz diorite pluton.
Dikes and sills	Quaternary and Tertiary	Basaltic-andesitic porphyry.	Intrude all rocks above the Triassic.
Lava flows	Tertiary	Andesite to basalt.	Lie unconformably on folded rocks of Talkeetna Formation.
Quartz monzonite	Late Early Jurassic to early Middle Jurassic	Pink to gray quartz monzonite stocks, dikes, and sills.	Intrudes quartz diorite batholith, Triassic and Lower Jurassic.
Quartz diorite		Gray to green quartz diorite, granite, granodiorite, gabbro, and syenite.	Large batholith intrudes Triassic and Lower Jurassic.
Dikes		Granite pegmatite, aplite, quartz diorite, quartz monzonite, lamprophyre, basalt.	Intrude batholith, Triassic and Lower Jurassic.
Horn Mountain Tuff Member (Talkeetna Formation)	Early Jurassic	Tuff, andesitic flows, and arkosic sandstone.	Lies unconformably under Tuxedni Group and probably conformably on the Portage Creek Member.
Portage Creek Agglomerate Member (Talkeetna Formation)		Pink volcanic agglomerate, breccia, and andesitic lava flows.	Considered to be conformable with underlying and overlying units.
Marsh Creek Breccia Member (Talkeetna Formation)		Green volcanic breccia and andesitic to dacitic lava flows.	Relationship to Triassic not well known.
Metamorphic rocks	Late Triassic	Metavolcanic lava flows.	Rest unconformably on crystalline metalimestone.

### PLUTONIC ROCKS

The plutonic rocks studied in the Iniskin-Tuxedni region are part of the Aleutian Range batholith. Only a small part of the batholith was mapped; the part included in this report is actually the border phase. It is not the intent of the present authors to go into an exhaustive discussion of these igneous rocks; this project was mainly concerned with the bedded rocks. However, the batholith was the main source of sediments during at least part of the Late Jurassic, and the authors consider a brief discussion pertinent to an understanding of these sedimentary rocks.

Most observations on the plutonic rocks were made by J. Werner Juhle in 1950 and 1951; Juhle was killed in the Valley of Ten Thousand Smokes before the

investigation was completed and his report (1955) is the only published data on these rocks. The brief discussion that follows was compiled from his field notes and report as interpreted by the present authors and from a few observations made by the authors during the investigations of the bedded rocks.

The plutonic rocks in the Aleutian Range batholith had been referred to as granite in most of the older reports on this part of Alaska (Martin and Katz, 1912, p. 75-78; P. S. Smith, 1917, p. 112-118, and Mather, 1925, 166-167). Juhle (1955) referred to these rocks as quartz diorite and quartz monzonite. In order to obtain a better idea of the kind of rocks present in the pluton, the senior author reexamined 13 thin sections from Juhle's collections (table 14).

TABLE 14.—Quantitative mineralogical content of selected rocks from Aleutian Range batholith

[Samples from Juhle's collection (1955). Only main minerals given. Percentages of these minerals estimated visually; four counts of 100 grains each were made for every slide. Johannsen's classification (1936) used in assigning names to the rocks]

Content	Sample												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz.....	20	15	9	15	35	23	12	20	5	2	12	20	34
Orthoclase, microcline, and microperthite series.....	45	3	5	58	45	22	15	26	3	35	48	26	50
Plagioclase <sup>1</sup> .....	An 22	Ol 20, An 16	Ol 35, An 15	Ol 8	Ol 12	An 26	An 35	Ol 15, An 10	Ol 7, An 40	Ol 12, An 8	Al 28	Ol 36, An 5	Al 5
Feldspathoids.....	0	0	0	0	0	0	0	0	0	10	0	0	0
Auxiliary light-colored <sup>2</sup> .....	8	6	4	4	3	4	3	4	5	3	7	5	7
Total quarfeldoids.....	93	60	68	85	95	75	65	75	60	60	95	92	92
Biotite.....	4	20	6	8	4	8	15	12	30	0	4	4	0
Amphibole (hornblende).....	0	15	20	3	0	12	17	8	8	10	0	3	0
Pyroxene.....	0	0	3	2	0	3	0	0	0	25	0	0	0
Auxiliary dark <sup>3</sup> .....	1	5	3	2	1	2	3	5	2	5	1	1	4
Total mafites.....	7	40	32	15	5	25	35	25	40	40	5	8	8

<sup>1</sup> Al, albite; Ol, oligoclase; An, andesine.

<sup>2</sup> Muscovite, tourmaline, and apatite.

<sup>3</sup> Magnetite, ilmenite, garnet, zircon, and chlorite.

1. Granite, muscovite-bearing (52AJu259) 6.4 mi N. 20° W. of mouth of Marsh Creek.

2. Biotite-hornblende quartz diorite (52AJu241) 7.3 mi N. 28° W. of mouth of Marsh Creek.

3. Hornblende-biotite diorite (52AJu187) 6.4 mi N. 45° W. of mouth of Marsh Creek.

4. Biotite granite (51AJu303) 6.2 mi N. 10° W. of Horn Mountain.

5. Granite (51AJu308) 7 mi N. 10° W. of Horn Mountain.

6. Hornblende-biotite quartz monzonite (51AJu214) 1 mi N. 28° W. terminus of Johnson Glacier.

7. Hornblende-biotite granodiorite (51AJu221) 3.3 mi N. 23° W. of terminus of Johnson Glacier.

8. Biotite-hornblende quartz monzonite (51AJu216) 1.1 mi N. 28° W. terminus of Johnson Glacier.

9. Biotite-hornblende diorite (51AJu249) 4.8 mi N. 40° W. of Mouth of Marsh Creek.

10. Syenite (51AJu314) 6.6 mi N. 18° W. of Horn Mountain.

11. Quartz monzonite (51AJu312) 5.9 mi N. 40° W. of Horn Mountain.

12. Quartz monzonite (51AJu240) 5.7 mi N. 27° W. of mouth of Marsh Creek.

13. Aplite porphyry (Alsbeckite) (52AJu68) 5.8 mi S. 65° W. of mouth of Marsh Creek.

Samples 11, 12, and 13 are from areas mapped as pink quartz monzonite on plate 1. The remaining samples are from the gray quartz diorite.

QUARTZ DIORITE

The granitic-textured rocks mapped as quartz diorite in this report actually have a wide compositional range, as can be seen from the samples tabulated on table 14. The samples grade from biotite granite through quartz monzonite, granodiorite, and quartz diorite. This range is to be expected in a marginal facies of a batholith. Most of the rocks are fairly rich in quartz, and the name "quartz diorite" given by Juhle (1955, p. 10) to the main mass of the batholith will be used in this report.

The batholith of which the mapped quartz diorite is a part is about 40 miles wide at the latitude of the Inskin-Tuxedni region. The known length is 120 miles, but the actual length is probably about 450 miles, extending from Becharof Lake on the Alaska Peninsula to the Talkeetna Mountains northeast of Anchorage. This region is part of one orogenic belt, and the intrusion probably dates from the same time. The rocks along most of the better known parts are mainly quartz diorite, granodiorite, and hornblende granite.

The rocks are generally medium grained and are commonly porphyritic. They are light in color in the main part of the batholith but near the margin

many are dark owing to a high content of ferromagnesian minerals. A few are allotriomorphic-granular to myrmekitic. The porphyritic habit of some of the rocks is due to large feldspar crystals, many of which are normally zoned.

Quartz forms about 15-25 percent of the most of the samples examined. Orthoclase is always present but is not as abundant as microcline and microperthite and often mantles the plagioclase feldspar. Andesine and oligoclase are the most common plagioclase feldspars, but labradorite is common in the more gabbroic rocks.

Hornblende and biotite are the chief mafic minerals present. They often form dark clots in the rock. Some of the hornblende and biotite forms very large phenocrysts that may exceed 1 cm in length, whereas the average for the light constituents is only about 5 mm. The mafic minerals usually appear fresh. Apatite and magnetite are present in all the rocks examined, forming about 1 percent in most samples

QUARTZ MONZONITE

Pink quartz monzonite is confined to small zones between the main part of the batholith in the Chigmit Mountains and the bedded rocks along the coast of Cook Inlet. The outcrops have a very irregular areal

distribution. The largest area, between Marsh Creek and West Glacier Creek, is about 5 square miles in extent; there are numerous outcrops too small to show at the map scale. The seven patches mapped probably do not exceed 10 square miles in total area.

Most of the rocks mapped as this unit probably have a composition similar to that of sample 11, which is a medium-grained rock, its average grain size being 2-3 mm; it is slightly porphyritic, having a few plagioclase crystals 4-6 mm in diameter. The mafic minerals are all less than 2 mm in diameter. Much of the euhedral albite is normally zoned. About half of the potassium feldspar is microperthite with albite inclusions. The color is due to pink orthoclase.

A variety of other igneous rocks having an overall pink coloration are included with the quartz monzonite for mapping convenience; samples 12 and 13 are two of these rocks. Most are in aplite and granite pegmatite dikes that were formed from residual solutions of the magma. The dikes are generally small and many do not show on the geologic map (pl. 1).

The quartz monzonite masses are probably small stocks that were emplaced at a date slightly later than the quartz diorite batholith, inasmuch as dikes of the pink quartz monzonite intrude both the bedded rocks and the batholith. The masses, particularly the one near Tuxedni Bay, are somewhat elliptical in ground plan, but in general have outlines that are more discordant than the batholith and that may indicate emplacement at a different time. On the other hand, these masses more nearly resemble cupolas that are actually a part of the batholith, and the slightly different mineral content may result from magmatic segregation of residual solutions in the magma. This segregation would also produce dikes that cut both the bedded rocks and the plutonic rocks. The authors believe the exact nature of the quartz monzonite intrusions cannot be determined from present field evidence.

#### DIKES AND SILLS

Numerous dikes and sills cut the rock of pre-Tertiary age. They are more common in the metamorphosed Triassic rock and in the bedded volcanic rock of Early Jurassic age than in the Middle and Upper Jurassic sedimentary sequence. Those in the Middle and Upper Jurassic sedimentary rocks are very similar to the Tertiary lava flows and undoubtedly were intruded contemporaneously with the flows. Some of the dikes and sills in the pre-Middle Jurassic rocks were probably intruded at the same time, but many probably date from the intrusion of the batholith in early Middle Jurassic time.

Most of the Tertiary intrusive rock is in the form of dikes rather than sills. The dike rock is a crystalline

basaltic andesite porphyry. Individual hornblende phenocrysts may be as much as one half inch long. The color varies from light gray to moderate olive brown. Most of the dikes are 1-2 feet thick, but thickness may range from a few inches to 10 feet.

Numerous dikes and sills in the immediate vicinity of Iliamna Volcano were probably intruded contemporaneously with the lava flows. The rocks are megascopically identical to the flow rocks. The felsic groundmass is cryptocrystalline to microcrystalline; it contains phenocrysts of feldspar and hornblende. The dikes and sills range in thickness from a few inches to 20 feet; they were probably intruded at a fairly low temperature, for the sedimentary rock is altered only a few inches beyond the contact.

## STRUCTURAL GEOLOGY

### REGIONAL SETTING

The Iniskin-Tuxedni region is part of the mobile belt of mountain building and volcanic activity that borders the north Pacific Ocean. The region lies between two of the major structural elements of southwestern Alaska (pl. 2), the Talkeetna geanticline to the northwest and the Matanuska geosyncline to the southeast (Payne, 1955; Miller and others, 1959). The Cenozoic Cook Inlet basin includes the northeastern part of the region.

The granitic intrusion and the change from volcanic rocks to the graywacke and arkosic facies of geosynclinal deposition show that the major elements came into existence during early Middle Jurassic time. Broad geanticlinal upwarps and geosynclinal downwarps have continued along these major northeastward-trending structural elements since Middle Jurassic time. Most of the present structures probably came into being as a result of the Laramide Revolution and date from early Tertiary. Recent volcanic eruptions, earthquakes, and the numerous raised beach deposits show that orogenic activity is still going on in this part of Alaska. A difference in intensity and direction of folding and the degree of induration between post-Lower Jurassic rocks and the Lower Jurassic and Triassic rocks suggests that the Talkeetna geanticline and the Matanuska geosyncline were superimposed on an older, more eastward-trending structural element.

Rocks of the Talkeetna geanticlinal belt are predominantly granitic-type intrusives of the Aleutian Range batholith and metamorphic rocks of late Paleozoic and early Mesozoic age. The Matanuska geosyncline contains mainly epieugeosynclinal sedimentary rocks of middle to late Mesozoic age.

## FOLDS

A southeastward-dipping monocline is the predominant structural feature in this region; it is the only feature present in the rocks north of Red Glacier. Minor local variations in strike and dip are due to movement along the numerous faults. South of Red Glacier, and in particular on the Iniskin Peninsula, the beds are folded into the Fitz Creek anticline and Tonnie syncline. These major structural features are separated by Gaikema Creek anticline and Fitz Creek syncline along the south side of Chinitna Bay. Small steeply plunging drag folds are present along the flanks and near the axial zones of the large folds.

The folds on Iniskin Peninsula are directly related to movement along the Bruin Bay fault system. North of Chinitna Bay and south of Red Glacier the folds are probably more closely related to uplift of the magma chamber under Iliamna Volcano; effects of movement along the Bruin Bay fault are secondary. The folds tend to parallel the northeasterly structural grain of the region as determined by the Talkeetna geanticline and Matanuska geosyncline.

### FITZ CREEK ANTICLINE

This major feature, about 22 miles long, extends in a northeasterly direction from Iniskin Bay to East Glacier Creek. North of East Glacier Creek the fold dies out and the beds become part of the southeastward-dipping monocline. A small anticline exposed on both sides of Red Glacier near the Bruin Bay fault apparently is not a continuation of this fold. Southwesterly plunge on Fitz Creek anticline, towards Iniskin Bay, indicates that the anticline probably dies out under the bay. The part of the anticline on Iniskin Peninsula is 14 miles long; it is this part that has received most attention as the site of a potential oil field and will be the part referred to in the following discussion of the anticline.

Fitz Creek anticline is a complex structure with moderately steep, slightly asymmetrical flanks. The structural high, at the surface, is just north of the Iniskin Bay Association well 1. From the vicinity of the structural high to Iniskin Bay the anticline has a single axial zone. Northeast of the high, the fold bifurcates, one axis continuing in the ridges southeast of Fitz Creek and the other axis in the ridges northwest of Fitz Creek. The northern segment of the anticline was referred to as Gaikema Creek anticline by Kirschner and Minard (1949) and that terminology is continued in this report merely to simplify the discussion of the anticline. The two axial zones are separated, near Chinitna Bay, by steeply dipping beds forming Fitz Creek syncline. The axial trace of the syncline is covered by alluvium.

The anticline is cut by five, and possibly more, cross faults. The actual cutting of the trace of the axial plane by a fault is seen at only the locality near Iniskin Bay. At all other localities, alluvium covers the area of intersection but offsets in the bedding traces or fault traces on opposite sides of the covered area indicate that the faults do cut the axial plane. Correlation of beds on opposite flanks of the anticline indicates that it is further complicated by a high-angle reverse fault that generally parallels the axial trace. This longitudinal fault starts near the pass between Right Arm and Oil Bay and continues northeast along the east side of the axial trace to the vicinity of Beal well 1; it passes between the Beal well and Iniskin Bay Association well 1. The fault apparently turns northwest about 2 miles northeast of the IBA well and continues under the alluvium along the west side of Fitz Creek valley. The exact position of the fault trace and the axial traces cannot be determined for a part of their length because they are covered by alluvium. Maximum displacement on the fault is interpreted as being about 1,200–1,300 feet in the vicinity of the structural high; displacement decreases away from the high.

Structure contour maps of Fitz Creek anticline were drawn for three selected horizons in the subsurface (pl. 6): top of upper sandstone unit of Red Glacier Formation; top of upper zone of oil and gas shows in Iniskin Bay Association well 1; top of the Lower Jurassic volcanic sequence.

The structure contour maps were compiled from both surface and subsurface information. They show closure on the fault of at least 1,000 feet. Apparently the closure does not die out at depth but may increase slightly. However, information for drawing the contour on the top of the Lower Jurassic sequence is very sketchy. The structural high on Gaikema Creek anticline, just south of the south shore of Chinitna Bay, is at least 500 feet higher than the high on Fitz Creek anticline, but closure on this part of the anticline cannot be shown by fieldwork. Geophysical work on Chinitna Bay would be required to prove or disprove closure. A small amount of closure is indicated for the main part of Fitz Creek anticline in Havenstrite Ridge, but this part of the area is so highly faulted that the exact amount cannot be determined with any degree of accuracy.

Chinitna Bay may obscure a cross fault between the parts of the structure on the north and south sides. Rocks exposed over the anticline on the north side of the bay are stratigraphically much higher than those exposed on the south side. If the difference is due entirely to plunge, the rate of plunge would be much greater to the north than to the south. There several reversals of plunge along the anticline on Iniskin Penin-

sula, but the overall plunge is towards the southwest. If a cross fault is not present under Chinitna Bay, the highest part of the anticline would be under the bay and not on Iniskin Peninsula.

#### TONNIE SYNCLINE

The axial trace of Tonnie syncline trends northeast from Right Arm to the south shore of Chinitna Bay. A sharp synclinal fold near the Bruin Bay fault on the north side of the bay may be a continuation of this fold. The syncline was not seen north of East Glacier Creek. The axial trace on Iniskin Peninsula generally follows the crestline of the mountains west of the Fitz Creek valley.

The syncline is asymmetrical, having a steeper west flank. This flank borders the Bruin Bay fault zone, and the asymmetry is probably due to thrust faulting in which the compressional forces came from the northwest. A normal fault having a small amount of displacement lies between the syncline and the major thrust fault. Near the fault the dip of the beds towards the synclinal axis is very steep. Plunge on the synclinal axis is about 20°-30° S. near Chinitna Bay, but decreases farther south. From Tonnie Peak to near Right Arm the plunge is less than 10°.

#### FAULTS

The rocks of this region are cut by numerous faults. Most faults are minor and have only a small amount of displacement, but a few are major. Insofar as can be determined, the faults are of four main types: thrust faults, cross faults (transverse and oblique faults having larger horizontal than vertical displacement), hinge faults, and normal faults.

#### BRUIN BAY FAULT

The Bruin Bay fault, or fault system as it properly should be termed, is one of the major faults in southwestern Alaska; it can be traced for 200 miles, from Becharof Lake on the Alaska Peninsula to Tuxedni Bay. The fault probably continues in both directions beyond these points but is either covered by surficial deposits on the Alaska Peninsula or is in an unexplored area north of Tuxedni Bay. The fault system is actually a series of high-angle reverse faults having major displacement along one fault.

Stratigraphic throw on the Bruin Bay fault is as much as 10,000 feet just north of Chinitna Bay. At this locality, rocks of the Horn Mountain Tuff Member of the Talkeetna Formation are in juxtaposition to rocks of the Paveloff Siltstone Member of the Chinitna Formation. The fault separates volcanic rocks of the Lower Jurassic from sedimentary rocks of Middle and Upper Jurassic along almost half of its length in this region. North of Red Glacier the fault is between

intrusive rocks and volcanic rocks; the amount of stratigraphic throw cannot be determined. The fault plane is exposed at many localities and ranges between extremes of 45° W. to vertical, most occurrences being 60°-70° W.

A combination of overthrusting and strike-slip movement probably explains the large stratigraphic throw on this fault. The compressional forces came from the northwest, and most of the stresses were relieved by overthrusting towards the southeast. The lateral displacement along the fault can be neither proven or disproven; however, a left lateral displacement of about 12 miles may be indicated by offset in the contacts of the Talkeetna Formation and Triassic metamorphic rocks between East Glacier Creek and Johnson River. If the rocks on the east side of the fault were moved south about 12 miles, the beds of these two stratigraphic units would join with little or no offset. However, most of the offset may be due to vertical displacement. Some of the stress may have been relieved by left-lateral movement along the fault plane.

#### CROSS FAULTS

Transverse and oblique faults, herein grouped under the general heading of "cross faults," are by far the most abundant in the Iniskin-Tuxedni region. Most are somewhat curved, so faults oblique to the strike of the beds are more common than those strictly transverse to the strike. The faults are mostly high angle and do not vary more than a few degrees to either side of vertical.

A combination of two factors probably explains the origin of the cross faults; likely some were formed by each method. The combination of compressional and tensional stresses set up by movement along the Bruin Bay fault was probably the most important factor in the formation of these faults, particularly the ones subparallel to the Bruin Bay fault. Some faults may be due to differential elevation and subsidence during eruptions of the magma chamber under Iliamna volcano; this type of fault probably would be restricted to the flanks of the volcano.

The cross fault between Right Arm and Oil Bay and the one through the Low Creek-Hardy Creek pass are probably the most important in the area. They crossed Fitz Creek anticline and caused the formation of oil and gas seeps by breaking the seal on the reservoir. Nearly all of the oil and gas seeps on Iniskin Peninsula are on these cross-fault traces.

#### HINGE FAULTS

Many of the faults in this region have rotational movement about an axis normal to the fault plane, but the movement is not great enough to classify them as rotational faults, for the rotary movement is clearly

secondary to other directions of movement on the fault plane. However, movement on two of the larger faults on Iniskin Peninsula is largely restricted to a hinge-type rotation of beds on opposite sides of the fault plane.

The most important of the hinge faults is the one along Fitz Creek. Displacement along the fault increases towards the northeast from a hinge point somewhere near the pass between Right Arm and Oil Bay. The exact location cannot be determined because the point is covered by surficial deposits. For most of its length the fault is covered by alluvium in Fitz Creek valley, but a comparison of beds on opposite sides of the valley indicates an offset of 1,200–1,300 feet in the vicinity of the oil wells. The structure is more complex north of the oil wells, where the Fitz Creek anticline bifurcates and a sharply folded syncline lies between the two anticlinal axes. Bedrock exposures are poor along the valley walls, but offset on the fault seems to decrease somewhat near Chinitna Bay. This decrease is probably due to folding of the rocks into an additional anticlinal and synclinal structural feature rather than to a greater amount of offset along the fault. The increased complexity of structure near Chinitna Bay is in turn related to the sharp northeast bend in the Bruin Bay fault between the south and north shores of the bay.

The other hinge fault starts just south of Chinitna Point and continues northwest about 1–2 miles north of, and roughly parallel to, Brown Creek. The fault postulated for Brown Creek valley may also be of the hinge type. Displacement on the one near Chinitna Point increases towards the northwest from a hinge point near the coast.

#### NORMAL FAULTS

Faults having downward movement on the hanging-wall block are fairly common in this region. About half of the cross faults have this type of movement, but the two important normal faults roughly parallel the regional structure. One is along the east side of Portage Creek valley about 0.5 mile east and parallel to the Bruin Bay fault. The other one is longer; it starts on the south side of Red Glacier and continues north to Tuxedni Bay. Stratigraphic throw on both faults is minor, about several hundred feet. Both are high-angle gravity faults probably formed by the release of compressional forces following thrust faulting along the Bruin Bay fault.

#### JOINTS

Joints are herein discussed with the faults, although they are a type of fracture along which there has been little if any movement except at right angles to the fracture plane. The sedimentary rocks of this

region are extremely jointed. Most of the minor streams in the Iniskin-Tuxedni region are subparallel and follow conspicuous closely spaced joint sets.

The most conspicuous joint sets on Iniskin Peninsula strike N. 35° E. and N. 55° W.; thus the northeast-striking joints are parallel to the overall strike of the folds and the northwest-trending joints follow the dip of the beds. These joints are the master sets that show a very close relation to the associated folds. (fig. 7).

In addition to the master joint sets, the rocks are fractured along many planes that do not show any preferred orientation. Most of these are probably tension joints, for they do not cut through concretions as do the shear joints. The fracture planes are usually inclined and change dip frequently.

#### AGE OF FOLDING AND FAULTING

The present configuration of the rocks in this region result from at least three stages of folding and faulting, only one of which is believed to represent a period of widespread orogeny that probably correlates with the Laramide Revolution.

The Lower Jurassic and Upper(?) Triassic rocks are more intensely folded than are the Middle and Upper Jurassic rocks, and an angular unconformity separates them. The intensely folded rocks represent the first stage of folding, which probably dates from late Early Jurassic time; this folding is believed to be contemporaneous with, or at least closely related to, the intrusion of the Aleutian Range batholith.

Most of the structural features shown on the geologic map date from an orogeny that started in Cretaceous time and culminated in the Tertiary and are probably associated with the Laramide Revolution. Evidence for this age is seen along the Bruin Bay fault. Middle (?) to upper(?) Tertiary extrusive rocks along the west side of this fault system are only very slightly altered, whereas older rocks on both sides of the fault are considerably deformed.

Elevation of the Kenai Formation along the mountains north of Chinitna Bay shows that the last stage of folding and faulting started in late Tertiary time and is still in progress. Recent uplift has also occurred in the elevated beach ridges along the coast and in wave-cut terraces on Gull Island.

#### GEOLOGIC HISTORY

The events in the geologic history of the Iniskin-Tuxedni region have been reconstructed on the basis of the lithologic character of the rock units, their depositional and structural relationships, and their ages as determined by identification of the faunas. Only that part of geologic time from the Triassic to the present is represented in this region.

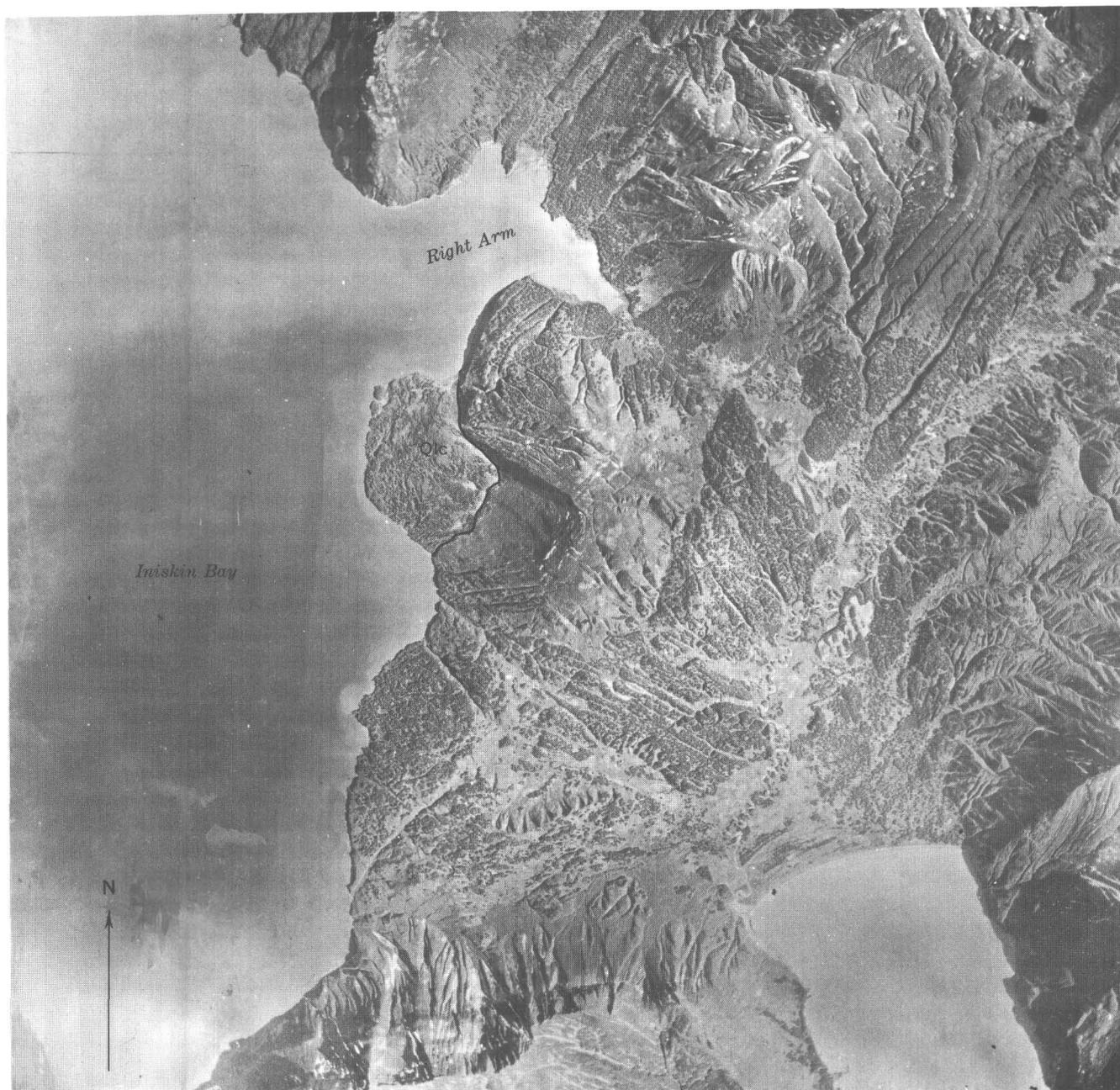


FIGURE 7.—Vertical view of master joint sets near the southwestern ends of Fitz Creek anticline and Tonnie syncline. Small streams have developed a trellis drainage pattern along the joints. The landslide (Qlc) near Right Arm is bounded on the north side by a prominent dip joint. Photograph by U.S. Air Force.

By the time the oldest rocks were being deposited in Late(?) Triassic time, this part of Alaska had been reduced to an area of low relief. Fine silt, mud, and lime were being deposited on what is now the Iniskin-Tuxedni region; occasionally layers of fine sand were added to the finer grained sediments. A few basaltic flows were added near the end of the Triassic. This submarine volcanism heralded a time of increased tectonic activity in the mobile belt along the margin of

the continent, a time in which the sedimentary regime would be changed completely.

Submarine volcanism that started near the end of Triassic time continued with increased vigor during most of Early Jurassic time. Massive units of breccia and agglomerate were added to lava flows that spread over the sea bottom until some of the area was raised above sea level. During infrequent intervals when the volcanic activity diminished, these deposits were re-

worked and became part of the sedimentary sequence that is interbedded with the volcanic rocks. Volcanic activity gradually diminished in the immediate area of the Iniskin-Tuxedni region near the end of Early Jurassic time, and the rocks are mainly thin-bedded tuffs derived from ash of volcanoes some distance from the region.

The time necessary to accumulate the 6,000–9,000 feet of volcanic rocks cannot be precisely determined in this region, because there are no fossils. However, a correlation can be made with similar rocks in the Talkeetna Mountains that do contain fossils. This correlation suggests that most if not all of Early Jurassic time is represented.

A hiatus is indicated for this region between the cessation of volcanic activity of the Early Jurassic and the beginning of epi-geosynclinal deposition in Middle Jurassic time. The interval was apparently of short duration but was a time of intense orogenic activity. The Talkeetna geanticline was strongly upwarped into a mountainous region, and the older rocks were exposed to subaerial denudation. The Aleutian Range Batholith was intruded into the core of the geanticline at this time and may have been partly responsible for its uplift. With the upwarp of the geanticline there was a corresponding downwarp of the Matanuska geosyncline that was to collect the sediments of the Middle and Upper Jurassic.

The Middle Jurassic was a time of rapid accumulation of sediments in the subsiding geosynclinal trough. High-gradient streams from the nearby mountains dumped so much debris into the trough that the sea was unable to sort it and most of the material was deposited as thick units of graywacke. This time was also one of intermittent uplift in the geanticline. Each period of uplift is clearly shown in the stratigraphic sequence by thick units of conglomerate. These units are in turn followed by sandstone, and finally by siltstone and shale as the streams approach base level. Several such cycles are present in the Tuxedni Group. Minor breaks in the section are indicated by the fauna and unconformities; the breaks probably occurred when local uplift exposed some of the deposits to subaerial erosion. In this way most of the beds representing the Bathonian Stage probably were removed.

During most of the Callovian Stage of Late Jurassic time the deposition of sediments was at a much slower rate than during the Middle Jurassic. The landmass had been reduced considerably and the streams were supplying mainly fine clastic material. At the beginning of Oxfordian time the Talkeetna geanticline was strongly uplifted and the batholith was unroofed; granitic intrusive rocks thus became an important

source of all later sediments. Massive cobble-boulder conglomerate and channel deposits in the Chisik Conglomerate Member of the Naknek Formation indicate that the landmass was nearby and that it was undergoing very rapid erosion. The rugged topography was quickly worn down and the stream loads were reduced to silt and mud. The last event in the Jurassic that is recorded in the rocks was a massive sheet wash of granitic debris that now makes up the Pomeroy Arkose Member of the Naknek Formation; this took place in early Kimmeridgian time.

The next recorded event in the Iniskin-Tuxedni region took place in early Tertiary time when the Kenai Formation was deposited. What happened during Cretaceous time cannot be known, for no record is preserved. Evidently at some time during the Cretaceous, and probably continuing into Tertiary, the region was uplifted, faulted, and folded into much the same structural pattern that now exists in the region. Cretaceous sediments, if present, as well as the upper part of the Jurassic, were removed; the continental beds of the Tertiary therefore now rest with an angular discordance on the older rocks.

The Tertiary was also a time of renewed volcanic activity in the region, as a few minor lava flows spread over the eroded surface of the older rocks. These flows probably came to the surface along some of the recently formed faults or other zones of weakness. Iliamna Volcano may have started in this manner, although most of its mass was extruded during the Quaternary.

The present landform of the region is mainly the product of the agencies of glaciation and fluvial action that took place during the Quaternary. The general configuration of the land probably has not changed greatly in Recent time, but it has been modified. The oldest glacial deposits recognized in the region date only from the Wisconsin Glaciation. Evidence of older stages of glaciation was removed or covered.

#### MINERAL RESOURCES

Recent field investigations in the Iniskin-Tuxedni region have confirmed the conclusion reached by previous workers that petroleum is the only mineral resource that offers a possibility of commercial development. A small magnetite deposit on the north side of Tuxedni Bay (Grantz, 1956) is not considered large enough for profitable commercial development. Other minerals found in minor amounts include pyrite, malachite, and azurite. In the early years of this century a few prospectors panned the stream gravels for placer gold, but without success.

**PETROLEUM  
OIL AND GAS SEEPS**

Indications of petroleum in the form of numerous oil and gas seepages first directed attention towards this region as early as 1853 (Martin, 1905). Martin states that a Russian named Paveloff collected the first samples of petroleum in 1882 from one of the seeps. Since that time the Iniskin Peninsula has been the scene of intermittent activity in the search for oil. Most of the early drilling was near oil seeps.

All the oil and gas seeps that could be located by the present authors are marked on the geologic map. These seeps have a strong flow and have been active since first reported by Martin. Some of the other seeps may still be active, but because Martin located them with reference to features that are no longer in existence, they could not be found. The large seep on the east shore of Iniskin Bay was not found and may be inactive.

The seep on Well Creek is about as active as when visited by Moffit in 1921 (1927, p. 48). The oil rises in a pool of water and collects as a dark scum on the surface. About one pint could be collected at any one time in 1951. The seep in Fitz Creek northeast of the Iniskin Bay Association well is visible only at times of low water. The oil is light green and bubbles to the surface of the stream every 5-8 seconds; it spreads until carried away by the water.

All these seepages are probably fault controlled. The one near the head of Oil Bay falls just northeast of a cross fault that starts on Iniskin Bay and continues down Well Creek and on into the cliffs on the north side of Oil Bay. There is good evidence, also, for fault control on the seep in Fitz Creek. Although the seep is in alluvium, it must be very close to the surface trace of the Fitz Creek fault. Evidence for the fault in Brown Creek valley is based mainly on apparent offset in beds on opposite sides of the valley, and while not conclusive, the evidence favors a fault. The impervious nature of much of the stratigraphic section on Iniskin Peninsula seems to indicate that the only route of escape would be along zones of faulting or fracturing.

**EARLY EXPLORATION AND DEVELOPMENT**

A detailed description of the early exploration and development on Iniskin Peninsula is given by Martin (1905, p. 37-49; 1921, p. 51-55), Martin and Katz (1912, p. 126-130), and Moffit (1927, p. 48-54). Only a brief resume is given here from the source material of Martin, who visited the area in 1903 and 1904 while drilling was in progress.

Martin stated that after the first samples of oil were collected by Paveloff in 1882, a man named

Edelman staked claims near the heads of Brown and Bowser Creeks in 1892. Pomeroy and Griffin staked claims in 1896 near the head of Oil Bay and organized the Alaskan Petroleum Co. in 1897. Some work began in 1898, but the actual drilling did not start until 1902. The first well, half a mile from Oil Bay, near Bowser Creek, was completed in 1903.

There is little authentic information about this well. Martin stated that it was reported to be 1,000 feet deep, that gas was tapped all the way below 190 feet, and that considerable oil was found. He reported production of 50 barrels a day and further stated that salt water was penetrated when the drillers attempted to deepen the well. A second well was drilled in 1904 about three-tenths of a mile northwest of the first well; it was abandoned at 450 feet because of caving shale. A third well, drilled the same year just south of the second well, penetrated three oil sands at 770 feet and was drilled to 900 feet. It is reported to have produced 10 barrels of oil a day and considerable gas. The fourth hole was started north of the first well but was not completed. Some of the rusted machinery was still there in 1951. No drilling was done at Oil Bay after 1906.

The Alaska Oil Co. started drilling at Dry Bay in 1902. The first well was drilled to 320 feet, where the tools were lost and the well was abandoned. A second well was started in 1903 but was also abandoned because of an accident to the equipment. There has been no drilling at Dry Bay since 1903.

**RECENT EXPLORATION AND DEVELOPMENT**

After the drilling in the early part of this century, there is no record of any activity on Iniskin Peninsula until 1934, when a geological party did some work on the anticline reported by Moffit (1927, p. 43-45). As a result of this work the Iniskin Bay Association was formed and took option on approximately 51,000 acres of land on Iniskin Peninsula. Equipment was moved in and drilling was started in 1936.

**INISKIN BAY ASSOCIATION WELL 1**

Iniskin Bay Association well is about 200 feet west of Fitz Creek on alluvial gravel. It is 4.5 miles S. 30° W. of the mouth of Fitz Creek and 1.9 miles S. 54° E. of Tonnie Peak in the SE¼ sec. 8 T. 5 S., R. 23 W. Seward meridian. A rotary rig was used to drill the well, which was started on September 7, 1936 and was suspended on September 4, 1939 at a depth of 8,775 feet; drilling was done only in the summer months.

This well was the first on Iniskin Peninsula whose hole was located on the basis of geologic information. Some of the complexities of the structure were not recognized at that time, and the well was located about 250 feet west of the surface trace of the Fitz Creek fault and about 2,000 feet southeast of the structural high.

The hole intersected the fault trace at about 4,900 feet, and the remainder of the hole was in beds with little effective closure on the east side of the fault.

During 1936 the well was drilled to a depth of 2,540 feet. It started in alluvium, which at that point is 33 feet thick. The well penetrated about 140 feet of Gaikema Sandstone below the gravel before entering the Red Glacier Formation of the Tuxedni Group. The section is mainly fine-grained sandstone and siltstone containing numerous thin seamlets of coal and several zones of coquina. There were no indications of oil or gas.

The section drilled during 1937 was mostly hard gray to brown shale containing streaks of brown siltstone and gray sandstone. An offshoot of the Fitz Creek fault was penetrated at about 3,600 feet and the main fault zone at 4,900 feet. A trace of oil and gas was observed in the cores and well cutting after the hole passed into the fault zone. The hole was suspended at 5,066 feet in September 1937.

The well had built up considerable gas pressure by the spring of 1938 and drilling was resumed on May 19. Small quantities of gas were tapped in the first few hundred feet of the fault zone. A thick sequence of greenish-gray sandstone was drilled between 5,000 and 6,400 feet. High-pressure gas was tapped through much of the sandy section. A thin oil-stained sandstone was drilled at 6,800 feet, but no commercial quantities of oil or gas were recovered and the operation was suspended for the year on August 11, 1938.

A final attempt was made in 1939 to attain production. When the well was opened in May it had 800 psi (pounds per square inch) pressure at the casing head, and 12 barrels of high-gravity oil were recovered. Most of the section drilled in 1939 was a hard, black to dark-gray calcareous shale containing a few stringers of sandstone and siltstone. Strong shows of oil and gas were found whenever a sandstone bed was drilled, but these shows were accompanied by strong flows of salt water. The drilling was finally suspended on September 4, 1939, at a total depth of 8,775 feet. At that time the well was flowing 240 barrels per day of salt water and also a little oil and gas. Samples of oil and gas were obtained in 1946. Analyses are given in table 15.

#### BEAL WELL 1

Exploration for oil and gas stopped on Iniskin Peninsula during World War II and the years immediately thereafter. In 1953 Russell Havenstrite, president of Iniskin Bay Association, formed a new group called Iniskin Unit Operators to drill additional wells on Fitz Creek anticline. A site was selected on the east side of Fitz Creek about 3,200 feet S. 26° W. of the Iniskin Bay Association well 1.

TABLE 15.—Analyses of crude oil and natural gas from Iniskin Bay Association well 1

[Samples obtained by C. E. Kirschner in 1946. Analysts: crude oil, J. C. Clark, U.S. Geological Survey; natural gas, Fred L. Mahler, National Bureau of Standards]

Constituent or property	Crude oil	(Percent approximate)
Light gasoline	-----	19.9
Total gasoline and naphtha (includes light gasoline)	-----	46.8
Kerosene distillate	-----	11.4
Gas oil	-----	10.1
Nonviscous lubricating distillate	-----	9.1
Medium lubricating distillate	-----	3.2
Residium	-----	11.9
Distillation loss	-----	7.5
Total	-----	100.0
API gravity	-----	47.6
Specific gravity	-----	.790
Percent sulfur	-----	.11
Saybolt universal viscosity at 70°F	-----seconds	33.0
Saybolt universal viscosity at 100°F	-----seconds	31.8
Pour point	-----	Below 0°F.
Color	-----	Green
Base	-----	Intermediate
<b>Natural gas</b>		
Methane	-----	75.1
Ethane	-----	7.1
Propane	-----	2.8
Butanes	-----	.9
Pentanes	-----	.2
Hexanes	-----	.1
Nitrogen	-----	13.5
Carbon dioxide	-----	.3
Total	-----	100.0

This site is in the NW¼ sec. 17, T. 5 S., R. 23 W. Seward meridian.

The initial phase of rebuilding the road from Chinitna Bay was started in the fall of 1953. Dock facilities, oil storage tanks, a construction camp, and an air strip were started at the same time and were completed early the next spring before the drilling started. A new rig having Wilson draw works was used by the Iniskin Drilling Co. on Beal well 1.

The well is on bedrock of the Fitz Creek Siltstone about 700 feet east of the Fitz Creek fault. The well head is 350 feet above sea level. The main part of the Fitz Creek fault does not intersect the hole, but a zone of steep dips and fractures in the hole at 6,403–6,424 are interpreted as resulting from the small cross fault mapped at the surface just north of the well. This fault may intersect the main fault at depth. Beal well 1 is approximately 1 mile southeast of the structural high in an area that has little provable closure.

Beal well 1 started near the top of the Fitz Creek Siltstone; it penetrated some sandstone interbeds in

the Fitz Creek but there were no oil or gas shows in the sandstone. The formation is a little thicker than the section exposed in Tonnie Creek. The top of the Gaikema Sandstone was reached at about 1,700 feet. The first show of gas in the well came from a gray-green calcareous sandstone at 2,454 feet, and a zone from 2,454 to 2,585 showed some possibility of gas production. The rocks were mainly fine-grained sandstone and siltstone, but the sandstone had a little higher porosity than most of the rocks penetrated. The top of the Red Glacier Formation is interpreted as coming just below this sandy zone at 2,650 feet. A thin sandstone unit in the Red Glacier Formation at 3,760 feet gave a brief show of gas. No other indications of petroleum were found, and drilling was suspended for the year on November 6, 1954 at a depth of 5,467 feet.

Drilling was resumed in the spring of 1955, and progress was fairly rapid at first. A zone of steep dips and fractures was entered at 6,403 feet. Most of the fractures were recemented with calcite, but the drill core near the fractures gave a good fluorescent cut when treated with carbon tetrachloride. At 7,700 feet a film of oil began to show in the mud; the show increased to a depth of about 7,800, where the well yielded 14 barrels of fluid having a high percentage of oil. The rocks to this point were mainly hard gray siltstone and claystone containing thin partings of siltstone and sandstone, all of which were quite fractured. Tuffaceous and bentonitic material, as well as limestone and dolomite, was found in the section below 8,000 feet. The top of the Lower Jurassic Talkeetna Formation was reached at 9,128 feet. There is no good evidence for an unconformity between the Middle and Lower Jurassic in this well. A zone of higher porosity and chloritized rock near the contact may be a slight indication of an old erosional surface. Drilling was extremely slow in the tuff beds of the Horn Mountain Tuff Member of the Talkeetna Formation, and the operation was suspended on October 27, 1955, at a total depth of 9,745 feet.

An attempt was made in 1956 and 1957 to obtain production from several of the zones that had shows of oil or gas. A Schlumberger electric log was made of the well, which was then cased to 9,370 feet, cemented, and perforated at selected intervals. A small quantity of oil and gas was obtained, and the gas was used to run the light plant at the camp for a few days. The casing pressure built up to 115 psi with a computed flow rate of 4,000 cu ft per day. Additional work was done on the well in 1958 and 1959 by Alaska Consolidated Oil Co., which had taken over the lease option from Iniskin Unit Operators in 1958. The results are not very encouraging.

#### ANTONIO ZAPPA WELL 1

The last well drilled on Iniskin Peninsula was started in December of 1958 by Alaska Consolidated Oil Co. Their Antonio Zappa well 1 is about 2,400 feet S. 83° W. of Beal well 1, along the line between secs. 17 and 18. This location is west of the Fritz Creek fault and near the crest of the anticline; it is in the best structural position of all the wells but is about 1.25 miles southwest of the structurally highest point along the crest of the anticline.

The log of the well and the drilling record are not available at present, but the operation was suspended in 1960 at a total depth of 11,200 feet. No correlation can be made with the two other wells, but the well is reported to have entered the Lower Jurassic sequence at 9,725 feet. This depth is lower than for the Beal well and suggests that the hole passed through the fault and into the downthrown block or that an unconformity of considerable relief is between the Middle and Lower Jurassic. An alternative possibility is that the top of the Lower Jurassic was not picked at the same place in the two wells.

#### PETROLEUM POSSIBILITIES

The presence of oil and gas in the rocks underlying Iniskin Peninsula is proven by the seepages that have been known in this area for more than 100 years. In addition, the wells drilled all produced a small amount or had a show of oil and gas.

The source of the oil on Iniskin Peninsula is in Jurassic or older sedimentary rocks. There is at least 16,000 feet of Middle and Upper Jurassic sedimentary rocks, most of which were deposited in a marine environment; only about 8,000–9,000 feet is structurally situated to produce oil that would be trapped. These rocks all contain abundant organic material in the form of fossils and dark shales and can be considered a possible source rock.

A thick sequence of Lower Jurassic volcanic rocks underlies the Middle Jurassic, mostly marine flows and associated pyroclastics. A few thin units of sedimentary rock are interbedded with the volcanics, but any evidence of organic material is lacking. These sedimentary beds cannot be ruled out as a possible source, but neither can they be considered a good source.

Triassic rocks probably underlie the peninsula, inasmuch as they are present in the mountains in the western part of the mapped area. Where exposed, the Triassic rocks are metalimestone, metachert, argillite, and quartzite. The condition of these rocks under the peninsula is unknown, but the authors believe they are probably metamorphosed as a result of their relationship to later geologic events and should

be excluded as a source of oil. The nature of the rocks underlying the Triassic is entirely unknown.

Rocks of the Middle Jurassic cannot be considered as having good reservoir characteristics. They are mostly dirty graywacke-type sandstone, conglomerate, siltstone, and shale. A few of the sandstone beds, and some of the conglomerate, have a fair degree of porosity. Some of these beds gave a show of oil or gas in the wells drilled, but apparently they are not porous enough to permit free flow of oil into the hole.

Salt water found near the bottom of all wells suggests that the oil horizons were higher on the structure and that all were within beds of the Tuxedni Group. The oil horizons on Fitz Creek anticline can be further restricted to the middle and upper parts of the Red Glacier Formation, one exception being the unconformity between the Middle and Lower Jurassic. Evidence of moderate porosity was found at this unconformity in the Zappa well 1.

The main concentration of oil and gas is associated with faults or zones of steeply dipping fractures. The authors interpret this feature as meaning that the rocks are not porous enough to permit free flow of oil and that any production will have to come from zones of faulting and fracturing. The seepages along fault traces confirm this supposition.

Fitz Creek anticline is the only structure in the Iniskin-Tuxedni region favorable for the accumulation of petroleum in commercial quantities. It is complicated by numerous cross faults, but movement along these faults may help rather than restrict the migration of oil. The fault along the axis of the anticline forms a structural trap, and a minimum of 500 feet of closure is interpreted at the structural high (pl. 6). South-west plunge of the structure is easily demonstrable, but northeast plunge is not easily proven. Apparent northeast plunge may result entirely from crossfaulting.

In conclusion it can be stated that petroleum is present in the rocks under Iniskin Peninsula, but that it has not been found in commercial quantities. The anticline cannot be considered as fully tested, for none of the wells are drilled on the structural high. However, the structure and lithology are not such as are normally favorable for the accumulation of a large quantity of petroleum, and the authors believe a commercial field is not likely.

#### MISCELLANEOUS MINERALIZATION

Small zones of mineralization were noted at several localities during the fieldwork. None of the deposits are large enough or of sufficient quality to be considered commercial. All deposits are in the Lower Jurassic or Upper Triassic rocks associated with the quartz diorite pluton and probably result from a

pyrometamorphic enrichment of the country rock by the intrusive.

#### MAGNETITE

A small magnetite deposit on an island along the north shore of Tuxedni Bay was investigated in 1950 by Arthur Grantz, who discussed the geology and extent of the deposit (1956, p. 95-106). Only a very brief description will be given here.

There are two areas of magnetite on the island, which is composed mainly of metamorphosed volcanic rock of the Talkeetna Formation, and one small outcrop of marble that is probably Upper(?) Triassic. These rocks were intruded by a biotite-hornblende quartz diorite of the Aleutian Range batholith and by dikes and stocks of pink granophyric quartz monzonite. Contact metamorphism altered the country rock to hornfels and marble in the vicinity of the intrusive. This metamorphic rock is garnet-rich and contains a massive lens of high-grade magnetite. Samples from the deposit run 50-67 percent iron and less than 1 percent sulfur (Grantz, 1956, table 1). The minable reserves of the deposits that lie above sea level were estimated by Grantz to be several thousand tons.

Other deposits of magnetite in a similar stratigraphic and structural situation were seen along Marsh Creek and on the east side of Iniskin Bay. These deposits are smaller than the one at Tuxedni Bay; no detailed work was done on them.

#### COPPER

A thin vein of azurite and malachite was found along Marsh Creek. The vein is 6-12 inches thick and cuts marble of Late(?) Triassic age. The marble is stained various shades of blue and green for a distance of 20-30 feet on either side of the vein. The ore minerals within the vein appear to be high grade, but no analysis has been made because the deposit is not considered large enough to be of value.

Float of azurite and malachite was found in the glacial debris covering Red Glacier and in a moraine on a tributary of East Glacier Creek. The source of the float was not found, but it is probably in the mountains formed of Lower Jurassic volcanic rock or the Upper(?) Triassic near the head of the glaciers.

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