Geology of Part of the Craig C-2 Quadrangle and Adjoining Areas Prince of Wales Island Southeastern Alaska

By C. L. SAINSBURY

MINERAL RESOURCES OF ALASKA

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The general and economic geology of an area 35 miles northwest of Ketchikan

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By C. L. Sainsbury

ABSTRACT

The area mapped is on the east coast of Prince of Wales Island, southeastern Alaska, about 35 miles northwest of the town of Ketchikan. Deposits of magnetite and copper in the mapped area and on Kasaan Peninsula, which adjoins it on the southeast, have been mined for copper and have produced more than 600,000 tons of ore valued at more than $6 million.

The bedded rocks of the area are composed of a great thickness of volcanic graywacke, tuff, conglomeratic volcanic graywacke, argillite, andesite, limestone, and conglomerate ranging in age from Middle Ordovician to Early Silurian(?). The age assignments of the bedded rocks, which previously were assigned to the Middle Devonian, are based upon six collections of graptolites. The thickness of the Middle Ordovician and Lower Silurian(?) rocks is not apparent, but it must be at least several thousand feet and may be as much as 17,000 feet. The structure of the bedded rocks undoubtedly is more complex than can be determined in the field.

An island in Kasaan Bay in the southern part of the mapped area is composed of limestone of Middle Devonian age. This limestone is in an anomalous position with respect to the older rocks and is thought to have been faulted into its present position sometime in the Tertiary, probably by thrust faulting on a major scale followed by block faulting.

Small deposits of Tertiary conglomerate of local derivation, some of which have the form of old deltas, lie unconformably on the older rocks. These Tertiary rocks are restricted to the lowland areas.

Surficial deposits of till, outwash gravel, and alluvium are widespread. Glacial features show that at one stage in the cycle of glaciation, ice flowed eastward from a center or centers west of the quadrangle. This is interpreted as evidence of valley glaciation that preceded and followed an ice sheet that completely buried mountains as much as 2,800 feet in altitude. Postglacial uplift amounts to at least 50 feet and may be more than 200 feet.

The older rocks are intruded by many stocklike bodies of probable middle Cretaceous age ranging in composition from granite to olivine-bearing pyroxenite, and by innumerable dikes. The age of 1 stock was determined on the basis of radiogenic lead to be 100 million years, or middle Cretaceous.

The igneous rocks of intermediate composition in places contain large amounts of alkali feldspar, and many dikes are converted to albite-rich rocks.

The identification of anorthoclase phenocrysts in some of the sodic dikes raises the question as to which of the sodic rocks are primary and which are albitized.

Three distinct periods of ore deposition are recognized, each with characteristic ore and gangue minerals. The oldest and most important is related to the intrusive activity of probable late Early to Late Cretaceous age; the second, of lesser importance, postdated the intrusion of diabase dikes, probably in the early Tertiary; and the youngest and least important either followed or was contemporaneous with the intrusion of pitchstone dikes that cut the Tertiary conglomerate.

The association of magnetite ore with older bedded rocks rich in magnetite and with pyroxene that tends to be rich in iron suggests that the bedded rocks may be the source of at least part of the magnetite in the magnetite-chalcopyrite ores.

INTRODUCTION

The regional geology of a part of the Craig C–2 quadrangle and adjoining areas, Prince of Wales Island, Alaska, an area that is of economic interest because of the many deposits of copper and iron, is described in this report. The location of the area is shown on figure 47. Although some of the copper deposits in the copper-magnetite district, a part of which lies on the Kasaan Peninsula, were known to the Russians (Wright, 1915, p. 15), most of the mineral locations were made between the years 1895 and 1900, and the bulk of the copper ore shipped was produced before 1921. The district has produced more than 600,000 tons of copper ore valued at more than $6 million. No magnetite ore has been shipped, although substantial reserves of high-grade ore exist (Warner and others, 1960). Several of the old mines currently (1960) are being drilled by the Utah Construction and Mining Co.

PREVIOUS INVESTIGATIONS

Several geologists of the U.S. Geological Survey have reported on the geology and ore deposits of Kasaan Peninsula and vicinity, Prince of Wales Island, part of which is included in the area shown on plate 33. In 1901, A. H. Brooks visited the district briefly, and in 1904 and 1905, C. W. and F. E. Wright visited the area and reported upon mining developments. Their reports described the mines and prospects in some detail, but they did not describe the regional geology in detail. In 1907 and 1908, C. W. Wright prepared a geologic map of Kasaan Peninsula and the area immediately north and west. Between 1910 and 1941, several geologists of the Geological Survey visited the mines and prospects, and in 1941, J. C. Reed and George O. Gates visited the district and recommended detailed geologic mapping of the mines and prospects.

During the years 1942–44, detailed geologic maps, supplemented by dip-needle surveys, were made of all the larger mines and most of the prospects. This work was begun in 1942 under the direction of E. N. Goddard and continued in 1943 and 1944 under the direction of L. A. Warner. The results of these studies were made available in mimeographed reports. A comprehensive paper embodying the previous reports and additional data bearing upon the regional relations of structure, stratigraphy, and ore deposition has been prepared by Warner and others (1960). In 1943 and 1944, the U.S. Bureau of Mines trenched, sampled, or diamond drilled many of the mines and prospects (U.S. Bur. Mines, 1944; Wright and Tolonen, 1947).

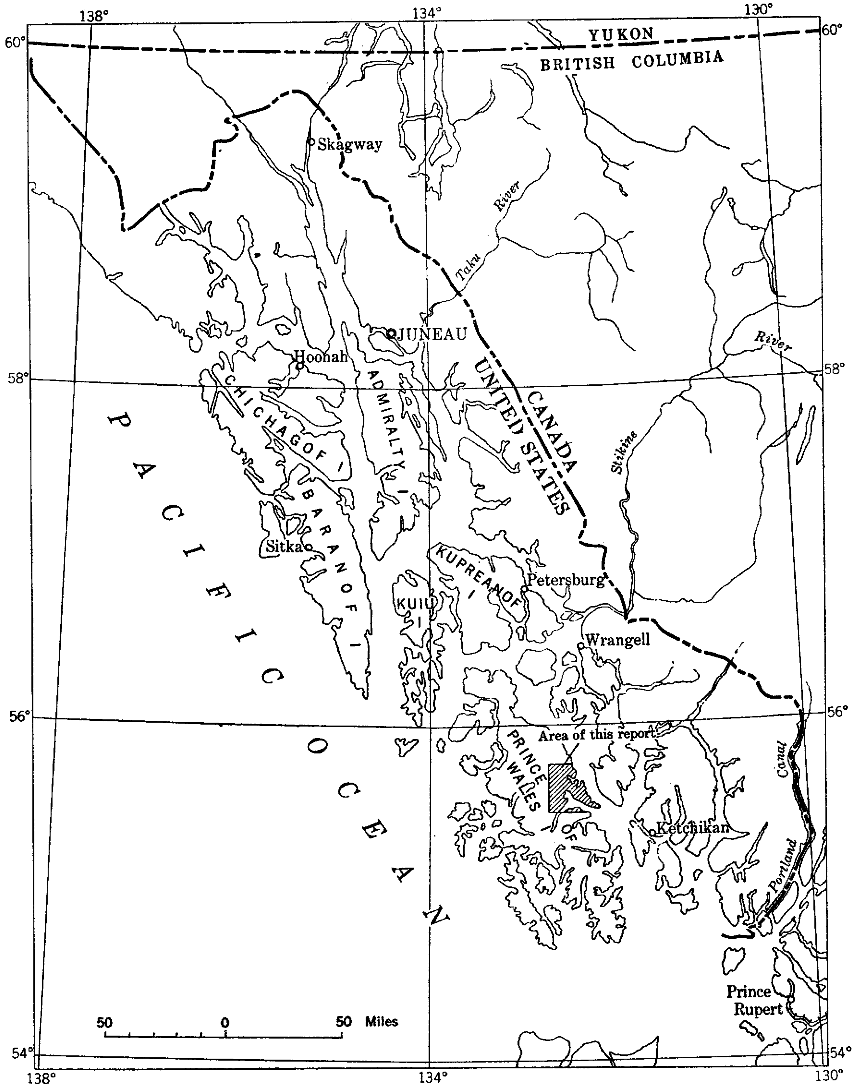

FIGURE 47.—Index map of a part of southeastern Alaska showing Craig C–2 quadrangle and adjoining areas, Prince of Wales Island, Alaska.

SCOPE OF THE PRESENT INVESTIGATION

In 1954, a project was undertaken to map geologically that part of the Craig C–2 quadrangle not covered by geologic maps made by Wright (1915) and by Warner and others (1960) in an attempt to establish the details of the stratigraphy and structure of the area and to determine the geographic and geologic limits of the copper-magnetite district. The geologic mapping of the mines and prospects by Warner and others was sufficiently detailed and little more could be done; hence, in the present investigation, no attempt was made to do more than visit some of the mines and prospects briefly. The pertinent information on ore deposits is only summarized here, and the reader is referred to the comprehensive paper by Warner and others for a detailed discussion of the economic geology of Kasaan Peninsula and the area between it and the Rush and Brown mine. A preliminary copy of the report by Warner and others was available during the fieldwork and was consulted freely during the writing of this report.

The fieldwork for this report was begun in 1954, when the writer, assisted by William Hibberd, boatman, spent 30 days in the field mapping the southern part of the area. In 1955, assistants were Gordon W. Herreid, geologist, and Donald Forbes, boatman; 3 months were spent in the field, during which time the remainder of the area covered by the geologic map was mapped. Herreid and the writer operated somewhat independently in the field, and much of the geologic data, especially in the area northeastward from the north arm of Thorne Bay, are Herreid's.

In May 1955, the U.S. Geological Survey made an airborne-magnetometer survey of the area near Salt Chuck to supplement a reconnaissance magnetic map made in 1945.

ACKNOWLEDGMENTS

Many favors were received during the fieldwork, especially from Russell Simpson of Ketchikan, a bush pilot who delivered supplies and mail and flew the field party to small lakes, much of the time in unfavorable weather. Juan Muñoz, a mining geologist engaged in work near North Pole Hill, accompanied us to his prospects and furnished geochemical and magnetic data. H. E. Anderson and other members of the U.S. Forest Service stationed at Hollis, and Clay Scudder of the U.S. Fish and Wildlife Service in Ketchikan provided storage for supplies. Officials of the Ketchikan Pulp Co. arranged mail delivery at their logging camp at Hollis during 1954. The help received is gratefully acknowledged.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

The area mapped is on the east shore of Prince of Wales Island, Alaska, about 35 miles northwest of the town of Ketchikan, which is the southernmost city in Alaska (fig. 47). The area encompasses the north shore of Kasaan Peninsula, a long peninsula extending southeastward, and part of the main mass of Prince of Wales Island. It is bounded on the east by Clarence Strait, a narrow seaway about 120 miles long that is open at the south end to Dixon Entrance, a part of the Pacific Ocean. Three bays—Kasaan, Tolstoi, and Thorne—indent the coastline and give good bedrock exposures and accessibility at tide level.

The area, which is accessible by boat and by plane, is served by scheduled and chartered airplanes and boats from Ketchikan. Before 1954, only a few people lived at Hollis, Kasaan, and Salt Chuck, but by 1954 several logging camps were being established to provide timber for the new pulp mill in Ketchikan. By 1955, logging camps were established at Hollis, Salt Chuck, Kina Cove, and on Thorne Bay; these logging operations require boat and plane service almost daily.

Roads and trails are almost totally lacking in much of the mapped area. A foot trail leads from Salt Chuck to Kasaan and to the south arm of Thorne Bay, and another leads from the mouth of the Karta River to the head of Salmon Lake. A few short logging roads are being made at the established logging camps. A good logging road has been made from Hollis, just west of the southwest corner of the mapped area, up Maybeso Creek for several miles and gives improved access to the gold lodes on the west slope of Granite Mountain. A foot trail leads from Salt Chuck to claims on North Pole Hill, and an old wagon road leads from a small cove north of the mouth of Karta River to an old ferry terminal of the Flagstaff mine at the outlet of Little Salmon Lake. The wagon road continues from the opposite shore up Granite Creek to the buildings at the Flagstaff mine, but it is thickly overgrown by heavy brush between the mine and the lake. Trails are nonexistent elsewhere within the mapped area, especially north and west of Thorne Bay—even game trails are lacking. Within most of the mapped area, foot travel is slow, uncertain, and difficult, owing to the dense timber and brush and to the swamps and muskeg areas. The numerous magnetic anomalies that are present render a compass useless for long traverses, and it is often very difficult to determine exact localities in the field.

TOPOGRAPHY AND DRAINAGE

Relief within the area is moderate, except in the extreme southwestern part where the higher mountains within a few miles of the sea rise to an altitude of about 3,500 feet. The topography of most of Kasaan Peninsula south of the low pass from Tolstoi Bay to Kasaan Bay is rugged, even though the higher mountains rise only to an altitude of about 2,800 feet. North of the head of Kasaan Bay the hills are low and rolling, and nowhere except locally in some of the steeper stream valleys are traverses prevented by steepness of the stream bed.

A conspicuous broad depression extends northwestward from the head of Kasaan Bay and continues up the valley of the Thorne River beyond the mapped area. Another low pass extends from the head of Tolstoi Bay to Kasaan Bay. Innumerable small lakes, bogs, and muskeg areas have formed in all areas of low relief, and some occur even on the higher slopes and hills, especially where bedrock is thinly veneered by glacial deposits.

The major drainage is controlled by the main preglacial valleys, except in the broad lowlands of the Thorne River valley, where glacial till and outwash gravel exert the primary control. The Thorne River, which is the largest stream of the area, flows mostly on alluvium or reworked outwash gravel, except for a short distance above the point where it curves southward to enter Thorne Bay. Here the river has cut a narrow, steep-walled canyon in bedrock. The small volume of alluvium in the present delta of the Thorne River, and the narrow, steep-walled canyon mentioned above, give evidence that the Thorne River altered its course in postglacial time. In preglacial time the Thorne River probably flowed southward past Angel Lake and emptied into the salt chuck at the head of Kasaan Bay.

In upland areas, streams flow on bedrock or in steep, youthful valleys containing glacial deposits that are being eroded rapidly. Larger lakes in upland areas are tarns or cirque lakes in bedrock basins. Salmon, Little Salmon, and Wolf Lakes occupy bedrock basins scooped out by glaciers, and the lake levels are controlled by bedrock lips at the outlets. During yearly high tides, salt water flows into Lake Ellen north of the Salt Chuck mine.

CLIMATE AND VEGETATION

The climate of this part of Alaska is characterized by mild, wet winters and by cool, wet summers. At sea level, rain may fall at any time during the winter, but at higher altitudes snow accumulates to a considerable thickness and lies until late summer. In late

August 1955, heavy snowbanks were found on Granite Mountain, west of the Flagstaff mine.

The mean annual precipitation at Ketchikan is about 151 inches, most of which falls as rain; the mean annual temperature is about 45°F. and averages about 32°F. in the winter months and 56°F. in July and August. The monthly precipitation ranges from a low of 6 or 7 inches in May, June, and July to a high of 20 to 24 inches in October and November (U.S. Weather Bureau, 1901–53). Wide variations in monthly rainfall occur from year to year—for instance, in 1954, the month of August was bright and sunny with only a few days of light precipitation, but in 1955, 15 inches of rain fell between August 1 and August 20. During the field season in 1955, the higher-than-average rainfall was a deterrent to fieldwork because storm clouds were so low for weeks at a time that no work could be done above an altitude of 800 feet. In addition, all streams were so high throughout the months of July and August that they were traversed only with difficulty, and many of the bedrock relations were obscured. Although camps were established at the base of Rush Peak on two occasions, the peak was shrouded in storm clouds for days at a time and could not be traversed to the summit even though it was the one mountain in the quadrangle composed of bedded rocks with excellent exposures.

A thick forest of evergreen trees, berry bushes, and alder mantles the terrain to an altitude of about 1,500 feet. Between 1,500 feet and 2,500 feet, some stunted spruce and hemlock are found, but scrub cedar is more common. The timber lies within the holdings of the Ketchikan Pulp Co., and logging operations, where thorough, are rapidly stripping the timber from large areas. Peat bogs, muskeg areas, and grassy peat flats, with large numbers of beaver dams, are interspersed with dense evergreen growths in lowland areas. Alder is common at the tide line and along the streams.

During summer months, from May to September, the insects, including whitesox, gnats, mosquitoes, and various types of black flies, are thick enough to be a constant irritation. The whitesox are particularly numerous and vicious.

THE GEOLOGIC MAP

The geologic map (pl. 33) is not an adequate portrayal of the regional geology of the area, except for the outlines of the larger intrusive bodies. The bedrock relations are largely obscured by a junglelike mat of evergreens and underbrush, by swamps and muskeg flats, and by the widespread glacial and alluvial deposits. In many areas, outcrops are limited to bare spots beneath overturned trees, where the roots have pulled up the thick mat of decaying vegetation, or to a few feet in creek bottoms where erosion has removed the glacial deposits and alluvium. In some areas, especially in the lowland northwestward from Lake Ellen to Angel Lake and the Thorne River, outcrops are so poor that an entire day's traverse might disclose but one outcrop beneath an overturned tree. On the geologic map, these outcrops are exaggerated to show the lithologic type. However, almost continuous outcrops are exposed along the shore, and relatively good exposures are found on slopes and creek bottoms in the higher mountains in the southwest part of the area.

The geology of the area mapped in this study is shown on plate 33. Although the geology of the Kasaan Peninsula was not plotted, the writer traversed enough of the peninsula to satisfy himself that the rocks in the area between Tolstoi and Thorne Bays are similar to those on the north end of Kasaan Peninsula, which are for the most part probably Early Silurian(?) in age; the geology of the peninsula is shown on the geologic maps of Wright (1915, pl. 15) and Warner and others (1960, pl. 1).

Some overlap exists between the geologic map (pl. 33) of this report and the geologic map of Wright, especially in a belt from the head of Tolstoi Bay to the area north of Karta Bay. The geologic interpretation of the areas between Tolstoi Bay and Karta Bay as shown on this map and the one made by Wright differs in many respects. Warner and others have also modified Wright's map in the areas near the principal mineral deposits of Kasaan Peninsula and at the Rush and Brown mine. The main differences in geologic interpretation, apart from minor variations in geologic contacts, that have resulted from these three studies can be summarized briefly as follows:

1. Plate 15 of Wright's report shows the regional strike of the bedded rocks on the south shore of Tolstoi Bay, on the peninsula between Thorne and Tolstoi Bays, and west of Loon Lake to be northwestward. The present writers' map shows that in these areas the rocks generally strike northeastward. Detailed mapping by Warner and others (1960) in the area along the west contact of the pluton at Tolstoi Point shows that the sedimentary rocks here strike northeastward.
2. Wright, on the basis of the fossils found in limestone on Kasaan Island, assigns a Devonian age to his basic map unit, the Kasaan greenstone, which he interprets as consisting predominantly of clastic rocks with volcanic affinities. Warner and others feel that a large part of Wright's Kasaan greenstone consists of altered igneous material of Cretaceous age injected into an older series of clastic rocks, probably of Paleozoic age.

On the basis of five collections of graptolites from argillite beds intercalated within rocks shown on Wright's map as Kasaan greenstone, it is concluded that the Kasaan greenstone in the vicinity of Tolstoi and Thorne Bays is of Early Silurian(?) age. It appears also that the Kasaan greenstone consists predominantly of volcanic graywacke, conglomeratic volcanic graywacke, and associated andesite flows with lesser amounts of argillite, feldspathic graywacke, conglomerate, limestone, and chert; and that the entire sequence is of the same age. No evidence of large-scale injection of andesitic igneous material during the Cretaceous was found. The interpretation of Warner and others probably is based upon the fact that much of their mapping was done near plutonic igneous rocks where metasomatism has changed the Kasaan greenstone so much that its clastic origin is no longer apparent. Thus, the writer finds himself disagreeing with Wright and agreeing with Warner and others with respect to the age of the Kasaan greenstone, but agreeing with Wright and disagreeing with Warner and others on the origin of the Kasaan greenstone.

The classification and distribution of the lithologic types shown on the geologic map (pl. 33) are the responsibility of the writer, as are the petrographic descriptions, the interpretation of structure, and the age relations of the units, including dikes.

GEOLOGY

The general geology of the mapped area is shown on plate 33. The rocks comprise a great thickness of pyroclastic rock, lava, volcanic graywacke, and conglomerate with intercalated feldspathic graywacke, minor argillite, chert, and limestone or limy-matrix clastic rock. These rocks are intruded by igneous rocks ranging in size from dikelets a few inches thick to batholiths and ranging in composition from rhyolite and pitchstone to pyroxenite and olivine-bearing diabase. The bedded rocks were deposited in Ordovician, Silurian, Devonian, and Tertiary time, and the igneous rocks were intruded at various times from the Silurian to the Tertiary. Most of the bedded rocks are volcanic graywacke, tuff, conglomerate, and argillite or slaty argillite, all of Middle Ordovician to Early Silurian(?) age. These rocks are slightly to moderately deformed and but slightly metamorphosed regionally. The metamorphism in large part consists of albitization and the development of low-rank metamorphic minerals found in graywacke. Near the larger intrusive bodies they are thermally and hydrothermally altered.

Highly fossiliferous and almost completely unmetamorphosed limestone of Middle Devonian age is found on Kasaan Island. It is intruded by dikes and sills of rhyolite and andesite, probably also Middle Devonian in age.

The Tertiary bedded rocks are conglomerate and conglomeratic sandstone that lie unconformably on older rocks in isolated patches at very low altitudes in the present stream valleys or lowlands. Quaternary glacial and glaciofluvial deposits are widespread throughout the entire quadrangle.

The major structural feature of the rocks appears to be a great syncline whose axis strikes northwestward, about parallel to Kasaan Bay, although the syncline is complicated by faults of unknown displacement. The relation of the Middle Devonian rocks of Kasaan Island to the older rocks cannot be established, but their position can be accounted for only by large-scale faulting, probably after the injection of the stocks in Cretaceous time. Near some of the larger stocks the bedded rocks are folded and faulted, and they are so complex structurally and are metamorphosed so completely that no attempt has been made to differentiate the lithologic types.

BEDDED ROCKS

The bedded rocks of the area are extremely monotonous lithologically and in origin. The greater part is graywacke, tuff, and conglomeratic graywacke of somber gray-green color. The rocks contain large amounts of detrital pyroxene that could have been derived by erosion of older lava and tuff, or by simple reworking of unconsolidated ash or tuff. In this report, such rock is called volcanic graywacke or conglomeratic volcanic graywacke to emphasize the unmistakable volcanic affinity as well as the textural relations common in graywacke (Pettijohn, 1949, p. 243–246). An alternative term might be "pyroxenitic graywacke" to parallel such accepted terms as "feldspathic graywacke" and "lithic graywacke." The usage, therefore, is similar to that of Williams, Turner, and Gilbert (1954, p. 303). Key beds are lacking entirely, and the only fossils are graptolites, which occur in some of the thin argillite beds that are intercalated in the generally unfossiliferous graywacke. These rocks have been deformed, and then intruded by many stocks, batholiths, and dikes. Near the larger intrusive bodies, thermal metamorphism has obliterated many of the earlier textures, and metasomatism has added large amounts of new material. These factors, combined with the generally poor exposures and the cursory nature of some of the early geologic work in the area, have led to confusion in defining the rocks lithologically and have led to some conflicting interpretations.

The bedded rocks of Kasaan Peninsula were grouped by Brooks (1902, p. 49–50) with other altered volcanic rocks east of Clarence

Strait and named the Kasaan greenstone. Brooks assigned them a probable age of post-Triassic, probably Early Cretaceous, although he correlated the thin limestone beds within the unit with limestone units in the Vallenar series of Devonian age, a rather improbable correlation.

In 1908 F. E. and C. W. Wright (1908, p. 110–111) described the rocks on Kasaan Peninsula, included by Brooks in the Kasaan greenstone, as altered sedimentary and pyroclastic rocks ranging from limestone to greenstone tuff, sandstone, and conglomerate composed largely of igneous material. They assigned no formation name and gave the age as Devonian, largely on the basis of the Middle Devonian fossils found on Kasaan Island.

Later, Wright (1915, p. 67–73) described the volcanic rocks of Kasaan Peninsula in greater detail, and in his descriptions he stressed the similarity of the rocks on Kasaan Peninsula to rocks on Thorne Bay and at the Rush and Brown mine west of Salt Chuck at the head of Kasaan Bay. Wright discarded the term Kasaan greenstone and states (p. 68):

> Nearly two-thirds of Kasaan Peninsula is occupied by clastic rocks, which in large part consist of a series of metamorphosed sediments, usually epidotized and containing crystals of amphibole or pyroxene. In texture these rocks range from fine-grained compact rocks, such as quartzites and graywackes, to coarse conglomerates. As these sedimentary rocks are composed of igneous material, and as they have been greatly altered, they closely resemble massive igneous rocks, though in most places their clastic texture may be recognized, especially on weathered surfaces.

Buddington and Chapin (1929, p. 77) collected fossil graptolites from the west side of the north arm of Thorne Bay that were referred to as being Ordovician in age. Buddington recognized the lithologic similarity of the volcanic rocks in Tolstoi and Thorne Bays to Silurian rocks exposed on the west coast of Prince of Wales Island, but he included the rocks of Kasaan Peninsula and the west part of the Craig C–2 quadrangle with his Devonian units.

Warner and others (1960) discuss in some detail the bedded rocks of Kasaan Peninsula and conclude that the clastic rocks are older than the altered andesitic rocks, for which they retain the term "greenstone." They conclude that the greenstone in large part probably represents altered andesitic rock intruded as great sills and sheets into the older clastic sedimentary rocks before intrusion of the dioritic stocks, but within the same general epoch of intrusion. This interpretation leads to the conclusion that much of the bedrock of Kasaan Peninsula and adjacent areas is intrusive and is much younger than the bedded rocks in which it is enclosed.

In view of the foregoing interpretations, which in part are conflicting, the petrology of the rocks that heretofore have been called

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greenstone on Kasaan Peninsula, around Tolstoi and Thorne Bays and in the vicinity of the Rush and Brown mine, are discussed here in some detail. Quite similar rocks form most of the bedrock of the entire quadrangle and extend south, west, and north of it and have been assigned ages ranging from Ordovician to Devonian. The origin and extent of these rocks must be clearly understood in order to make a regional correlation of the various map units and correctly interpret the geologic history of the area.

The writer concurs with Wright that most of the bedded rocks are clastic rocks composed of igneous material that underwent but little chemical alteration during its erosion and subsequent deposition. Most of the massive andesitic rocks within the sediments are volcanic in origin and belong to the same general volcanic epoch that produced the andesitic flows interbedded with the clastic rocks. A few irregular bodies of andesitic intrusive rocks could belong to the middle Cretaceous intrusive epoch, but these form a very minute percentage of the bedrock. No large-scale injection of andesitic sills preceded the intrusions of the granitoid rocks in the Cretaceous.

BEDDED ROCKS OF MIDDLE ORDOVICIAN TO EARLY SILURIAN(?) AGE

Bedded rocks predominantly of Early Silurian(?) age comprise a great thickness of somber volcanic graywacke, tuff, conglomerate, feldspathic graywacke, and andesitic flows that crop out continuously along the entire shore from Tolstoi Point, on Kasaan Peninsula, to Snug Anchorage, north of the entrance to Thorne Bay (pl. 33). The age assignment of the rocks in this area is based upon several fossil collections made in Tolstoi and Thorne Bays, in the Thorne River south of the confluence of Lava Creek, and on the hill west of the north arm of Thorne Bay. Lithologically similar rocks crop out in a wide belt exposed on the south shore of Kasaan Bay from a point south of Kasaan Island westward to Twelvemile Arm, and on the west shore of Kasaan Bay from the entrance of Twelvemile Arm to Karta Bay and thence northward to Salt Chuck. Similar rocks but undated by fossils, crop out along much of the shore from the village of Kasaan to a point south of the Rich Hill mine and on the shore east of the entrance to the salt chuck at the head of Kasaan Bay. These undated rocks, which are so similar to the Lower Silurian(?) rocks of Thorne and Tolstoi Bays, are almost certainly correlative with them, but in the absence of fossils they can only be included with a unit shown as Middle Ordovician to Lower Silurian(?) rocks west of Kasaan Bay and the strong linear that trends northwestward from Karta Bay to the Thorne River. Within this unit of clastic, pyroclastic, and effusive rocks are thin beds of limestone, argillite, phyllitic argillite, chert, and limy-matrix conglomerate, some of which may represent pyroclastic material. Where these different rock types are sufficiently diagnostic to be recognized in the field and where they are sufficiently large, they are shown separately on the geologic map as units within the predominant rock type, which is volcanic graywacke and conglomeratic volcanic graywacke that locally contains tuffaceous material admixed with mechanically eroded volcanic material.

VOLCANIC GRAYWACKE, TUFF, AND CONGLOMERATIC VOLCANIC GRAYWACKE

Volcanic graywacke, tuff, and conglomeratic volcanic graywacke are shown as Early Silurian in age in the northeast part of the map area where fossils of probably Early Silurian age were found, and as Middle Ordovician to Early Silurian in the southwest part of the map area where fossils of Middle Ordovician age were found in but one locality in a thick sequence of rock lithologically similar to the lower Silurian rocks. The dominant lithologic types of the Middle Ordovician to Lower Silurian(?) rocks are coarse-grained volcanic graywacke and tuff in beds ranging in thickness from a few feet to more than a hundred feet, and conglomeratic volcanic graywacke containing abundant rounded cobbles of coarsely porphyritic volcanic rocks and a few cobbles of other rock types, principally chert. The cobbles of the conglomeratic volcanic graywacke usually are not in contact, and individual beds may reach a thickness of a hundred feet or more without significant variation. Bedding within such rocks is extremely difficult to observe except on weathered surfaces or at the tide line, where the rocks are continuously exposed over long distances. Bedding is shown by local beds of finer grained graywacke and tuff in which graded bedding is visible (pl. 34*A*), and by parallel alinement of cobbles (pl. 34*B*). The graded bedding shows that the beds are right side up. The volcanic graywacke, tuff, and conglomeratic volcanic graywacke are dark greenish gray to grayish green, are highly indurated, and locally are calcareous. The rocks fracture across the cobbles, pebbles, and lithic fragments. The mineral and lithic constituents of the volcanic graywacke, conglomeratic volcanic graywacke, and tuff vary considerably from place to place, and it is extremely difficult even in thin section to classify accurately any single specimen into 1 of the 3 types listed. Their most striking feature is the large amount of euhedral to angular augite crystals that in places constitute at least 40 percent of the rock. In small outcrops, these rocks appear to be igneous, and where they have been altered by thermal fluids, albitization, or metamorphism, the texture created by the alteration of the pyroxene crystals and groundmass certainly suggests an altered igneous rock. However, detailed search within any area usually discloses bedding and establishes the rock as being sedimentary. The clastic nature of the rock becomes accentuated by weathering, for cobbles and pebbles almost identical mineralogically to the groundmass are distinctly visible on weathered surfaces. The volcanic graywacke and conglomeratic volcanic graywacke contain some potassium feldspar where associated with lithic graywacke containing abundant fragments of porphyry that contains potassium feldspar. Elsewhere the content of potassium feldspar is low, generally less than 1 or 2 percent.

The bedded fragmental and clastic rocks in the Thorne and Tolstoi Bay areas have been partly to completely albitized, but the degree of albitization varies from place to place. In general the groundmass of the volcanic graywacke has been more completely albitized than the individual clasts, indicating that grain size may have had some effect on the albitizing process. However, these rocks are cut by dike rocks that are not albitized and that contain phenocrysts of albite or anorthoclase, indicating that some of the albitization may have been caused by albite-rich igneous emanations. This is discussed further on page 320.

Four samples of the volcanic graywacke were analyzed chemically. The results are reported in the following table. Samples 1 and 2 are from a thick sequence of volcanic graywacke in the entrance to Thorne Bay. Sample 3 is the matrix from the thick conglomeratic volcanic graywacke from the head of Karta Bay and is shown in plate 35, and sample 4 is a composite chip sample from the numerous cobbles of pyroxene porphyry encased in the matrix of volcanic graywacke. These analyses show that the volcanic graywacke is but little changed chemically from the original volcanic rocks from which it formed, the chief change being the albitization of the rocks represented by samples 1 and 2.

FELDSPATHIC AND LITHIC GRAYWACKE

Beds of feldspathic graywacke and lithic graywacke are interbedded with the volcanic graywacke and tuff. The feldspathic and lithic graywacke form isolated well-graded lenses in the tuff and volcanic graywacke. The feldspathic graywacke is a bluish-gray rock consisting of quartz and feldspar with minor lithic fragments and some magnetite. Locally it is highly calcareous. The lithic graywacke commonly contains fragments of black argillite, numerous volcanic rocks, and light-greenish-gray chert, although many other rock types are sparingly present. The matrix is recrystallized to epidote, zoisite, chlorite, and prehnite. Potassium feldspar is almost completely absent from the rocks except where they are associated with fragments of feldspar porphyry containing orthoclase.

Chemical composition in percent by weight, of conglomeratic volcanic graywacke, Craig C–2 quadrangle, Prince of Wales Island, Alaska

[Analysts: Paul L. D. Elmore, Katrine E. White, and Samuel D. Botts]

	1	2	3	4
SiO_2	50. 3	51. 3	44. 3	48. 4
Al_2O_3	18. 3	18. 8	18. 0	17. 2
Fe_2O_3	5. 0	5. 7	3. 5	3. 1
FeO	3. 5	3. 0	8. 5	6. 4
MgO	4. 1	3. 4	6. 2	4. 3
CaO	8. 3	7. 6	8. 7	10. 5
Na_2O	4. 5	5. 2	1. 4	1. 8
K_2O	1. 9	1. 0	1. 3	1. 2
TiO_2	. 53	. 74	. 85	. 74
P_2O_5	. 24	. 28	. 37	. 43
MnO	. 16	. 16	. 17	. 14
H_2O	2. 00	1. 80	4. 50	3. 40
CO_2	. 48	. 34	1. 80	2. 20
Total	99.	99.	100.	100.

1. Chip sample of more than 100 feet of albitized conglomeratic volcanic graywacke or conglomeratic tuffaceous graywacke, north shore of entrance to Thorne Bay; sp gr, 2.967; laboratory No. 145070.
2. Chip sample of albitized conglomeratic volcanic graywacke or conglomeratic tuffaceous graywacke, south shore of entrance to Thorne Bay near south arm of bay; sp gr, 2.900; laboratory No. 145071.
3. Matrix of conglomeratic volcanic graywacke from head of Karta Bay, 900 feet south of old wagon road to Flagstaff mine (see pl. 35*B*); sp gr, 2.975; laboratory No. 147327.
4. Cobbles of pyroxene porphyry in sample 3; sp gr, 2.970; laboratory No. 147326.

FINE-GRAINED ROCKS

Within the volcanic graywacke, tuff, and conglomeratic graywacke that form the bulk of the bedrock are beds of finer grained rocks whose lithologic characteristics are sufficiently different from the enclosing rocks as to warrant their designation on the geologic map. In the field the rock types were classified as feldspathic and lithic graywacke, argillite, chert, and limestone. Although these rocks occur sparingly throughout the entire map area, and usually grade imperceptibly into each other or into volcanic graywacke, they form the bulk of the bedrock in some areas, particularly in the northeastern and southwestern parts of the map area. The geologic boundaries of these areas of fine-grained rocks are not formational boundaries, as is shown by the universal horizontal and vertical gradation into other rock types; but within the general areas shown as fine-grained rocks they form the bulk of the bedrock. The limestone units in particular have rather sharp contacts, and a few of the larger limestone beds are shown separately on the map.

A thick sequence of deformed and slightly schistose argillite and slate with minor chert, conglomerate, and graywacke beds lies on the southwest contact of the pluton in the southwestern part of the quadrangle. It has been shown as a separate unit on the geologic map. Rocks farther southwest, however, are volcanic graywacke, tuff, and conglomeratic volcanic graywacke, and it is not known if this very thick slate-argillite unit is local or whether it reflects a major change in sedimentation.

ARGILLITE

Beds of grayish-black argillite are intercalated within the feldspathic and lithic graywacke. The beds range in thickness from a dark film to as much as several inches and alternate with beds of feldspathic graywacke normally of greater thickness. Interbedded argillite and feldspathic graywacke in places reach a thickness of at least 100 feet. Where intercalated with beds of massive volcanic graywacke, the argillite and feldspathic graywacke are intensely deformed, presumably because they were relatively incompetent during deformation. The argillite is a hard rock that fractures conchoidally, but in thin section it is seen to consist predominantly of small grains of quartz and feldspar with graphitic argillaceous bands that create a slight tendency toward fracturing parallel to the bedding. Even the most argillaceous and graphitic argillite contains more than 50 percent detrital mineral grains, chiefly quartz and feldspar. The more graphitic zones in the argillite have yielded graptolites that date the rocks in the area of Tolstoi and Thorne Bays as Early Silurian(?) in age.

CHERT

Within the volcanic graywacke, tuff, and conglomeratic graywacke are thin beds of pale-grayish-yellow to pale-greenish-yellow chert in beds ranging in thickness from 1/8 of an inch to as much as 6 inches, interstratified with dusky-yellow-green to dark-gray argillite with a chert matrix. The beds are lenticular and grade into volcanic graywacke. Beds of this type are especially common in the area from Snug Anchorage to the north boundary of the mapped area, but they occur sparingly throughout the bedded rocks over the entire mapped area. They form a large part of the area of fine-grained rocks north of the pluton in the southwestern part of the mapped area. Chert and argillite of this type are more common in the volcanic graywacke than in the feldspathic graywacke. In thin section the chert is seen to contain abundant rounded fragments of quartz and feldspar encased in cryptocrystalline silica.

LIMESTONE

Thin beds of limestone or marble, limy-matrix graywacke, and limy-matrix tuff are contained within the thick series of volcanic graywacke, tuff, and conglomeratic volcanic graywacke, especially in Thorne and Tolstoi Bays. The purer marble is white to greenish white and contains isolated fragments of volcanic rocks and tuff. Locally the limestone is very schistose, but at some places it is quite massive. Dark aphanitic dikelets and tuff beds intercalated in the limestone have been disrupted during regional deformation to produce limestone in which angular fragments of dark rock lie isolated in a limestone or marble matrix. Locally the limestone is intricately folded (pl. 36). Of special interest are the beds of limestone in Kina Cove, on the beach north of the pluton at the mouth of Twelvemile Arm, and in Thorne Bay that contain round porphyry cobbles, heavily pyritized, in crudely stratified beds. The limestone contains no sulfide minerals; beds of this type probably were formed from volcanic ejecta that had been previously pyritized, probably in the throat of a volcano, and that fell into limy mud. No fossils have been found in the limestone.

CONGLOMERATE

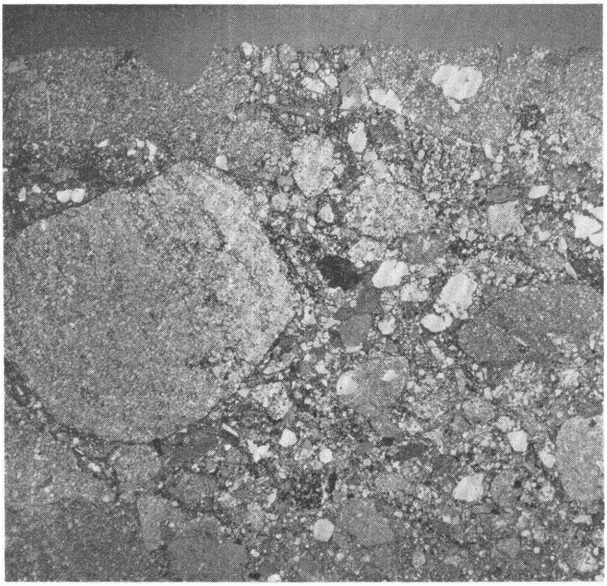
Thick lentoid beds of conglomerate are common within the finer-grained rocks. Three distinct types of conglomerate are recognized. One consists of cobbles and pebbles of volcanic rocks in a matrix of volcanic graywacke. Conglomerate of this type grades laterally and vertically into conglomeratic volcanic graywacke which merely reflects less winnowing and sorting. This conglomerate grades so imperceptibly into conglomeratic volcanic graywacke that its separation on the geologic map has not been attempted.

The second type of conglomerate contains well-rounded to subangular fragments of diverse rock types, many of which are not recognized in place in the map area, and it is sufficiently different from the conglomerate first described to be shown on the geologic map as a distinctive unit within the volcanic-graywacke unit. The conglomerate forms lentoid pods or piles, some of which are at least several hundred feet thick, isolated within volcanic graywacke, tuff, or conglomeratic graywacke. Many of the lenses grade laterally and vertically into conglomeratic graywacke, and some grade into lithic graywacke with intercalated argillite beds. Many of the steep cliffs in the map area are developed in this type of conglomerate, for it is resistant to erosion and glacial plucking has removed large joint blocks.

The lithologic types most common in the conglomerate are rhyolite porphyry, light-gray to light-bluish-gray chert or chalcedony, and buff-weathering limestone. The conglomerate also contains lesser amounts of banded chert, quartz-diorite, fine-grained light-colored andesite, rhyolite, argillite, vein quartz, slate, sandstone, and very minor amounts of other lithologic types. The cobbles in the conglomerate generally are in contact, either throughout the unit or within the thicker conglomerate beds that are separated by finer conglomerate or conglomeratic graywacke. Stream channels and shingle pebbles and cobbles are common in the conglomerate, which was undoubtedly deposited by running water. Very thick conglomerate of this general type forms the north slope and east base of Rush Peak, and it is sufficiently different to warrant individual discussion. This conglomerate contains a larger amount of slate, argillite, and graywacke than the conglomerate in the Lower Silurian rocks of Thorne and Tolstoi Bays, and on the lower north slope of the mountain, certain beds several hundred feet thick consist almost entirely of very large cobbles of buff-weathering unfossiliferous limestone. Buff-weathering sandstone, a lithologic type not recognized in the conglomerate elsewhere in the map area, occurs sparingly, and locally the conglomerate grades to a fine-grained facies with a black argillaceous matrix. The conglomerate on the higher north slope of Rush Peak displays marked shingling, good grading, and abundant stream channels, suggesting subaerial deposition. However, within the conglomerate, and beneath it, are beds of black argillite interstratified with beds of lithic graywacke, which undoubtedly were deposited in water.

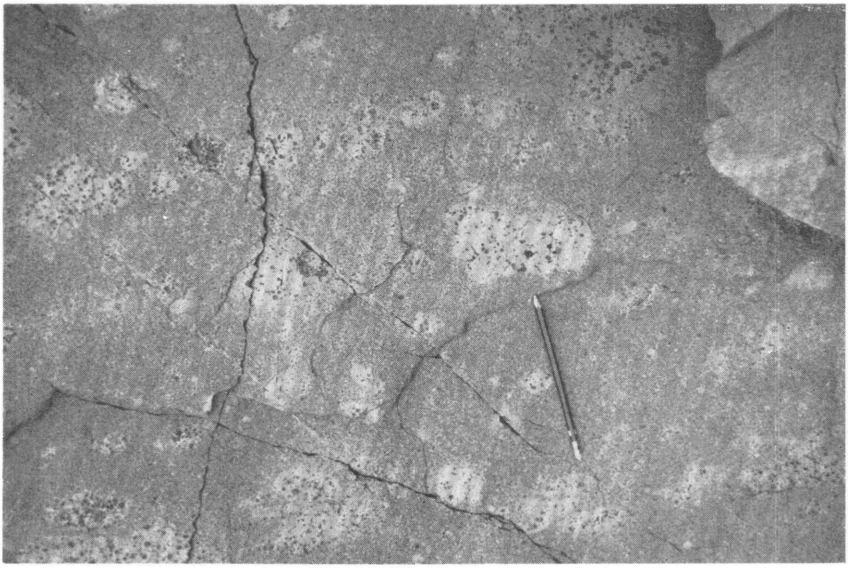
The collection of Middle Ordovician fossils from argillite at the east base of Rush Peak shows that some of the rocks in this area are Middle Ordovician in age, and it is entirely possible that the conglomerate of Rush Peak is also Ordovician, especially in view of the differences noted between this conglomerate and other conglomerate in the Thorne Bay–Tolstoi Bay areas. However, in spite of the differences noted, the similarities are more striking than the dissimilarities, for both types of conglomerate contain chert, graywacke, argillite, limestone, vein quartz, chalcedony, quartz diorite, several types of light-colored felsitic rocks, some of which have flow lines, and porphyritic volcanic rocks similar to those forming the cobbles in the conglomeratic volcanic graywacke. Furthermore, the physical characteristics are quite similar; both types of conglomerate locally are well sorted, contain cobbles in contact with each other, contain intercalated lithic graywacke beds, and vary rapidly lithologically and in physical properties. In short, their source rocks and their depositional environments were very similar, and without additional fossil evidence to indicate an age disparity the writer is reluctant to assign them a different age.

Conglomerate of the type just described seems to have been deposited by streams whose transported load was derived from a geologic terrane containing diverse rock types, and much of the



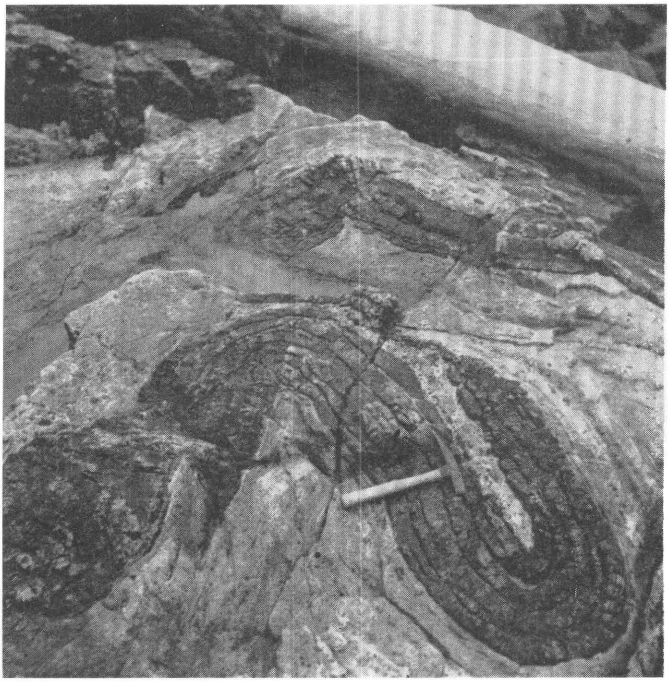
A. Photomicrograph of typical lithic graywacke along the shore of Thorne and Tolstoi Bays. About × 6, crossed nicols.

B. Conglomeratic volcanic graywacke or tuff on the north shore of the entrance to Thorne Bay.

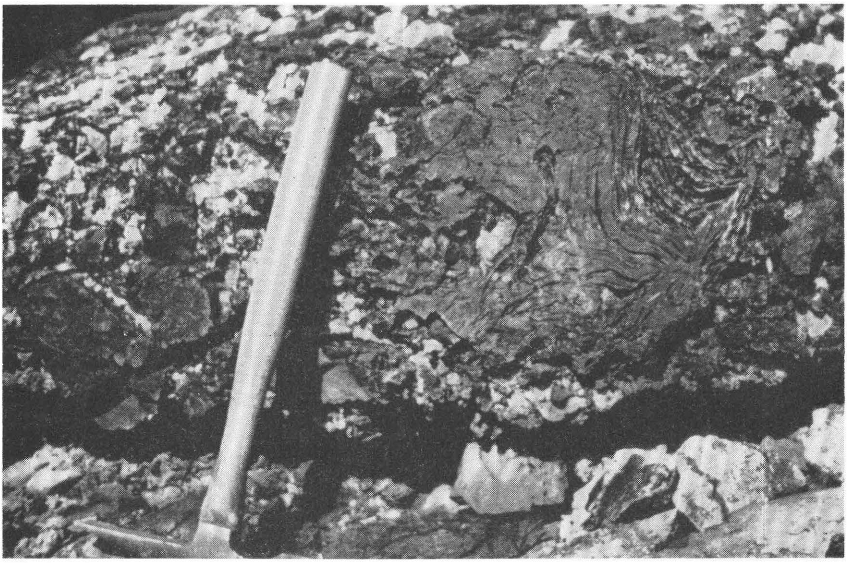


A. Conglomeratic volcanic graywacke from the head of Karta Bay, with crude stratification of cobbles. Dark specks in cobbles and matrix are pyroxene crystals. None of the cobbles are amygdaloidal.

B. Conglomeratic volcanic graywacke from the head of Karta Bay, with crude stratification of cobbles and fine-grained beds (upper right). Small white spots are barnacles.

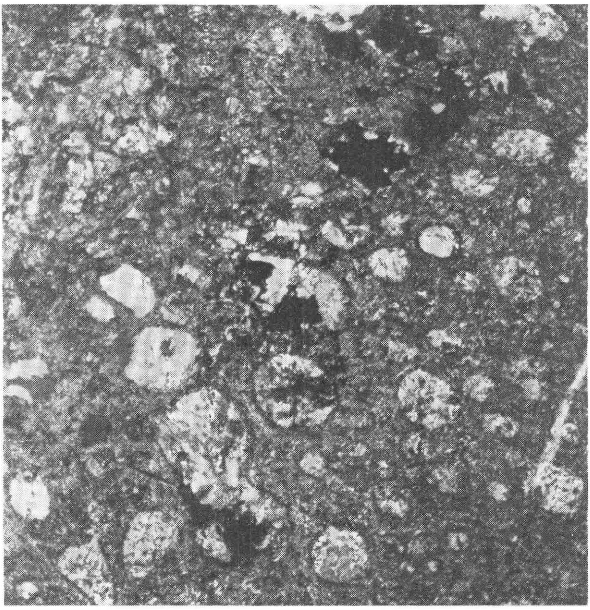


Folded limestone with intercalated tuff beds on east shore of Snug Anchorage.



A. Contorted fine-grained sedimentary rocks in slump conglomerate with limestone matrix on south shore of south entrance to Thorne Bay.

B. Limestone-matrix slump conglomerate on north shore of island in entrance to Thorne Bay.



A. Photomicrograph of typical amygdaloidal lava flow from the area west of Thorne Bay. About × 12, crossed nicols.

B. Photomicrograph of trachytic lava flow with carbonate amygdules, Tolstoi Bay. About × 6.

A. Tertiary conglomerate on a beach near the north end of Craig C–2 quadrangle.

B. Photomicrograph of conglomerate from Berry Island, Kasaan Bay, showing magnetite pebble (black). About × 6.

conglomerate was deposited where the streams entered salt water or flat areas near sea level. The preponderance of cobbles of rocks that in general are very resistant to erosion seems to be of particular significance, indicating that they were transported some distance from their source area.

Limy-matrix conglomerate, which apparently represents submarine landsliding of coarse material into limy mud, is exposed only on the islands at the entrance to Thorne Bay, and along the shore of the south entrance to Thorne Bay. It represents the third distinctive type of conglomerate, but it does not occur in units large enough to be shown separately on the geologic map. The conglomerate contains boulders as much as several feet in diameter, which locally are in contact with each other. These cobbles generally are similar to the cobbles in the enclosing conglomeratic volcanic graywacke, but locally they are composed either of large fragments of contorted fine-grained sediment that was only partly lithified at the time of slumping (pl. 37) or of rounded pebbles of chert and argillite.

ANDESITE

Andesite flows are found throughout the sequence of volcanic graywacke and associated rocks, but most of the flows are too small or too poorly exposed to be shown individually on the geologic map. However, two areas in which flows form the bulk of the bedrock are shown, one of about 15 square miles in the north-central part of the quadrangle and a small one west of the south arm of Thorne Bay. The flows of the two areas are distinctly different.

The flows west of Thorne Bay are dark-greenish-gray porphyritic and amygdaloidal andesite. The phenocrysts, which are composed entirely of plagioclase feldspar, are as much as 5 mm in length and constitute about 20 percent of the rock. The phenocrysts are imbedded in a pilotaxitic groundmass of microlites of albite, or of sodic oligoclase rimmed by albite. The amygdules consist entirely of calcite, of calcite cores rimmed with chlorite, or of plagioclase feldspar rimmed with chlorite. Most of the amygdules contain chlorite (pl. 38*A*). These andesite flows contain no phenocrysts of mafic minerals.

The flows in the north-central part of the quadrangle are more varied and form a thin lower group of andesite flows somewhat similar to those west of Thorne Bay, and of amygdaloidal and nonamygdaloidal flows and flow-breccia that are characterized by a large proportion of phenocrysts of pyroxene and smaller amounts of plagioclase feldspar. Many of the pyroxene phenocrysts are broken euhedral crystals. Two types of pyroxene occur, one having an optic angle near 60° and a beta index of refraction of 1.705, and

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the other having an optic angle ranging between 22° and 30° and a beta index close to 1.71. These optical properties indicate that the pyroxenes are calcic augite or augite, and pigeonitic augite. The plagioclase phenocrysts are andesine. In some of the flows the groundmass is composed principally of hornblende, pleochroic in blue green, and in others it consists of plagioclase laths, fragments of pyroxene, and epidote, prehnite, and cryptocrystalline quartz or feldspar. The amygdules consist either of feathery quartz that rims a core of calcite or wholly calcite, prehnite, or finely twinned albite.

Thin lava beds occur elsewhere (pl. 38*B*), and a few exposures show that lava locally engulfed and deformed the underlying fine-grained rocks prior to their lithification. No pillow structures were found in the flows despite the fact that they are interstratified with rocks that were deposited in a predominantly marine environment. It is possible that pillow lava would be found if exposures were more extensive.

STRUCTURE AND THICKNESS

The structure of the Middle Ordovician to Early Silurian bedded rocks is complex, owing to both folding and faulting, and much of it cannot be determined in the field. The apparent regional structure is a major synclinorium, the axis of which trends about N. 45° W., roughly parallel to Kasaan Bay. The southwest limb of the synclinorium contains smaller folds that cause great variations in strike and dip, but the rocks of the northeast limb are more constant in attitude, local disruptions of attitude being caused primarily by plutons. Impressed upon the broad synclinorium are numerous smaller folds whose axes trend both parallel to and at wide angles to the axis of the synclinorium. A system of northeastward-trending folds is apparent locally as shown by the axes of smaller folds and drag folds in the argillite and the slate-argillite band in the southwest part of the mapped area, where the axes of small folds plunge rather consistently northeastward. Folds trending northeastward were noted by Warner and others (1960) on Kasaan Peninsula, and folds trending northeastward were noted to be the major structural features on the west side of Prince of Wales Island (Eberlein, G. D., written communication, and Buddington and Chapin, 1929, p. 290).

The continuity of the rocks is interrupted by large and small faults, the displacement of which could not be determined because of the lithologic similarity of the rocks and the scarcity of outcrops. The faults actually determined in the field are shown as solid lines on plate 33, and faults inferred from a study of aerial photographs are shown as questioned faults. The faults form three sets, one striking northwestward, one northeastward, and the third northward. Some of the faults are bordered by a zone of sheared rock of considerable width, indicating that the faults have appreciable displacement. The largest faults, which trend northwestward, and the northward-trending faults north of Thorne Bay, are bordered by several feet of sheared rocks and gouge.

A second possible interpretation of the regional structure of the Middle Ordovician to Lower Silurian(?) rocks involves major movement on the fault that is assumed to be marked by the strong linear running from Kasaan Bay to the Thorne River valley and beyond. If this is a major fault with downthrown side to the east, the apparent regional structure could be caused by displacement that dropped the rocks east of the fault that strike northward or northeastward and dip westward or northwestward into contact with rocks west of the fault that strike northwestward and dip northeastward. Evidence supporting this conclusion is that the fault marks the rough boundary between rocks on the west from which was collected one group of fossils of Middle Ordovician age and rocks on the east that are believed to be virtually continuous with rocks of similar lithology and probable Early Silurian age west of the south arm of Thorne Bay. In general, the fault also separates rocks of known complex structure to the west from rocks of more simple structure to the east. This fault, if a major one, probably continues beneath Kasaan Bay and could help explain the anomalous position of Middle Devonian rocks on Kasaan Island, which is discussed later.

The thickness of the Middle Ordovician and Lower Silurian(?) rocks cannot be established with the present data. The rocks are moderately to strongly folded and faulted, and no distinctive beds have been found that enable one in the field to be certain of the stratigraphic position of any bed. However, some idea of the thickness may be obtained from areas where faulting and folding are moderate and where exposures are good along beaches.

The rocks from Tolstoi Bay to the head of Thorne Bay and thence to Snug Anchorage strike northeastward, and they dip northwestward at angles that range from 20° to 50° and average 30° to 40°. No faults have been recognized along the shores of the entrance to Thorne Bay, and only minor folds are known, none of which involve repetition of beds. A thickness of volcanic graywacke, tuff, conglomeratic volcanic graywacke, and argillite of at least 6,000 feet is indicated in this section.

A line from Forss Cove, north of Snug Anchorage, to the mouth of Falls Creek on the Thorne River also roughly cuts across the strike of the beds, and although this area is faulted, no repetition of major units is recognized. The bedded rocks may be as much as 17,000 feet thick in this area.

A thick section of conglomeratic volcanic graywacke, tuff, and argillite is exposed on the north shore of Twelvemile Arm between the quartz diorite (pl. 33) and Karta Bay. These rocks are at least several thousand feet thick and probably are the equivalent of similar rocks exposed in Thorne and Tolstoi Bays.

METAMORPHISM

The Middle Ordovician to Lower Silurian(?) bedded rocks are regionally metamorphosed. The metamorphic rank is low and does not reach even the rank of the greenschist facies, except in the thermal metamorphic aureoles near the intrusive rocks. In the volcanic graywacke the regional metamorphism produced mineral assemblages that are characteristic of indurated graywacke that has been deeply buried without being dynamically metamorphosed. The volcanic graywacke consists of discrete mineral and rock fragments that retain their original texture and in part their original composition. The groundmass is recrystallized to epidote, chlorite, calcite, prehnite, and other minerals characteristic of low-rank metamorphism. Reaction between matrix and grains is noticeable in some sections, but in others the grain boundaries are sharp and distinct. The grains in the fine-grained argillite have retained their form, and magnetite has not begun to clot. Bedding is everywhere preserved, and nowhere is regional fracture or flow cleavage developed. Limestone within the graywacke is recrystallized, and locally it is schistose, especially near faults. Some of the fine-grained argillite and slaty argillite is folded on a small scale, but even in these folds no fracture cleavage is developed. Fine-grained brittle cobbles in the conglomerate are not fractured. In short, all the regional metamorphic effects are those that might be expected from burial and moderate to slight folding at moderate depth and low temperature. The incompetent beds of argillite and shaly argillite, and the thin beds of limestone, were deformed complexly where interbedded with thick graywacke or conglomeratic graywacke, and some of the faulting that attended and followed the folding was in part localized by the less competent beds. The schistosity in the limestone at the head of Tolstoi Bay and on the south arm of Thorne Bay was produced by faulting.

Near the plutons the rocks are changed considerably by thermal metamorphism and by metasomatic metamorphism involving chiefly the introduction of albite and orthoclase. However, these metamorphic changes are separate and distinct from the regional metamorphism, and in view of the low rank of the regional metamorphism in the mapped area, the writer disagrees with the use of the term "greenstone" that has been applied to the bedded volcanic graywacke, conglomeratic volcanic graywacke, and associated rocks (Brooks, 1902, p. 49, 97; Warner and others (1960)). He agrees with and supports the conclusion by Wright (1915, p. 68) that the bedded rocks are largely clastic in origin with composition and texture still readily discernible.

AGE AND CORRELATION

The age of the thick sequence of volcanic graywacke, tuff, conglomerate graywacke, and minor beds of limestone, argillite, and chert is based upon six fossil collections made in the summer of 1955.

These collections were studied by J. T. Dutro, Jr., of the U.S. Geological Survey, who reports as follows:

Collection 55–AHd–330: Contains *Dicranograptus* sp. and *Climacograptus* aff. *C. bicornus* (Hall). The age is Middle Ordovician. Lat 53°38′14″ N., long 132°38′ W., about half a mile west of north end of Foot Lake.

Collection 55–ASn–184: Contains *Hallograptus*?, *Climacograptus*, *Amplexograptus*?, several other types of diplograptids, and indeterminate fragments of inarticulate brachiopods. The faunule is possibly of Ordovician age. The predominance of diplograptid forms suggests a pre-Silurian age, whereas the absence of any leptograptids points to a post-Early Ordovician age. Lat 53°40′ N., long 132°33′04″ W., about 1.2 miles S. 70° W. of Davidson's logging camp, north arm of Thorne Bay.

Collection 55–ASn–216: Contains *Orthograptus*?, *Climacograptus*?, and several undetermined diplograptids plus indeterminate inarticulate brachiopod fragments. This collection resembles 55–ASn–184 rather closely and may be of the same age. Lat 53°39′05″ N., long 132°26′40″ W., west shore of Tolstoi Bay, south of small cove near inlet.

Collection 55–ASn–240: Contains only indeterminate diplograptid fragments. Sainsbury indicates that this collection is from about the same bed as 55–ASn–216, and is, without doubt, the same age. Lat 53°37′55″ N., long 132°27′ W., west shore of Tolstoi Bay, 1 mile from head.

Collection 55–ASn–125: Contains *Rastrites*?, *Climacograptus*?, *Monograptus*?, *Lingula*?, *Orbiculoidea*?, and indeterminate pelecypod fragments. The age is Early Silurian(?). Lat 53°39′56″ N., long, 132°30′40″ W., west shore of Thorne Bay, opposite entrance.

Collection 55–ASn–232: Contains *Climacograptus*? and diplograptids of uncertain generic affinities, monograptids, and fragments of inarticulate brachiopods. The age is possibly Early Silurian(?), based on the comparison of this material with that of 55–ASn–125. Lat 53°42′20″ N., long 132°36′30″ W., east bank of Thorne River, 0.3 mile south of the mouth of Lava Creek.

All collections are from argillite or slaty argillite beds.

These collections indicate that the rocks in the general area of Thorne and Tolstoi Bays are Early Silurian(?) in age, and that some of the rocks west of Foot Lake are Middle Ordovician in age. The writer was unable to distinguish everywhere the Lower Silurian(?) rocks from the Middle Ordovician rocks, and west of the fault running north from Karta Bay both are included in the same map unit. This unit on the geologic map is noted as Middle Ordovician to Early Silurian(?) in age. It is entirely possible that these rocks range in age from Middle Ordovician to Early Silurian. Buddington and Chapin (1929, p. 79–80) state that the lowermost formation of the Silurian system cannot be distinguished with certainty from the Middle Ordovician rocks, which is in accord with the findings of the present report. The fossils reported above show many similar forms, and Dutro, who identified these fossils, suggests that collections 55–ASn–184, –216, and –240 could be pre-Silurian in age. Collections 55–ASn–216 and –240 are from the lowest stratigraphic sequence on the north shore of Tolstoi Bay and may represent the lowermost Silurian rocks mapped, but collection 55–ASn–184 comes from rocks that are believed to be stratigraphically higher than any possible Ordovician rocks in the Thorne Bay area. Thus, both lithologic and fossil evidence suggests that it is impossible at present to differentiate the Lower Silurian rocks from the Middle Ordovician rocks, but because a definite Early Silurian(?) fauna is found in one area in Thorne Bay it seems preferable to assign an age of Early Silurian(?) to those rocks and to similar rocks in the area north and west of Tolstoi and Thorne Bays. On the map explanation these Lower Silurian rocks are shown as a separate unit from the Middle Ordovician to Lower Silurian map unit.

Because of the almost complete lack of detailed mapping on Prince of Wales Island, it is difficult to correlate with reasonable confidence the Middle Ordovician and Lower Silurian(?) rocks of the mapped area with other rocks on Prince of Wales Island. Buddington and Chapin (1929, p. 76) list Ordovician graptolites including *Climacograptus bicornis* var. *tridentatus* from rocks on Klawak Lake about 14 miles west of the probable Middle Ordovician rocks at the base of Rush Peak, and on their map they show a large area of Ordovician rocks north of Klawak Inlet. These rocks are not lithologically similar to those of Rush Peak, but it is probable that Ordovician rocks, possibly with infolded or infaulted Lower Silurian(?) rocks, form a continuous belt from Klawak Inlet to Rush Peak.

The Lower Silurian rocks exposed on Thorne and Tolstoi Bays are the equivalent, in part, of rocks mapped by Buddington and Chapin (1929, p. 75) and by Eberlein (written communication) on the south side of Heceta Island and vicinity, on the west side of Prince of Wales Island. These rocks are lithologically similar to the rocks on Thorne and Tolstoi Bays, and fossil collections establish them as Early Silurian(?) in age. They represent the next to the lowest formation within the Silurian system on Prince of Wales Island.

If the undated beds of volcanic graywacke and conglomeratic graywacke exposed south of Karta Bay and along the south side of Kasaan Bay from Baker Point to Twelvemile Arm are Early Silurian(?) in age, as they appear to be, then the slate-argillite belt south of the pluton at the mouth of Twelvemile Arm may represent the lowest formation of the Silurian system as exposed elsewhere on Prince of Wales Island. Buddington and Chapin (1929, p. 81–82) state that the lowermost Silurian formation consists predominantly of dark to black graphitic slate with interbedded graywacke and some associated limy layers and sparse conglomerate. Rocks of this lithologic type lie beneath the volcanic graywacke and conglomeratic volcanic graywacke in the south part of the mapped area. These rocks locally are highly schistose, with bedding almost obliterated. The degree of deformation and the dynamic metamorphism cannot be correlated entirely with nearness to intrusive rocks and may indicate that these rocks are appreciably older than the overlying beds.

CONDITIONS OF DEPOSITION

The Middle Ordovician and Lower Silurian(?) rocks of the mapped area appear to have been deposited for the most part in a marine environment in a region of active volcanism undergoing rapid marine erosion. The basin of deposition must have bordered either a volcanic archipelago or an older landmass containing predominantly volcanic rocks that furnished the lithic pebbles and the pyroxene fragments of the volcanic graywacke and conglomeratic volcanic graywacke. The bulk chemical composition of the volcanic graywacke closely approaches that of andesite, and the bulk chemical composition of the matrix of the conglomeratic volcanic graywacke is so close to that of the pyroxene porphyry cobbles that only the slightest chemical decay occurred between the erosion of the volcanic rocks and their subsequent deposition as marine volcanic graywacke.

The basin of deposition also received volcanic material from contemporaneous volcanism, as evidenced by the tuffaceous beds in the volcanic graywacke, the interbedded flows, and the pyritized porphyry ejecta encased in limestone. The cleaner feldspathic graywacke is probably the distal equivalent of the coarser volcanic graywacke, and locally conditions were such that fine-grained argillite and chert were deposited. In deeper parts of the basin the fine-grained rocks approached a shaly composition, and within these beds were buried the graptolites that date the rocks. Streams from the eroding lands discharged into the margin of the basin, building up thick piles of conglomerate containing foreign rock types, and locally the conglomerate graded laterally and vertically into volcanic graywacke or conglomeratic graywacke of local derivation. In some areas submarine landsliding of angular and rounded cobbles and boulders into unconsolidated limy mud gave rise to the limestone-matrix conglomerate, and locally the recently buried rocks were reelevated and eroded to form local conglomerate composed of argillite, graywacke, and chert fragments. The general geologic environment may have resembled that of parts of the present Aleutian Islands, where older volcanic rocks are being rapidly eroded and the detrital sediments admixed with new volcanic material, stream conglomerate, chert and argillite, and limy-matrix clastic material.

The source of the dioritic and rhyolitic cobbles of some of the conglomerate apparently lies outside the mapped area, for no Paleozoic rocks of dioritic composition are known in the map area, and only a few rhyolite dikes are known, their number within the mapped area being too small to account for the great predominance of rhyolite and rhyolite porphyry cobbles in some of the conglomerate. Buddington and Chapin (1929, p. 83) note Lower Silurian rhyolite flows and breccia at Sarheen Cove, El Capitan Passage, on the west coast of Prince of Wales Island, and this may be the source area of the rhyolite in the Lower Silurian(?) rocks near Thorne and Tolstoi Bays.

LIMESTONE OF MIDDLE DEVONIAN AGE

The Middle Devonian limestone of the mapped area is confined to Kasaan and Round Islands in Kasaan Bay. It consists of gray- to buff-weathering limestone, both thin bedded and massive, in beds ranging in thickness from 1 inch to more than 100 feet.

The limestone on both islands is highly fossiliferous, and some beds are composed almost entirely of fossils. Fossils in a collection made in 1905 by E. M. Kindle are reported by Wright (1915, p. 70–71) to be of Middle Devonian or late Early Devonian age. On Kasaan Island the limestone is completely unmetamorphosed and is gently folded, but on Round Island it is strongly folded but unmetamorphosed, with folds plunging eastward at angles up to 70°. On Kasaan Island the limestone in general strikes northwestward and dips northeastward at angles ranging from 10° to 50°, although the strikes and dips change rapidly on numerous small folds that trend northwestward and northeastward. These folds are exposed particularly well on the shores of the small lagoon on the south side of the island.

The limestone on Kasaan Island is intruded by, and in part interbedded with, platy rhyolite that was described by Wright (1915, p. 70) as sandstone, and by Buddington and Chapin (1929, p. 97) as Tertiary rhyolite. Detailed observations by the writer and G. D. Eberlein at the small cove on the south side of Kasaan Island show that the rhyolite is in part intrusive into, and in part contemporaneous with, the limestone and therefore is Middle or late Early Devonian in age. The limestone is intruded also by diabase dikes and contains one small area of contact rock composed of garnet and lime silicate minerals at the contact of a diabase dike.

Warner and others (1960) feel that the Middle Devonian limestone of Kasaan and Round Islands is in an anomalous position with respect to the rocks of Kasaan Peninsula 2 miles to the east. They note that all the limestone observed by them on Kasaan Peninsula is highly metamorphosed and intricately folded, in great contrast to the fossiliferous and unmetamorphosed limestone on Kasaan Island.

The writer agrees fully with their conclusions and feels that the Middle Devonian limestone of Kasaan and Round Islands must be part of a fault block moved into its present position in the Late Cretaceous or early Tertiary. Additional supporting evidence is as follows:

1. Marmorized unfossiliferous limestone intruded by abundant dikes and sills of metamorphosed pyroxene porphyry forms the bulk of the bedrock on Berry Island, about 1500 feet north of Kasaan Island. The proximity of the two types of limestone, one highly metamorphosed and intruded by abundant pyroxene porphyry dikes and the other unaltered and intruded only by diabase dikes, is strong evidence of a structural disconformity between them.
2. A small reef about 600 feet west of Kasaan Island is a hybrid rock composed of pink diorite and feldspathized volcanic graywacke, and the rocks on the shoreline west of Kasaan Island are so extensively metasomatized and contain so many dikes of diorite porphyry that it seems probable that a diorite pluton must underlie Kasaan Bay west of Kasaan Island. If the present position of Kasaan Island were its original position, this pluton almost certainly would have metamorphosed the limestone of the island.
3. Kasaan Island is intruded only by rhyolite of Devonian age and diabase dikes believed to be Tertiary in age. It is unlikely that so large an area could be found anywhere else within the mapped area that does not contain other dikes related either to the vol-

canic rocks or to the plutons injected in the late Early to the Late Cretaceous. This also suggests that the limestone is not in its original position.

4. Two of the diabase dikes, which are identical to those found throughout the mapped area and which intrude the rhyolite just east of the mouth of the lagoon on the southwest shore of Kasaan Island, are badly shattered and deformed. These are the only diabase dikes in the mapped area that were seen to be disturbed tectonically, which further suggests some tectonism of Kasaan Island in the Tertiary.

Evidence that Kasaan and Round Islands are part of a fault block that moved into position after the intrusion of the plutons in Late Cretaceous time, and possibly in early Tertiary time, is extensive, and it seems best not to attach regional significance to the fossils of Kasaan Island or to use these rocks to date others in this area.

BEDDED ROCKS OF TERTIARY AGE

CONGLOMERATE, SANDSTONE, AND CONGLOMERATIC SANDSTONE

Tertiary sedimentary rocks that lie with pronounced disconformity on older rocks are exposed at scattered places within the mapped area. The Tertiary rocks near Coal Bay and Little Coal Bay, on the south shore of Kasaan Bay, were described by Buddington and Chapin (1929, p. 263) as flat-lying sandstone unconformably overlying Devonian greenstone and sedimentary rocks.

The Tertiary rocks of Coal Bay are exposed discontinuously in a creek bed for a short distance from the beach. They consist of light-gray to light-buff graywacke-sandstone containing carbonized logs with branches attached. The attitude of the sandstone cannot be determined, but it appears to dip gently, if at all. The underlying rocks are probably of Early Silurian age.

In Little Coal Bay the Tertiary rocks are exposed in the creek bed for about three-quarters of a mile from the beach. Near the beach they consist of conglomeratic graywacke-sandstone in which the rounded cobbles reach a maximum diameter of 10 inches. The cobbles are not in contact with each other, and they consist predominantly of unweathered diorite; a few of the smaller cobbles are argillite.

The stream rapidly erodes the graywacke-sandstone, leaving the diorite cobbles scattered along the stream channel. A few discontinuous flat-lying seams of lignitic coal that are a few inches thick and that contain marcasite crop out in the creek bottom.

At an altitude of about 30 feet the rock is boulder conglomerate with a graywacke-sandstone matrix. The boulders and cobbles are composed predominantly of diorite and are in contact with each other. The graywacke-sandstone matrix contains abundant slate fragments and is a very light gray on fresh fracture. No coal or carbonized wood is visible.

The Tertiary strata at Coal and Little Coal Bays are for the most part covered by till and outwash gravel, and their extent cannot be determined. From the known relations of the Tertiary rocks elsewhere in the general area, it is probable that they are restricted to an area of not more than 1 or 2 square miles. The preponderance of cobbles of diorite and black argillite suggests that the source area may have been to the west where the bedrock contains a high percentage of these two rock types.

CONGLOMERATE

Friable and weathered Tertiary conglomerate is exposed at an altitude of about 100 feet for a few hundred yards along the logging road leading west from Davidson's logging camp on the north arm of Thorne Bay. The rock is grayish purple, and the pebbles consist predominantly of gray, white, and light-green chert, argillite, various types of andesitic lava and dike rocks, and a few pebbles of quartz in a matrix of the same material. The conglomerate contains terrigenous iron oxides, and in fresher part the matrix is seen to be lithified so that the rock fractures across some of the pebbles. These rocks are covered by glacial till, and their extent cannot be determined, but they probably do not extend more than a few hundred yards in any direction from the outcrops.

Three small bodies of Tertiary conglomerate crop out in the valley of Lava Creek, in the north-central part of the quadrangle. The lowermost is about one-fourth of a mile from the Thorne River at an altitude of 80 feet and is well exposed in the bed and banks of Lava Creek, which has cut downward into it for at least 30 feet. The conglomerate is in the form of a delta, with foreset beds dipping about 60° downstream. It contains abundant pebbles and cobbles of metamorphosed argillite, gneiss, trachytic and amygdaloidal lava, biotite granite, schist, and chert, and the lithified matrix contains rounded fragments of quartz, orthoclase, and microcline in addition to small fragments of the rocks listed. The detritus of all these rock types is derived locally. The conglomerate here is cut by pitchstone dikes that are somewhat fractured and deformed. The conglomerate is overlain by till and alluvium or glaciofluvial deposits.

Bodies of conglomerate of similar lithologic and physical composition are exposed at altitudes of 220 feet and 240 feet in the bed of Lava Creek; each appears to be deltaic conglomerate, and they probably were deposited as isolated bodies rather than as a continuous conglomerate.

Another very small body of Tertiary conglomerate crops out at the tide line near the head of the small cove at the extreme north part of the mapped area. It consists of rounded to angular pebbles, cobbles, and boulders as much as several feet across that consist of dioritic igneous rocks and metamorphic rocks, most of which were derived from the batholith or its metamorphic aureole that form the bedrock east of Lava Creek (pl. 39*A*). The matrix of the conglomerate is fine and sandy in part and weathers to dull light brown or moderate yellowish brown. In general appearance and color this conglomerate resembles superficially some of the Lower Silurian conglomerate in the south entrance to Thorne Bay. It lacks the distinct red color of the Tertiary conglomerate in Thorne Bay and Lava Creek.

CONDITIONS OF DEPOSITION

All the Tertiary rocks of the mapped area have certain characteristics in common: Most are poorly sorted; they consist of lithologic types that were derived locally; and they lie at low altitudes, the highest being about 220 feet above sea level. Some contain coal seams and carbonized logs. They seem to have been deposited by torrential streams which, debouching from an area of considerable relief, deposited the transported load as alluvial fans, deltas, or piedmont gravel in a brackish-water environment (Buddington and Chaplin, 1929, p. 267).

AGE

The Tertiary rocks in the mapped area are dated by their degree of lithification, by their complete lack of metamorphism, by the fact that they contain igneous and metamorphic rocks believed to be of middle Cretaceous age, and by the fact that in at least one place conglomerate is cut by pitchstone dikes that also are found cutting the batholith in the north-central part of the quadrangle. The Tertiary conglomerate resembles in detail other conglomerate in the Ketchikan areas described by Buddington and Chapin (1929, p. 263) and assigned by them to the Eocene. North of Prince of Wales Island, on Zarembo, Kupreanof, and Kuiu Islands, the Eocene rocks contain large amounts of rhyolite, and if the pitchstone dikes cutting the conglomerate on Lava Creek are related to this period of extrusion of rhyolite, then the conglomerate must be at least as old as the Eocene.

UNCONSOLIDATED DEPOSITS

Unconsolidated deposits comprising till, glaciofluvial gravel, alluvium, and beach gravel are widespread throughout the mapped area; till and outwash gravel are by far the most abundant. The boundary of the till is not clear, for the till ranges in thickness from a few inches to at least 100 feet. In general, the thickness decreases with increasing altitude, except in upland valleys containing relatively young moraines. The till, moraines, glaciofluvial gravel, and partly reworked outwash gravel are classed as glacial deposits on the geologic map and are distinguished from alluvium and beach gravel. It is extremely difficult to separate glaciofluvial deposits, alluvium, and wave reworked till and outwash gravel, because much of the alluvium is composed of till with the rock-flour matrix removed, and almost all the present beaches are formed from till or glaciofluvial deposits that have been reworked by wave action and contain only small amounts of material eroded by waves from the underlying bedrock. Where till has been exposed to strong wave action, such as on the islands and shorelines at the head of Kasaan Bay, the fine matrix is removed entirely, and the striated and faceted cobbles are worn and rounded. As postglacial uplift has amounted to at least 50 feet, and possibly as much as 200 feet, all the till beneath this altitude has been exposed to the violent storms that sweep Kasaan Bay and has been reworked to varying degrees.

To further complicate the matter the reworked till on the islands at the head of Kasaan Bay is exposed to tides with a current as swift as many low-gradient rivers, giving rise to deposits that cannot be classified correctly as till, alluvium, or beach deposits.

In this report, unconsolidated deposits that obviously are reworked by water action not related to outwash streams are classed as alluvium or beach gravel, although it is recognized that much of the material is derived from till.

The contact between the unconsolidated deposits and the bedrock is arbitrarily drawn on the map where bedrock becomes so obscured by surficial deposits that the numbers of outcrops is not sufficient to establish even the general lithology of the underlying rocks.

GLACIAL DEPOSITS

OLDER MORAINES AND TILL

The oldest glacial deposits are represented by scattered glacial erratics and thin till that lie upon the highest mountains and the upland areas. Many of the erratics are quartz diorite and possibly were transported from the Coast Ranges to the east; however, many of the numerous plutons in the mapped area are quartz diorite, and these plutons could be the source of the quartz diorite erratics. One small area of older high-level till that is noticeably weathered is exposed in a small creek at an altitude of 750 feet, near the roof pendant in the pluton east of Lava Creek. It contains diorite cobbles that are badly weathered and chert and argillite cobbles that are weathered to a depth of one-quarter inch.

A short distance above the point where Lava Creek turns abruptly northwestward and cuts a small gorge in bedrock, till with partly indurated matrix is exposed in the creek banks and in the stream-beds. Similar till is also exposed at one point along the trail that follows the north shore of Salmon Lake. Thin till with noticeably weathered cobbles is exposed at scattered places in the gently sloping highlands in the extreme northwest part of the mapped area. The matrix of these older tills generally is weathered to very light gray to tan, whereas the matrix of the younger till is blue gray. The partly indurated and weathered tills are believed to be related to a period of continental glaciation that preceded a period of wide-spread valley glaciation after the retreat of the continental glaciers.

YOUNGER MORAINES AND TILL

Younger glacial deposits form a widespread mantle in the low-lands of the Thorne River valley and in the lowland area between Kina Cove and Little Coal Bay. The deposits in the Thorne River valley comprise till, glaciofluvial gravel that is in part reworked by the Thorne River, and local areas of blue lake clay. These deposits are but slightly weathered, and they contain cobbles of most of the rock types known in the mapped area. North of Angel Lake and in the Thorne River valley they contain a large amount of dioritic and aplitic igneous rocks and gneiss and a lesser amount of various types of volcanic rocks, graywacke, limestone, argillite, and chert.

The drumlinoids in and south of the Thorne River valley probably are bedrock knobs veneered to varying depths with till, for locally, at the extreme summit, bedrock can be found where glacial plucking has left a steep rock face. For the most part, however, these drumlinoids are completely mantled by till. They show that the major ice flow in the Thorne River valley was toward the south-east. Much of the ice belonged to a sheet extending far to the north and east, but some of it probably originated in the highlands west of the mapped area, for the long axes of the drumlinoids swing more to the west in the region adjacent to the northwest part of the mapped area.

At Coal Bay, stratified glaciofluvial gravel covers a marine till containing fragments of barnacles and small pelecypods. The top of the till is at an altitude of about 50 feet, and the stratified gravel above is at least 20 feet thick. The till contains a large amount of gray to black argillite cobbles, chert cobbles, and fewer cobbles of limestone, volcanic rocks, and diorite. The cobbles are faceted, striated, and grooved, and the rock types are those exposed along

Twelvemile Arm. Similar till is exposed at an altitude of 380 feet on the hill to the southeast, but no thick till was found higher. A mile to the east, at an altitude of 380 feet, bedrock is moderately well exposed and is not mantled by glacial deposits, but strong glacial grooves strike S. 30° E., and plucking pits indicate that the ice flowed southeastward.

Marine till containing shell fragments was observed in the lower valley of Maybeso Creek, which enters Hollis Anchorage from the north. A modified terminal moraine loops across the valley of Maybeso Creek about 1½ miles above Hollis. The moraine contains a high percentage of rock-flour matrix, and the poor drainage through the deposit has inhibited the growth of the evergreen forest in the valley. The poor stand of timber was recognized by foresters of the U.S. Forest Service and led them to seek the explanation, which was resolved when the terminal moraine was recognized.

Small glacial moraines containing till of local derivation are present along the upper valley of Lava Creek and in upper Falls Creek. Locally the creeks have cut through the moraines, exposing the underlying bedrock. These moraines are at least 100 feet thick in places, and they contain cobbles derived from local rocks, among which is pyritized rhyolite dike rock not found elsewhere in the mapped area. These moraines are fresh and completely unindurated, and striated and faceted cobbles and pebbles are common.

A small high-level moraine and gravel deposit of local derivation occurs at the head of Granite Creek. The moraine, which is relatively young as indicated by its position on a very steep slope, consists almost entirely of black argillite and diorite in a gray matrix of rock flour. Small creeks on the east side of Granite Creek have cut steep gulleys as much as 30 feet deep into the deposit without exposing bedrock.

The thick surficial deposits that form the islands at the head of Kasaan Bay contain cobbles of diverse rock types. The cobbles are as much as several feet long and are rounded. Cobbles of quartz diorite from the pluton in the southwestern part of the mapped area occur with cobbles of lava breccia that is common in the northwestern part of the mapped area. These thick deposits are believed to represent a reworked intermediate moraine deposited where a glacier flowing southeastward from the Thorne River valley met a glacier or glaciers flowing eastward or northeastward from the valley of Big Salmon Lake and Twelvemile Arm, respectively. These deposits, which have been reworked by the intense wave action of violent storms that blow up Kasaan Bay and by moderately strong tidal currents, are shown on the geologic map as beach gravel.

ALLUVIUM

Alluvial deposits exist where stream erosion has reworked glacial till, removing the rock-flour matrix and smaller particles and depositing the transported material in flat lowland areas and on tidal flats. Most of the material shown as alluvium on the geologic map is derived from glacial deposits; very little has been derived from stream-eroded bedrock, for most of the streams flow in courses covered with coarse cobbles left from eroded glacial deposits. The only important exception to this is the alluvium deposited by Granite Creek, which is building a delta into Little Salmon Lake. This alluvium is derived from an area of strong relief from which Granite Creek is actively removing talus, bedrock, and glacial deposits.

BEACH GRAVEL

Beach gravel in deposits large enough to be shown on the geologic map is restricted to the beaches at the head of Kasaan Bay and to a small island in the south entrance to Thorne Bay. These beach deposits consist for the most part of glacial and glaciofluvial deposits that have been reworked by wave action and locally by tidal currents. Their origin from glacial deposits is attested to by the lithologic similarity of the cobbles and boulders to those in nearby glacial deposits. The cobbles and pebbles, however, are rounded and unstriated, and the rock-flour matrix is removed, indicating considerable modification by wave action. It is probable that typical glacial deposits with rock-flour matrix could be found at shallow depth beneath many of the beaches, but their surficial shape and the shape of the boulders and cobbles is such that it seems best to show them on the geologic map as beach deposits.

INTRUSIVE ROCKS OF PRE-TERTIARY AGE

Intrusive rocks in the form of dikes, stocks, bosses, and batholiths intrude the bedded rocks of the mapped area and form a large part of the bedrock. They range in size from dikelets and small bosses less than a mile in diameter to batholiths that continue into adjacent areas, and they range in composition from olivine-bearing pyroxenite and gabbro to rhyolite and pitchstone. The igneous rocks exhibit considerable variation in structure and physical composition and in their effects upon the country rocks.

The larger intrusive bodies probably are satellitic bodies of the Coast Range batholiths to the east, and their chemical composition approaches diorite or quartz diorite similar to the Coast Range batholiths. The dikes, however, form a bewilderingly complex group of rocks that differ markedly in texture, orientation, and composition, and their sequence of intrusion has been deciphered only in part.

PLUTONIC ROCKS

Under the term "plutonic rocks," the writer groups all the larger bodies of intrusive rocks that form bosses, stocks, and batholiths. In this report, these intrusive bodies are called plutons. The plutons conform to the regional structure in only a general way. The large pluton of quartz diorite in the southwestern part of the quadrangle conforms very well to the strike of the enclosing rocks, but the gabbro-pyroxene body near Salt Chuck crosscuts the regional strike at a large angle, as do many of the plutons.

The plutons exhibit considerable variation with respect to their contacts, their effect upon the enclosing rocks, and their metamorphic aureoles. Considerable variation in texture and grain size also exists between plutons, yet each pluton is reasonably constant within itself. In view of the differences, each pluton more than one-half square mile in area is discussed separately below. Some of these plutons, notably the 2 at the head of Kasaan Bay and the 1 at the extreme southeast point of Tolstoi Bay, have been described previously by Wright (1915, p. 77) and Warner and others (1960) in the course of their investigations of the mineral deposits of Kasaan Bay and vicinity. In view of certain differences of opinion, these are discussed in more detail in this report.

PYROXENITE AND GABBRO

Pyroxenite and gabbro in large bodies are confined to the two plutons that crop out in the Salt Chuck (Goodro) mine area and at the head of Kasaan Bay.

Pluton in the Salt Chuck mine area.—The intrusive body in which the Salt Chuck mine lies ranges in composition from an olivine-bearing pyroxenite rich in augite and labradorite feldspar to a rock type that could be called diorite containing as much as 30 or 40 percent orthoclase feldspar that is replacing labradorite. Magnetite ranges from as much as 10 percent of the rock to as little as 2 percent, and a peculiar type of mica, resembling prochlorite, at places reaches a maximum size of several inches. Locally, the rock contains as much as 60 or 65 percent phenocrysts of calcic augite that reach a maximum size of 1.5 cm in an altered groundmass consisting of chlorite, epidote, zoisite, and prehnite. The distribution of the various phases is complex, and exposures within the body are not sufficient to establish their mutual relations and areal extent, although Gault (1945, p. 6) in his studies of the Salt Chuck mine came to the conclusion that the gabbro intrudes, and is younger than, the pyroxenite.

In thin sections of the more leucocratic facies studied, the potassium feldspar rims and replaces labradorite, and the texture suggests that the diorite is formed from the pyroxenite by addition of potassium feldspar. It also seems significant that at the northwest end of the pluton, irregular areas of diorite contain pyrite and epidote, which also suggests an origin by metasomatic replacement of pyroxenite. Generally speaking, however, the pyroxenite is more common than the gabbro, which is more common than the diorite.

This intrusive body is of economic interest, for confined within it are most of the prospects containing bornite and (or) palladium. One mine, the Salt Chuck, has produced more than 300,000 tons of ore containing copper and palladium. In addition to the prospects within the intrusive rock, one small vein containing bornite is found in altered conglomeratic volcanic graywacke, about 1 mile southwest of the Salt Chuck mine.

Because this pluton crops out throughout most of its length in an area of low relief that is thickly covered by trees and brush, exposures of the contact are rare. However, the pluton cuts across the strike of the enclosing rocks, and north of Power Lake the contact is sharp. The contact also is exposed in a small creek that drains North Lake into Lake No. 3, but here the pluton is diorite containing epidote and pyrite and rocks along the contact are altered.

The thermal metamorphic effects around the pluton are minor, for the clastic texture of the surrounding conglomeratic volcanic graywacke and volcanic graywacke is still discernible. In the vicinity of the Rush and Brown mine the pluton is diorite or gabbro and the two dikelike apophyses from it also are dioritic. No schist is developed near the contact of the pluton.

The only dike known to cut this pluton is the dike noted by Gault (1945, p. 5) in the Salt Chuck mine. The dike is altered, contains ore minerals, and is undoubtedly older than the ore body at the Salt Chuck mine.

Pluton at the head of Kasaan Bay.—The pluton that crops out at the head of Kasaan Bay is a complex rock of unusual texture. It ranges from very fine grained to coarse-grained gabbro cut by thin pegmatitic bands. The coarse-grained gabbro forms rounded masses isolated within, and cut by, the fine-grained gabbro. Locally, pegmatitic facies of plagioclase and pyroxene cut the rock and in places are cut by the fine-grained gabbro. Thin veinlets of quartz and plagioclase feldspar cut all the facies listed, and smaller dark veinlets. Magnetite is present in small amount throughout the rock.

In thin section both the coarse- and fine-grained facies of the rock are seen to consist of a mixture of plagioclase feldspar, some of which is sodic bytownite, and pyroxene that has an optic angle ranging from 32° to 48° and a beta index of refraction from 1.705 to 1.71. These optical properties determine the pyroxene to be augite, very close to ferroaugite in composition.

The actual contact of this pluton was not observed. The metamorphic aureole about the pluton must be restricted to a zone not more than a few tens of feet wide, for the enclosing rocks near the north, the northwest, and the southwest sides are not visibly affected.

Near its west margin the gabbro has been sheared and altered by solutions that deposited abundant pyrite and hematite. This alteration probably is related to the fault that follows the topographic linear that trends across the intrusive body into the valley of the Thorne River. No copper-bearing minerals were observed at any place in the gabbro.

This intrusive body is cut by a diorite porphyry dike, by several pyroxene porphyry dikes, and by diabase dikes, all of which in general trend northwestward or northward.

QUARTZ DIORITE AND RELATED ROCKS

PLUTONS

The other plutons shown on the geologic map range in composition from diorite to granite, but diorite or quartz diorite are the most common. The plutons of this composition not described by Warner and others (1960) are described in some detail in this report.

Pluton east of Lava Creek.—The pluton exposed east of Lava Creek is the south end of a batholith that extends northward for a distance of about 15 miles. Within the mapped area the pluton is notably complex in texture and composition, in its metamorphic effect on the enclosing rocks, and in internal structure. The pluton includes large quantities of what is best described as diorite gneiss, and also a large roof pendant of metasomatized clastic rocks. Metasomatism of all the contacting rocks is widespread, and much of the intrusive mass contain abundant introduced pink feldspar as grains and veinlets.

The pluton ranges in composition from diorite to sodic granite. The sodic granite occurs in small areas where the rocks have been modified by potassic metasomatism. The unaltered rock is hornblende diorite with faint gneissic banding and is best exposed in the beds of the creeks that flow northeastward toward Clarence Strait. In the higher hill that rises to an altitude of 1,400 feet to the west, the gneissic banding is much more noticeable. With increasing acidity the hornblende gives way in part to biotite, and in the most acid facies the dark minerals consist entirely of biotite and chlorite. The plagioclase feldspar of the diorite facies is calcic andesine, and the rock contains less than 5 percent alkalic feldspar. In the more alkalic facies the plagioclase is sodic oligoclase surrounded by large anhedral perthite crystals and a groundmass mozaic of albite and quartz. A few crystals of microcline occur in the alkalic facies. Magnetite or ilmenite is a common accessory mineral, and locally apatite is very common. The texture of the rock is variable, but normally the diorite is more gneissic and finer in grain size than the more acid facies in which the introduced potassium feldspar forms ragged porphyroblasts.

The bedded rocks surrounding this pluton are metasomatized, and in places large porphyroblasts and veinlets of pink orthoclase and albite are found. The potassium feldspar clearly is introduced into such rocks. Owing to the widespread introduction of feldspar into the surrounding rocks, and to the gneissic structure, the contact is gradational, at some places over a distance of several hundred feet. On the geologic map (pl. 33) the distribution of the contacting rocks affected by potassium metasomatism is shown by an overlay pattern. Along the southwest margin a little skarn is developed near the contact, and a zone of thermal metamorphism that has produced biotite schist from argillite, and hornblende gneiss from volcanic rocks, surrounds the body. Where volcanic graywacke or other clastic rocks border the pluton, the metasomatic and thermal aureole is widest, and gradational contacts are commonest. The west contact is beneath the glacial deposits east of Lava Creek, but the creek bed exposes innumerable dikes or apophyses of the pluton, and a large apophysis intrudes the andesitic flows west of Lava Creek. Similar conditions are seen in the bed of the creek flowing eastward from the east contact, except that in this area the rocks contain a high percentage of argillite and other fine-grained rocks, and these rocks are schistose and thermally metamorphosed to biotite and hornblende schist much farther from the contact than are the rocks along the west contact.

This pluton is cut by dikes of coarse-grained granite, trachytic rhyolite, and pitchstone, some of which are altered and contain abundant pyrite. A small magnetic anomaly lies near the skarn along the southwest margin, but only a very little magnetite was found at the surface in this area.

Pluton north of Salt Chuck.—The small pluton about a mile north of the pyroxenite at Salt Chuck is poorly exposed, but the most common facies is coarsely porphyritic quartz diorite with phenocysts of zoned plagioclase feldspar that reach a length of one-half inch. The phenocrysts form about 20 percent of the rock, and the groundmass consists of plagioclase, quartz, and minor orthoclase. Locally, especially along the southwest contact, the rock is altered and albitized and contains specks and minute veinlets of pyrite and chalcopyrite. A large dike identical in composition to this intrusive body crops out on the hill west of Thorne Bay.

Pluton in the southwest part of the mapped area.—The large pluton in the southwest part of the mapped area is remarkably homogeneous quartz diorite containing free quartz in amounts as great as 30 percent. The plagioclase is sodic andesine or calcic oligoclase, and potassium feldspar is completely lacking. The mafic minerals are chlorite and locally a very little hornblend. The texture is granitoid and the grain size is medium. The rock is slightly gneissic near the contact, which is sharp in most places.

The aureole of thermal metamorphism that surrounds the pluton is much more marked on the north margin, where the enclosing rocks dip gently northward, than on the south margin, where the contacting rocks dip steeply. Biotite is developed in the bedded rocks on the north side, and locally the diorite near the contact and the metamorphic rocks adjacent are heavily charged with pyrite and pyrrhotite. The volcanic graywacke and conglomeratic graywacke on the north contact near Twelvemile Arm are altered and metasomatized and locally resemble the diorite in texture.

The slate-argillite beds on the southwest border of the pluton are intricately folded, and the fold axes trend parallel to the strike of the contact. Cliff exposures in the steep divide leading from Granite Creek to the valley of Maybeso Creek near Hollis Anchorage show that the slate-argillite beds are faulted. Many of the faults dip into the pluton at low angles, and one small fault is a low-angle thrust fault. This complex structure may reflect the forceful intrusion of the pluton.

The pluton is cut only by irregular diabase dikes and by quartz veins containing gold and sulfide minerals.

Pluton on the east shore of Twelvemile Arm.—The pluton that crops out on the east shore of Twelvemile Arm is lithologically similar to that on the west side, and probably is part of it. A few small areas of skarn are associated with this eastern part of the pluton, and pyrrhotite with minor specks of pyrite is common in the biotite schist near the contact.

Pluton east of Baker Point.—The pluton exposed to the east at Baker Point is coarse-grained quartz diorite containing about 35 to 40 percent quartz, 50 to 60 percent andesine feldspar, and about 5 percent biotite. The rock is badly crushed, and locally it is albitized along joints and fractures. It is intruded by a great many diabasic dikes that in the vicinity of Baker Point are so numerous as to constitute a dike swarm. The pluton has sharp contacts, and on the south contact some magnetite in pods and thin beds replaces thin-bedded argillite.

Elsewhere within the quadrangle are small bodies of quartz diorite that attain a maximum width of a few hundred feet. Some are shown on the geologic map but are not discussed here.

CHEMICAL COMPOSITION

Three samples of typical quartz diorite and related rocks were analyzed chemically. The results and the norms calculated from these analyses according to the CIPW system are shown in the following table.

Chemical composition of quartz diorite, Craig C–2 quadrangle and vicinity

[Analysts: Samples 1–3, Paul L. D. Elmore, Katrine E. White, and Samuel D. Botts, U.S. Geological Survey; sample 4, F. E. and C. W. Wright (1908)]

	1	2	3	4
CIPW norm				
Quartz	3.60	7.980	24.186	--------
Orthoclase	6.12	18.348	6.672	--------
Albite	26.20	40.348	35.632	--------
Anorthite	26.69	15.969	19.792	--------
Diopside	11.26	--------	--------	--------
Hypersthene	18.31	6.684	4.453	--------
Ilmenite	1.82	.912	.730	--------
Magnetite	3.48	5.104	4.176	--------
Hematite	--------	--------	.800	--------
Calcite	.20	1.600	.600	--------
Apatite	.99	.654	.592	--------
Corundum	--------	.673	.228	--------
Total	100.07	99.672	99.261	--------
CIPW classification				
Class	II 1.74 Dosalic	II 5.5 Dosalic	I 7.50 Persalic	--------
Order	5 .06 Perfelic	3 1.07 Quarfelic	4 .39 Quardofelic	--------
Rang	4 .45 Docalcic	2 1.74 Domalkalic	3 1.23 Alkalicalcic	--------
Subrang	4 .32 Dosodic	4 .428 Dosodic	5 .183 Persodic	--------
Chemical composition				
SiO_2	52.8	58.4	64.2	61.0
Al_2O_3	15.9	17.7	17.4	17.5
Fe_2O_3	2.4	3.5	2.9	1.6
FeO	7.5	2.4	1.9	2.7
MgO	5.5	2.3	1.5	2.4
CaO	8.9	4.5	4.7	6.9
Na_2O	3.1	4.8	4.2	3.3
K_2O	1.0	3.1	1.1	2.3
TiO_2	.98	.52	.38	1.0
P_2O_5	.44	.34	.26	.30
MnO	.21	.12	.13	.10
H_2O	1.40	1.40	1.40	.90
CO_2	.10	.70	.28	--------
Total	100.23	99.78	100.35	100.00

1. Stock at Tolstoi Mountain at east end of the south shore of Tolstoi Bay; collected from island off Tolstoi Point, and along shore in small cove half a mile south; sp gr, 2.915; laboratory No. 147328.
2. Stock that forms south end of Kasaan Peninsula (not shown on geologic map); collected along half a mile of beach south of steep cliff due east of south tip of Kasaan Island; sp gr, 2.765; laboratory No. 177330.
3. Large stock in Twelvemile Arm; collected along beach from north end of small cove in center of stock to point north of cove at south end of stock, northwest shoreline; sp gr, 2.763, laboratory No. 147329.
4. The average chemical composition computed for seven specimens of quartz diorite from Ketchikan area, Alaska, by F. E. and C. W. Wright (1908).

In chemical composition and in modal and normative mineral composition these rocks belong to the quartz diorite family. Sample 1 is diorite and sample 3 is leucodiorite.

AGE

The three rocks analyzed were submitted for age determination by means of radiogenic-lead content. Only sample 1, from Tolstoi

Point, contained enough of the required accessory minerals for age determination in a sample of 100 pounds. Its age was determined as 100 million years, or roughly in the middle of the Cretaceous.

The plutonic rocks probably were intruded throughout most of the middle of the Cretaceous, if it is assumed that all the plutons of the quadrangle were intruded in the same general cycle of intrusive activity and that the most basic ones were intruded first, as the pluton at Tolstoi Point is one of the more basic of the plutons of intermediate composition. In addition, most of the plutons are cut by diabase dikes believed to be of Tertiary age; the gabbro pluton south of Salt Chuck is cut by at least two diorite porphyry dikes of the type that is believed by Warner and others (1960) to be related on Kasaan Peninsula to the stocks of intermediate composition, and the composite pluton in the north-central part of the quadrangle is cut by trachytic rhyolite dikes as well as by pitchstone dikes equivalent to those that cut the Tertiary conglomerate on Lava Creek.

DIKE ROCKS

PALEOZOIC DIKES

Owing to the extreme diversity of the dikes of the quadrangle, both mineralogically and texturally, and to the few exposures that reveal intrusive relations between various types of dikes, the writer has recognized only one type that he believes is definitely of Paleozoic age.

This Paleozoic intrusive rock is rhyolite that crops out over a large part of Kasaan Island and that intrudes, and in part is interbedded with, highly fossiliferous limestone of Middle Devonian age. Wright (1915, p. 70) describes these rocks as sandstone and conglomeratic sandstone interbedded with limestone. Buddington and Chapin (1929, p. 266) call these rocks platy rhyolite and include them with their Tertiary rocks. In 1955, the writer and G. D. Eberlein found good evidence that some of the rhyolite is contemporaneous with the limestone, for rhyolite fragments are very common in the limestone immediately above some of the larger rhyolite flows. No fossils are present in the limestone immediately above the flows, but the fossils gradually become more abundant higher up in the limestone, and within a foot may amount to 50 percent of the limestone, suggesting that the marine life was killed by the rhyolite, but was soon reestablished. This evidence is almost conclusive that the rhyolite is of Middle Devonian age.

The rhyolite is extremely platy because it has marked flow foliation. On the northeast side of Kasaan Island the platy structure bends around two pluglike masses of coarse-grained rhyolite that has no flow foliation, suggesting that these were centers of extrusion.

The microscope reveals several distinct textures ranging from extremely fine-grained to porphyritic. In some sections the rock contains corroded quartz phenocrysts with euhedral albite phenocrysts surrounded by albite and orthoclase microlites with trachytic texture; in others the phenocrysts are oligoclase feldspar or minor quartz in a nontrachytic groundmass of albite and orthoclase; and on the east side of the island, corroded garnets are the phenocrysts. In coarser grained parts the groundmass contains a little hornblende.

Thin diabase dikes cut the rhyolite, and locally they are faulted and folded into complex folds.

Two samples of the rhyolite were analyzed chemically, and the results are shown in the following table.

Chemical and normative composition of rhyolite, Kasaan Island

[Analysts: Paul L. D. Elmore, Katrine E. White, and Samuel D. Botts]

	1	2
CIPW norm		
Quartz	34.02	25.50
Orthoclase	21.24	16.68
Albite	38.152	44.54
Anorthite		
Diopside		
Hypersthene	.50	1.50
Ilmenite		.061
Magnetite	.464	1.972
Hematite	.40	.40
Calcite	.40	2.70
Apatite	.448	.616
Corundum	3.06	4.48
Total	99.76	99.45
CIPW classification		
Class	I 52.7 Persalic	I 20.3 Persalic
Order	4 .575 Quardofelic	4 .42 Quardofelic
Rang	1 Infinity Peralkalic	1 Infinity Peralkalic
Subrang	4 .548 Dosodic	4 .358 Dosodic
Chemical composition		
SiO_2	75.2	68.0
Al_2O_3	14.6	16.2
Fe_2O_3	.8	1.8
FeO	.16	.96
MgO	.18	.59
CaO	.22	1.8
Na_2O	4.5	5.3
K_2O	4.0	2.9
TiO_2	.01	.3
P_2O_5	.14	.32
MnO	.02	.08
H_2O	1.00	1.00
CO_2	.16	1.2
Total [1]	100.99	100.45

[1] Includes water.

1. From platy rhyolite from southwest side of Kasaan Island, west of entrance to small cove; sp gr, 2.420; laboratory No. 147802.
2. Composite of several samples from east side of Kasaan Island; sp gr, 2.445; laboratory No. 147803.

DIKES OF PALEOZOIC AND MESOZOIC AGE

Dikes that probably were injected during the epoch of the intrusion of the plutons are widespread in the mapped area. They range in thickness from a few inches to as much as 200 feet and in composition from gabbro to granite. They generally are more common near the plutons of felsic and intermediate composition, where their mineralogic composition is varied and in part controlled by metasomatic introduction of albite and orthoclase. Many are coarsely porphyritic, others are fine-grained, and all gradations exist between the two types. They range in color from brownish black and grayish olive green to pale or moderate red and grayish orange pink. Many exhibit marked flow foliation and chilled borders; others are unfoliated and have only slight marginal chilling. Some are deformed, and near the plutons most types are deformed or metasomatized at one place or another. At places they constitute dike swarms, which may form a large part of the bedrock. The dikes constitute a bewilderingly complex assemblage, and the relations among them can be deciphered only in part.

The grouping of these dikes in this report, which in part follows and in part differs widely from the grouping by Warner and others (1960) or Wright (1915, p. 77–84) is given below. This classification is based upon the mineralogic and textural relations that made possible in the field the grouping of certain of the dikes. Although in subsequent microscopic studies it was seen that the mineralogic and chemical compositions vary considerably within any one group, it seems advantageous, because there are so few chemical analyses, to retain this classification, for it permits a reasonable grouping which fits the field relations. Because the dikes are metasomatized to varying degrees near some of the plutons, a chemical classification of such dikes would be misleading.

Most of the dikes are not shown on the geologic map, for the following reasons:

1. The dikes are exposed best along steep shorelines, and a plot based on these exposures would give an unrealistic picture of the distributional density of the dikes.
2. The dikes seldom are traceable under the vegetal and surficial cover, and the attitude observed at any one place may not reflect the true attitude.
3. At places the dikes are so numerous as to constitute a high percentage of the bedrock, and even if these dikes were traceable, the scale of the map is such that it would be impossible to plot them.

In view of the above, it seems advisable to discuss the general distribution of the dikes rather than to attempt to plot them on the map. A few of the largest dikes are plotted where their size and extent are known and are commensurate with the map scale.

DIORITE PORPHYRY AND RELATED ROCKS

Feldspar porphyry.—Dikes of feldspar porphyry correspond in general to those described by Warner and others (1960) as diorite porphyry dikes. Their common feature is a coarsely porphyritic texture caused by plagioclase feldspar phenocrysts that may reach a length of one-half inch; flow foliation is distinct, and in some dikes it is very well marked. The dikes vary in thickness from a few inches to more than 200 feet. Most have sharp contacts and chilled borders. A few of the more irregular dikes near the margins of plutons have been altered and metasomatized, the contacting rocks resemble diorite, and the boundary between original dike rock and country rock is transitional. The strike is variable and seems to depend in part upon the association with certain plutons. In the vicinity of Tolstoi and Thorne Bays the dikes strike northeastward, on the shoreline of Kasaan Bay west of Kasaan Island many strike southward, and in the area south of Coal and Little Coal Bays the strike is varied but many strike northwestward.

The dikes are variable in length; the longest seen in good exposure are two that strike northeastward for about three-quarters of a mile along the shoreline from the east contact of the small quartz diorite pluton at the cove at the northeast end of Tolstoi Bay. Others in the mapped area probably are as continuous.

The dikes are most common in the area near Tolstoi and Thorne Bays and on the south shore of Kasaan Bay between Kasaan Island and Kina Cove, and Warner and others (1960) indicate that they are common on Kasaan Peninsula. Similar dikes have been found on the hill north of Rush Peak.

The microscope discloses that the composition of the dikes is complex. The feldspar of the phenocrysts normally is andesine but may range down to sodic oligoclase, particularly in those dikes in which the feldspar phenocrysts are small. Some contain minor quartz phenocrysts, and some contain corroded augite phenocrysts. The groundmass usually consists of quartz, orthoclase, hornblende, and plagioclase, all in various stages of alteration to chlorite, epidote, calcite, and sericite. Magnetite, often in amounts as much as 2 percent, is always an accessory mineral, and abundant leucoxene in the altered dikes suggests that the magnetite contained ilmenite.

Hornblende porphyry.—Dikes of hornblende porphyry are distinguishable from the other porphyry dikes because the phenocrysts usually are basaltic hornblende. Hornblende is a common constituent of the feldspar porphyry dike rocks, but in such dikes it always is pleochroic in shades of blue and green. The hornblende porphyry dikes in general are relatively dark and fine grained, and the prismatic hornblende phenocrysts may reach 7 mm in length. The dikes vary in thickness from a few inches to a maximum of about 6 feet, and the average thickness probably is about 4 feet. The dikes have chilled borders, and a faint lineation is seen in all hand specimens. The dikes vary considerably in strike and appear to have no regionally constant attitude. These dikes are most numerous in the area from Thorne Bay northward, but a few are found cutting the gabbro pluton south of Salt Chuck, where they are somewhat irregular in outline but strike northeastward and slightly west of north. None of these dikes have been traced, and their average length is not known.

The microscope discloses that the dikes are variable in composition and texture, but not as varied as the feldspar porphyry dikes. The groundmass may contain abundant orthoclase, in which case the hornblende is pleochroic in dark olive green and greenish brown; but normally it consists of intergrown oligoclase ranging into albite, quartz, and orthoclase, all in part altered to epidote, chlorite, calcite, and quartz. Some of these dikes contain a small proportion of augite phenocrysts. In composition the dikes probably range from diorite to monzonite. Magnetite is a ubiquitous accessory mineral and at some places it is very abundant.

Pyroxene porphyry.—Pyroxene porphyry dikes that closely resemble in color and texture some of the cobbles that are common in the conglomeratic volcanic graywacke are very numerous in the northeast part of the mapped area but are found sparingly elsewhere.

All the pyroxene porphyry dikes have certain features in common—all contain numerous stubby pyroxene phenocrysts, have chilled borders and are unfoliated, and are a somber gray-green color. Few of the dikes exceed a thickness of 7 feet, and most are less than 3 feet thick. The dikes are extremely erratic in orientation, both regionally and locally. They are most common in the area between Thorne and Tolstoi Bays, north of the entrance to Thorne Bay, on Berry Island, and on the shoreline south of the pluton at Baker Point. A few are albitized in areas far removed from the plutons, and some are metamorphosed to hornblende porphyry, especially in the area north of Forss Cove. The albitization and metamorphism suggest that these dikes are older than most of the other types of dikes, and their relative abundance in the tuff, volcanic graywacke, and conglomeratic volcanic graywacke that in the same area are almost free of other dikes suggests a genetic relationship to the volcanic rocks. No dikes of this type are known to cut any of the plutons. On weathered surfaces these dikes are almost in-distinguishable from the volcanic graywacke that contains euhedral augite crystals, and in the field there was little doubt that they were related to the Early Silurian volcanism. However, at two places these dikes were found cutting alkalic dikes and diorite porphyry, and therefore it appears doubtful that they should be assigned a Paleozoic age with certainty.

The microscope discloses that in some of these dikes pyroxene and hornblende phenocrysts are equally abundant, and that a few dikes contain a few plagioclase feldspar phenocrysts of smaller size. The pyroxene phenocrysts are augite that is close to ferroaugite in composition, having an optic angle near 53° and a beta index of refraction of 1.710. The groundmass consists of epidote, albite, chlorite, zoisite, calcite, and prehnite and resembles the matrix of the volcanic graywacke.

TRACHYTE AND RELATED ROCKS

Dikes of trachyte and related rocks are characterized by fine grain, marked trachytic texture, light-tan to reddish color, and a high content of albite in addition to the orthoclase. These dikes and irregular dikelike bodies probably are equivalent in part to similar rocks on Kasaan Peninsula, which are classed by Warner and others (1960) as alkalic granodiorite and alkalic dacite. The dikes and bodies are as much as several hundred feet in width. In color the dikes range from pale orange to light pale red. A marked flow structure is developed locally, and such foliated rocks are similar in texture and composition to the Middle Devonian rhyolite on Kasaan Island. A few are tabular and have sharp contacts, but some, such as those in the area west of Lava Creek near the two small lakes at the north end of the mapped area, crop out in irregular outline and include altered andesite and tuff. Two irregular bodies are exposed in the bed of Lava Creek below the apophysis from the pluton to the east. One forms the bedrock where exposed discontinuously in the creek for several hundred feet, but the shape of the mass is not determinable, for most of it is covered by gravel and till. Several tabular dikes as much as 12 feet thick occur in the southwestern part of the pluton east of Lava Creek. One is shattered and cut off by the fault on the west side of the room pendant in this pluton.

The trachyte dikes are the most numerous in the area north of the north arm of Thorne Bay, and they are the most numerous dikes in the pluton east of Lava Creek. None were found west of Kasaan Bay or in the Salt Chuck area. Their occurrence near Tertiary pitchstone dikes suggests that some of them may be of Tertiary age.

The microscope discloses that the phenocrysts, which are scattered and many of which are too small to discern megascopically, normally are albite or orthoclase, but quartz forms phenocrysts in subordinate amounts.

The length of the crystals of the groundmass ranges from 0.1 to 1.0 mm; in some, orthoclase forms the bulk of the groundmass, and albite is subordinate, and in others, albite is dominant over orthoclase. In a few, hornblende in small needles that are pleochroic to brilliant blue and blue green, suggesting a sodic amphibole, forms part of the groundmass.

SODIC RHYOLITE PORPHYRY, RHYOLITE, AND SODIC ANDESITE PORPHYRY

The dikes of sodic rhyolite porphyry, rhyolite, and sodic andesite porphyry are distinguished from the preceding group by the general absence of trachytic texture and the greater size and number of phenocrysts. Their chemical similarity and association with dikes of the previous group indicate that the two groups are closely allied. The dikes are thin, many have very gradation contacts with the enclosing rocks, and they range in color from light brownish gray to medium light gray. They are well exposed on the shoreline of Tolstoi and Thorne Bays and are very numerous in the metasomatized country rock on the shoreline west of the pluton at Tolstoi Point. Dikes of this composition are found at other places in the mapped area and are more abundant near the borders of the plutons. The southwest shore of Kasaan Bay opposite Kasaan Island has a great many pale-red dikes and irregular masses within the metasomatized zone shown on the geologic map (pl. 33), and similar effects are noted in the metasomatized zone on the north border of the pluton on Twelvemile Arm. Similar dikes and metasomatized rocks are common along the southwest shore of Kasaan Bay opposite Kasaan Island.

The microscope discloses that the groundmass of the dikes generallv is so fine grained that the rock looks almost glassy. The phenocrysts have a maximum length of 5 mm and may be quartz, albite, microline, or anorthoclase. The groundmass generally consists of minute laths of orthoclase and albite, the proportion of the two differing in different rocks. The dikes containing microcline phenocrysts are confined to the area east of Kina Cove; these dikes are a light olive green, and their color, microcline phenocrysts, and spatial distribution indicate that they probably are not genetically related to those in the northeast part of the quadrangle.

The feldspar phenocrysts in some of the sodic andesite porphyry dikes are of special interest. The feldspar is pink and on first examination was thought to be orthoclase. However, it was found that these phenocrysts would not take a potassium cobalt nitrite stain. Subsequent examination with the universal stage showed that the optic angle (—) of the phenocrysts consistently averaged between 52° and 58°. A sample of the phenocrysts gave an X-ray powder defraction curve corresponding to albite that seems to be a mixture of low- and high-temperature albite (Tuttle and Bowen, 1950, p. 574). The optic angle is reasonably consistent with data of Tuttle and Bowen (1950, p. 574) for high-temperature albite. However, the feldspar could be anorthoclase insofar as the optical data are concerned. The spatial relation of the dikes with areas of alkalic metasomatism of the enclosing rocks seems significant, but it is not possible to state whether the sodic dikes are responsible for the abundance of alkalic feldspar, or whether the dikes are sodic because they have been subjected to alkalic metasomatism connected with the plutons. Both processes seem necessary to explain the field relations between dikes and the irregularly metasomatized rocks near the plutons.

SODIC GRANITE, MONZONITE, AND QUARTZ PEGMATITE

Coarse-grained dikes of sodic granite and monzonite are restricted to the area in and near the pluton east of Lava Creek, where they are exposed best in the bed of Lava Creek along the west margin of the pluton. Many cut the pluton. The dikes attain a maximum thickness of 150 feet, and many have gradational contacts with the bordering gneiss and schist. The trend of the dikes is variable. They range from grayish pink to very light gray. The texture also is variable, ranging from coarse-grained, granitoid to porphyritic in which the phenocrysts are orthoclase, albite, antiperthite, or oligoclase, the orthoclase and albite enclosing and rimming other grains. The groundmass consists of interlocking quartz, albite, oliglocase, and orthoclase. Myrmekitic intergrowths of quartz and feldspar are common. Magnetite is a constant accessory mineral, and in some of the dikes amounts to more than 1 percent of the rock. In some specimens apatite is relatively abundant. The orthoclase content ranges from about 30 to 50 percent, and albite ranges from about 10 to 30 percent. The mafic constitutents are hornblende and biotite, which seldom exceed 10 percent of the rock.

The texture of the alkalic granite and monzonite dikes, and their occurrence in rocks containing an abundance of introduced pink feldspar, lead to the conclusion that many of these dikes were modified by metasomatic replacement by orthoclase and albite of the plagioclase feldspar in older dikes of dioritic composition. As noted before, much of the diorite of the pluton in this area has been metasomatized and converted to monzonite and granite.

The quartz pegmatite dikes are confined entirely to the vicinity of the pluton in the southwestern part of the quadrangle. The biggest occur on the east side of Twelvemile Arm in the vicinity of the quartz diorite pluton. They range in thickness from a few inches to 8 feet, and the longest one has been traced for about 900 feet. Their texture is coarse grained and pegmatitic, and they consist almost entirely of quartz and oligoclase feldspar with a little biotite. Micrographic intergrowths of quartz and oligoclase are common. Some contain pyrite and magnetite, and such dikes probably are transitional between quartz pegmatite and the quartz veins found in the same area. One quartz pegmatite dike is intensely folded, suggesting that it is older than the pluton in the southwestern part of the quadrangle.

CROSSCUTTING RELATIONS

In order to illustrate the complexity of the age relations of the dikes, a few of the observed crosscutting relations are listed below. The station numbers are those on the original field map, which is in the collection of the Geological Survey.

1. Station 273, in diorite pluton at a point about one-half mile west of Tolstoi Point, south shore of Tolstoi Bay: Diorite is cut by a dike, 2 feet thick, of pink fine-grained sodic rhyolite. A dark diorite porphyry dike cuts the pink dikelets associated with the pink dike. Nearby a diorite porphyry dike with feldspar phenocrysts cuts pink dikelets. The pink dike is much jointed, the other dikes are not.
2. Station 291, near center of north shore of Tolstoi Bay: A thick coarse-grained diabase dike is cut by a smaller diabase dike almost identical in hand specimen, except for its finer grain.
3. Station 305, about midway on south shore in south entrance to Thorne Bay: A gray diorite porphyry dike is cut by a dark-green diorite porphyry dike, and to the west a light-gray diorite dike. The dark-green diorite dikes display chilled borders against the light-gray dikes.
4. Station 309, southeast tip of large island in entrance to Thorne Bay: A diorite porphyry dike with feldspar phenocrysts is cut by a pink fine-grained sodic rhyolite dike. Both dikes are cut by a dark pyroxene porphyry dike. A fine-grained gray andesite dike nearby cuts none of these dikes, but it contains xenoliths of the diorite porphyry.

   On the east shore of the same island, a dark-green pyroxene porphyry dike is cut by a diorite porphyry dike with feldspar phenocrysts.

   On the northeast shore of the island a light-colored andesite porphyry dike with feldspar phenocrysts is cut by a dark-green pyroxene porphyry dike. Several diabase dikes cut the diorite porphyry.

5. Station 385, small island close by shore near northwest head of Thorne Bay: A diorite porphyry dike with large feldspar phenocrysts is cut by a hornblende porphyry dike, and both are cut by a dike of fine-grained basalt which probably is diabase. These dikes are not altered or deformed, but nearby a fine-grained red sodic rhyolite porphyry dike is badly mashed, broken, and crushed, and it obviously is older.
6. Station 91, west shore of Kasaan Bay opposite south end of Kasaan Island: Coarse-grained quartz diorite locally cuts and locally is cut by dark fine-grained basalt dikes.

The foregoing descriptions are sufficient to show that the sodic rhyolite is cut by many types of dikes and that complex crosscutting relations are common among all dikes except the diabase, which cuts all types listed. It is inferred that dikes of similar texture and composition probably were injected at different times from separate magma chambers, and that the more felsic dikes cannot be considered as end members in a regional dike sequence in which basic dikes were intruder first, followed by the sodic rhyolite and andesite.

INTRUSIVE ROCKS OF TERTIARY AGE

The intrusive rocks considered to be of Tertiary age consist only of dikes of diabase and pitchstone, but possibly some of the sodic dikes cutting the rocks in and west of the pluton east of Lava Creek may be Tertiary in age. The diabase dikes are widespread throughout the quadrangle, but the pitchstone dikes are confined to the north-central part. The relatives ages of the two types of dikes have not been established, but the pitchstone dikes cut the Tertiary conglomerate on Lava Creek, indicating that they may be the younger.

DIABASE

The diabase dikes range in width from a few feet to as much as 100 feet, but the average width is probably about 10 feet. The dikes are relatively fresh and were intruded in large part along the direction of the strong joints, which trend northeastward in the bedded rocks. They are very common in the joints in the pluton near Twelvemile Arm, where on the high slopes bare of vegetation the dark diabase stands out in sharp contrast to the light-colored quartz diorite. Several very large diabase dikes are exposed on the north shore of Tolstoi Bay and on the islands at the entrance to Thorne Bay. They seem to be particularly abundant in the area between Loon Lake and Power Lake. A very large body of diabase midway along the north shore of Tolstoi Bay strikes northward and is shown on the geologic map (pl. 33). Another very large dike of irregular form crops out on the steep north slope of Granite Mountain and is also shown on the geologic map. Many of the gold lode deposits in this pluton lie along the contacts of diabase dikes. The diabase is a fine- to medium-grained dark rock that is distinctly heavy in hand specimen, owing to the high content of magnetite. The texture is ophitic in dikes containing a high percentage of pyroxene, but it approaches trachytic in fine-grained dikes showing flow structure. The dikes invariably have chilled borders.

The microscope discloses that the mineral composition of the diabase is somewhat variable, the most abundant type consists of augite, ferroaugite or titaniferous augite, and labradorite feldspar in highly zoned crystals. In one dike, olivine constitutes about 12 percent of the rock, and in some, hornblende constitutes several percent. Biotite is rare, and the common accessory minerals are magnetite, apatite, and pyrite. Alteration products consist only of chlorite formed at the expense of hornblende or pyroxene.

PITCHSTONE

The pitchstone dikes are rare, and few of those seen exceed a thickness of 10 feet. They are confined entirely to the extreme north end of the mapped area. Some are associated with faults and some form pitchstone-cemented breccia along faults. At one place, pitchstone and sodic rhyolite dikes are intimately associated in a small fault, suggesting that the two are of the same age.

The pitchstone dikes are so completely glassy that only a few minute crystals, of plagioclase feldspar, are seen in thin section. Minute needlelike crystallites show up under crossed nicols and show that the pitchstone has flow structure. The index of refraction of the glass is about 1.48, suggesting that the pitchstone is rhyolite. The pitchstone dikes are important because they have been brecciated in places by faults that contain abundant pyrite and a little chalcopyrite, which proves some Tertiary metallization in this area.

GLACIAL HISTORY AND POSTGLACIAL UPLIFT

The major geomorphic features of the quadrangle probably existed before Pleistocene glaciation, which merely modified the shape of the mountains and disrupted the drainage to some degree. As noted in the discussion of unconsolidated deposits two distinct types of glacial deposits are recognized and are referred to as older and younger deposits. The time relation of these deposits to major glacial advances cannot be asserted definitely, but at least two distinct glacial advances are indicated. At the height of glaciation, the entire mountain mass of Kasaan Peninsula was overridden by ice (Wright, 1915, p. 66; Warner and others (1960)). At this stage of glaciation, the highest mountains in the mapped area, with the possible exception of Granite Mountain, were buried beneath the ice, but some of the mountain to the west, which exceed 3,300 feet in height, may have stood as nunataks above the ice level. It is not known if ice ever flowed southward over the island from continental glaciers originating in the Coast Ranges to the east or whether it flowed radially outward from an ice center in the highlands west of the mapped area, but the general southeastward trend of ridges, valleys, roches moutonnées, and lakes suggests that most of the existing glacial sculpture was accomplished by ice moving eastward and southeastward from the highlands west of the mapped area and outward in all directions from cirques on the higher peaks on Kasaan Peninsula. As the maximum height of these highlands to the west is about 4,000 feet, and the highest glaciated mountains on Kasaan Peninsula are 2,800 feet high, it seems unlikely that ice flowed eastward and completely buried Kasaan Peninsula unless the highlands were buried deeply under the ice. However, if the ice was sufficiently thick, it is possible that at such a time the continental glaciers from the Coast Ranges would have advanced westward in such thickness as to force a general movement of ice westward over much of the lowland areas of Prince of Wales Island. An alternate hypothesis is that even at the height of Pleistocene glaciation a separate ice center coincided with the highlands west of the mapped area, and that ice flowed outward and met the ice from the Coast Ranges east of the mapped area. Probably the latter interpretation is the more likely of the two.

Following (and undoubtedly also preceding) the widespread glaciation discussed above was a period in which valley glaciers flowed radially outward from the highlands west of the mapped area, continuing the formation of horns, serrate ridges, and U-shaped valleys heading in cirques now occupied by tarns. Roches moutonnées, glacial striations, and plucking pits well preserved even at tide level show beyond any doubt that during this glaciation ice moved generally eastward until it reached and partly filled the existing valleys now occupied by salt water. Roches moutonnées related to this stage of glaciation are found at an altitude of 380 feet southwest of Baker Point, which indicates that ice probably filled Kasaan Bay. Moraines that are believed to represent time intervals within this general glacial stage are found at Kina Cove and in the Thorne River valley, and the extensive deposits on the islands at the head of Kasaan Bay are reworked moraines of this same stage. As noted before, the course of the Thorne River probably was changed by moraines related to this glacial stage. During this time, cirques in mountains that in places did not exceed 2,600 feet in height were occupied by ice in the area north and west of the quadrangle. Jacobs

Mountain on Kasaan Peninsula, which reaches an altitude of 2,370 feet, is a broad horn between 3 large cirques, 2 of which are occupied by cirque lakes. The large moraine in the valley of the Thorne River was formed by coalescing glaciers from highlands to the west and by smaller glaciers heading in lower hills north and west of the mapped area.

No glaciers exist today on Prince of Wales Island, but perennial snowbanks exist in the highlands. The last glaciers probably disappeared not more than a few hundred years ago; the presence of high-level till of local derivation on the steep slope at the head of Granite Creek supports this conclusion. The ridge at an altitude of 3,200 feet between the 2 peaks of Granite Mountain is an arête with large joint blocks of granite sapped apart and sitting one atop the other. If the Thorne River was forced into a new channel by glacial deposits formed in the period of valley glaciation, as postulated here, the time since this glacial stage was sufficient to enable the Thorne River to cut a narrow canyon at least 80 to 100 feet deep in bedrock west of the mouth of Falls Creek.

Marine till with shell fragments was found at an altitude of about 50 feet above high-tide level in the stream at Little Coal Bay, and very similar till, but without shells, was found at an altitude of almost 200 feet in the valley of Maybeso Creek, just west of the south end of the mapped area. Marine till with shell fragments is found above high-tide level at the mouth of the small stream that flows northeastward into Clarence Strait from Salamander Lake.

The islands at the head of Kasaan Bay reach a height of at least 100 feet and are made entirely of reworked till or outwash. Wright (1915, p. 66) recognized various levels of erosion on Kasaan Peninsula, at altitudes between 100 and 150 feet, between 250 and 300 feet, at 500 feet, between 1,100 and 1,300 feet, and at 1,850 feet. In the present investigation not all of these levels were recognized elsewhere in the quadrangle, but postglacial uplift is proved by the raised marine till and by the fact that near their mouths most of the streams flow on, or expose, bedrock, whereas at altitudes ranging roughly from 50 to 100 feet they flow on alluvium and till or reworked till. Thus, postglacial uplift amounts to at least 50 feet and may amount to 200 feet or more.

ECONOMIC GEOLOGY

The regional distribution, mineralogy, mineral paragenesis, classification, and origin of the ore deposits on Kasaan Peninsula and northwestward to the Rush and Brown mine are discussed in detail by Wright (1915, p. 85–108) and by Warner and others (1960). Individual deposits are discussed in detail by these writers, and the

Salt Chuck (Goodro) mine is discussed by Gault (1945). No useful purpose would be served by repeating here their lengthy descriptions. The purpose of the present investigation was to attempt to apply the factual data developed by previous work in a search for additional areas where copper or magnetite ore might be expected, to establish the regional geologic relations among lithologic units, to interpret the geologic structure, and to gain additional data on the genesis of the different types of ore within the quadrangle. These objectives were achieved with varying degrees of success, as illustrated in part in the foregoing pages.

Only those prospects or areas of possible economic interest not discussed by previous writers are described in this paper. Conclusions and contributions that support or go beyond those expressed by earlier writers are also presented.

PRE-TERTIARY COPPER-MAGNETITE DEPOSITS NOT PREVIOUSLY DESCRIBED

A few previously undescribed prospects and areas that contain ore minerals were found in the mapped area, but surface exposures do not indicate that any are large enough or rich enough to be of immediate economic interest.

MAGNETITE SOUTH OF BAKER POINT

Banded magnetite ore is found on the south side of the small cove on the south contact of the pluton at Baker Point. The magnetite forms thin pods and lenses as much as several inches thick in banded chert and argillite intercalated in an altered pyroxene-bearing rock that could be a dike or a flow. To the south is deformed limestone, and the banded chert and argillite are in part calcareous. The absence of either skarn rock or massive hornblende, which generally are associated with the larger deposits elsewhere, indicates that this deposit is small and of little economic interest.

At an altitude of 120 feet, near the south contact of the same pluton, a prospect tunnel, now partly caved, was driven at least 50 feet S. 20° W. along a joint in altered volcanic graywacke. The dump discloses pyritized greenstone, with specks of magnetite, that is cut by epidote veinlets. No copper minerals were observed. The absence of skarn and hornblende rock indicates that the prospect is of little economic significance.

CHALCOPYRITE NEAR KINA COVE

Chalcopyrite disseminated in a recrystallized limestone bed is exposed in the creek bottom on the west side of Kina Creek at an altitude of 40 feet. The chalcopyrite is the only ore mineral, and it forms about 2 percent of the bed, which ranges from 4 to 6 feet in thickness. Beds above and below the limestone contain no chalcopyrite, and the length of the metallized bed is unknown, for its westward extension is buried under creek gravel. No chalcopyrite was found in the bed on the east cutbank of the creek, where bedrock is well exposed.

In 1954, workmen from the logging camp at Kina Cove blasted a bedrock knob uncovered in the process of bulldozing for a logging road just above the beach. The blast unearthed recrystallized limestone containing as much as 5 percent chalcopyrite in selected specimens. The extent of the metallized limestone could not be determined, owing to the glacial deposits and thick vegetation.

On the west side of the small peninsula between Kina Cove and Twelvemile Arm, the rocks on the south contact of the quartz diorite contain pyrite and pyrrhotite and locally consist of skarn composed of garnet and diopside. Chalcopyrite is disseminated in a quartz vein 6 inches wide that cuts the skarn. Elsewhere in this general area are small quartz veins and veinlets containing pyrrhotite and pyrite and occasional specks of chacopyrite. Locally, the country rock, which here is metamorphosed to quartz-mica schist, contains as much as 5 percent pyrrhotite. No magnetite was observed.

NORTH CONTACT OF PLUTON WEST OF TWELVEMILE ARM

Sulfide minerals are disseminated irregularly in the bedded rocks along the entire north contact of the quartz diorite of the pluton west of Twelvemile Arm. Locally the sulfide minerals constitute several percent of the rock, and at many places they form small lenticular pods and veinlets. The minerals include pyrrhotite, pyrite, and at places a little chalcopyrite. At the east end of Salmon Lake, the quartz diorite and the contacting schist contain more than the usual amount of disseminated sulfide minerals. The sulfide minerals in places constitute as much as 5 percent, by volume, of the rock along the contact in a zone several hundred feet wide that includes at least 150 feet of the intrusive mass. Small veinlets of quartz, containing pyrite, pyrrhotite, and occasional specks of chalcopyrite, and pyrite veinlets are common in the schist exposed in the bed of the small creek flowing into Salmon Lake at the outlet, and along the trail to the west. A few of these small veinlets contain some galena and marmatite, and a sample from 1 quartz veinlet 2 inches wide contains 2 grains of scheelite.

A chip sample was taken across 300 feet of sulfide-bearing quartz diorite and schist, at right angles to the contact, at the outlet on the south shore of Salmon Lake. The sample was analyzed quantitatively for gold, silver, and copper, and part of the panned concentrate was analyzed qualitatively spectroscopically to detect minor amounts of other elements of economic interest. The analysis showed no gold or silver and only 0.02 percent copper. The spectrographic analysis disclosed no elements of economic interest in more than trace amounts.

PROSPECT ON NORTH BRANCH OF PAUL YOUNG CREEK

Several pits and opencuts mark an old prospect on the slopes of the small creek that flows southward into Paul Young Creek. Although the prospect is in the general area of one previously described as the Venus prospect (Wright, 1945, p. 100), it is described briefly here because the geologic occurrence is unlike that of the Venus prospect. The location of the pits is shown on the geologic map (pl. 33).

The prospect is at an altitude of about 170 feet and consists of several trenches, over a distance of about 350 feet, aligned along the creek and the fault followed by the creek. The southernmost pit, sunk in pyritized argillite heavily stained with iron, discloses pyrite and chalcopyrite in seams and replacement quartz veins, the most continuous of which strike N. 40° E. and dip 85° NW. along a joint in the argillite. Pyrite and chalcopyrite form solid layers ranging from ⅛ to ¼ inch in thickness. One fault plane observed strikes N. 50° W. and dips 75° SW.

About 40 feet upstream, an opencut 75 feet long and trending N. 55° E. discloses black argillite containing disseminated pyrite and chalcopyrite and small sulfide veinlets striking along the cut. The dump contains fragments of calcite containing sulfide minerals.

The third cut, 200 feet upstream, discloses pyritiferous calcite veins that reach a maximum thickness of 6 inches and follow joints in black argillite. In the face of the opencut is a small fault that strikes N. 20° E. and dips vertically. Both walls of the fault are argillite of similar appearance, which indicates that displacement on the fault is minor.

The wallrocks along the great fault that continues northwestward and northeastward from the prospect pits are broken and pyritized, indicating that the ore minerals at this prospect may be part of a larger zone of sulfide-bearing rock related to hydrothermal solutions that rose along the fault.

PROSPECTS ON NORTH POLE HILL

During the summers of 1954 and 1955 Juan Muñoz, a mining geologist prospecting near Salt Chuck, completed magnetic and geochemical exploration at several points on North Pole Hill. Small pits were sunk to bedrock in two areas where the concentration of copper in soil samples was encouraging. In each pit bornite was found in the bedrock, which is pyroxenite or gabbro of the large pluton containing the ore body of the Salt Chuck (Goodro) mine about 2 miles east. East of the pits exposing bornite, Mr. Muñoz has made a shallow opencut that exposes several veins ranging from 6 to 18 inches in width and containing pyrite and quartz. The veins are said by Mr. Muñoz to assay about $7 in gold per ton. No copper minerals are associated with the pyrite. These veins are near a fault locally known as Murphy's Slip that can be traced from the Rush and Brown mine.

Elsewhere on North Pole Hill, Mr. Muñoz found bornite in gabbro or pyroxenite. He also found magnetic and geochemical anomalies, many of which are associated with intersections of small linears that are assumed to be faults.

The prospects on North Pole Hill are of interest because they are similar in mineralogy and geologic setting to the Salt Chuck (Goodro) mine, which produced more than 300,000 tons of ore containing copper and palladium.

OTHER AREAS OF INTEREST

The diorite porphyry that forms a complex pluton about 1 mile northeast of Lake No. 3, near Salt Chuck, is altered and pyritized near many parts of the contact, especially along the south margin. In some hand specimens chalcopyrite is visible, but it does not exceed 1 percent of the rock. As vegetation is thick in this area, discovery of deposits of economic interest would require detailed prospecting, supplemented by digging of shallow pits to test the metallized areas.

The bedrock at many places is bleached, pyritized, and silicified along the fault zone that extends northwestward from Kasaan Bay to the Thorne River. Most of this area is very low and is covered by thick brush, muskeg, and glacial deposits. It is possible that detailed prospecting of this zone might reveal deposits of economic interest, but prospecting would require geophysical methods supplemented by pits and trenches.

A magnetic anomaly is associated with skarn on the southwest contact of the pluton east of Lava Creek. The anomaly lies on the east shore of the small lake on the fault zone that strikes northward from the head of Thorne Bay. The area of skarn is small, and the country rock consists of altered flows and volcanic graywacke; elsewhere in the area this is not a good host rock for copper-magnetite deposits. The location of the skarn and the anomaly in a strong fault zone near an igneous contact is of interest. Bedrock in this area is covered with peat, muskeg, and till, and prospecting would be difficult. Dip-needle readings taken in a line trending about N. 20° E. from the southwest end of the lake to the contact of the pluton indicate that the vertical magnetic intensity is greatest for a distance of 600 feet from a point about 30 feet northeast of the lake. The vertical magnetic intensity lessens appreciably over the pluton and southwest of the lake.

At many places in the mapped area are small areas of bedrock that are bleached and pyritized; many of them contain disseminated magnetite and chalcopyrite. Many of these areas are along shear zones or faults, but none has proved to be of economic interest. In the aggregate, however, they show that deposition of copper and iron minerals has been widespread in large parts of the quadrangle.

TERTIARY DEPOSITS

GOLD QUARTZ VEINS NEAR GRANITE CREEK

The gold quartz veins in the southeast part of the mapped area have been described by F. E. and C. W. Wright (1908, p. 164). Several small mines on similar lodes were developed in the area north and west of Hollis Anchorage, but the Flagstaff mine is the only one established on lodes within the mapped area. This mine is described by Twenhofel, Reed, and Gates (1949, p. 10–13); and their descriptions of these deposits are not repeated here. The location of the other old prospects found in the mapped area by the writer are shown on the geologic map (pl. 33). All the prospects are located on quartz veins ranging in strike from N. 20° W. to N. 50° W., and all dip northeastward. The veins range from 2 to 5 feet in thickness, and many are along the contacts of diabase dikes believed to be of Tertiary age. The ore minerals are pyrite, subordinate chalcopyrite and galena, and gold. On the southeast side of the divide between Granite Creek and the valley of Maybeso Creek, the veins are in black slate and argillite. The mineralogy is similar to that of the veins in the quartz diorite.

The average gold content of the gold quartz veins has not been determined. The Flagstaff vein is discussed by Twenhofel, Reed, and Gates who say, "The value of the ore is reported by the operators to average about $12 per ton, but recovery as indicated by production returns is considerably less."

The vein near the contact on the south slope of Granite Mountain has a zone about 4 inches thick on the hanging wall that contains visible grains of gold. Two chip samples of the vein east of the divide between Granite and Maybeso Creeks contained only a trace of silver and 0.03 ounce of gold per ton.

TERTIARY PYRITE-CHALCOPYRITE VEINS NEAR PLUTON EAST OF LAVA CREEK

Tertiary veins believed to be younger than those near Granite Mountain were found at several places in the north-central part of the quadrangle and in the area immediately north. The veins, or lodes, are variable in physical structure, but all are characterized by pyrite as the dominant sulfide. Chalcopyrite is associated with pyrite in some, especially where carbonate minerals form part of the gangue. The lodes consist of altered, bleached, and pyritized fault zones, along some of which are intruded trachyte and pitchstone dikes, or of pyritized breccia cemented by pitchstone. Near some of the lodes, introduced fine-grained silica has formed a chertlike rock that transgresses other rock types. Because no metallic minerals other than pyrite and occasional specks of chalcopyrite were observed in any of the lodes, they are assumed to be of little economic value, at least in the area mapped, although they were not studied in detail.

CONCLUSIONS

REGIONAL DISTRIBUTION OF ORES

The present study supports the conclusion that most of the copper-magnetite bodies of economic interest in the mapped area appear to be limited to the area near and in the pyroxenite intrusive body near Salt Chuck, and to the area along the south shore of Kasaan Bay from Twelvemile Arm to a point south of Baker Point. The peninsula between Thorne and Tolstoi Bays and the large area north of Thorne Bay are singularly lacking in metallized areas, except for the Tertiary pyrite metallization noted previously. Rush Peak also appears to be barren of deposits.

The structural localization of ore deposits throughout the mapped area is in general conformity with the ideas expressed by Warner and others (1960). The deposits containing a high percentage of magnetite show close spatial relationship to igneous rocks, and many sulfide-rich deposits with little magnetite are localized along igneous rocks. Calcareous sedimentary rocks were replaced in preference to pure limestone, and most of the ore deposits containing magnetite are associated with skarn. However, disseminated ore minerals are found in fault zones without associated skarn or magnetite.

Pyrite and pyrrhotite are common near plutons where dark argillaceous and cherty rocks are thermally metamorphosed. The scarcity of chalcopyrite in such rocks, and the absence of hydrothermal alteration, suggests that the sulfide minerals were formed by the addition of sulfur to iron-bearing minerals that were already in these rocks before their metamorphism.

Quartz veins are relatively rare except in and near the pluton in the southwestern part of the quadrangle, but these gold-bearing quartz veins, which have been described by F. E. and C. W. Wright (1908, p. 158–168), are of Tertiary age and are not allied with the copper-magnetite deposits. The pyritized Tertiary dikes in the north-central part of the quadrangle also represent a distinct type of metallization.

PERIODS OF ORE DEPOSITION

Three distinct periods of metallization were recognized in the present study, each with characteristic ore and gangue minerals. The oldest is that which produced the copper-magnetite deposits, and deposition of which probably was confined to the Late Cretaceous epoch. The Salt Chuck mine, which contains bornite as the principal ore mineral and platinum-group metals in small amounts, seems to represent a unique type of ore within the district. It is highly unlikely that bodies of similar mineralogy will be found beyond the borders of the pyroxenite-gabbro pluton.

The next oldest period of ore deposition produced the gold quartz veins, of which those in the southwest part of the mapped area are a small part. These veins are younger than the diabase dikes of probable early Tertiary age.

The most recent period of ore deposition is that which produced the pyrite-bearing fault zones in the north-central part of the mapped area. These deposits contain only a little chalcopyrite. This period of ore deposition definitely is later than the pitchstone dikes with which the deposits are closely related. The pitchstone dikes are younger than the Tertiary conglomerate on Lava Creek. This last period of ore deposition has not been recognized previously, and its areal distribution and economic potential are unknown.

The question of the relative ages of the two periods of ore deposits of Tertiary age cannot be resolved with certainty. A younger age is assigned to those associated with the pitchstone dikes only on the evidence that diabase dikes are not known to cut the bedded rocks assigned to the Tertiary, whereas the pitchstone dikes do.

ORIGIN OF MAGNETITE-CHALCOPYRITE ORES

The genetic relation of the deposits of magnetite-chalcopyrite ore to the plutons was pointed out by Wright (1915, p. 67). Warner and others (1960) suggest that the ores show a rough zonal arrangement with respect to the late granodiorite intrusive bodies, such as that at Tolstoi Mountain, and that the ore bodies lie in a belt trending northwestward from the Mount Andrew mine to the Salt Chuck mine, parallel to the topographic depression that extends into the Thorne River valley. The present writer found by chemical analysis that the intrusive rock at Tolstoi Mountain is the most mafic of the three plutons sampled and believes that the high content of orthoclase and albite of the rocks from this pluton described by Warner and others (1960) is a result of alkalic metasomatism, such as is very common about the pluton east of Lava Creek.

The pluton west of Twelvemile Arm is the most silicic of those analyzed chemically, and it is intruded into a thick sequence of rocks containing a high percentage of argillite, chert, and slate. However, no deposits of copper or magnetite of economic interest are found near this pluton. This apparently conflicts with the explanation given by Warner and others (1960) and is, therefore, further explained below.

Petrologically, the rocks of the Craig C–2 quadrangle are characterized by the ubiquitous occurrence of abundant free magnetite and of pyroxenes that tend to lie in the augite field described by Hess (1941), near the ferroaugite field. Almost every thin section of the bedded or dioritic intrusive rocks studied by the writer contained abundant magnetite, and in some sections of the cleaner graywacke, magnetite is seen to be concentrated as if it represents sedimentary enrichment. The conglomerate on Berry Island contains some rounded pebbles of volcanic graywacke in which magnetite forms the bulk of the pebbles (pl. 39*B*). Similar pebbles have been obtained from Thorne Bay, showing that magnetite was clotting into large grains before the intrusion of the plutons. It seems probable that the source of part of the magnetite in the ore bodies is the magnetite of the volcanic rocks, which may, in fact, be the ultimate source of most of the magnetite by having contributed iron to the igneous rocks which assimilated large amounts of volcanic rock. The apparent scarcity of magnetite deposits about the stock in the southwest part of the quadrangle possibly is due to its low initial iron content and to the fact that it was emplaced into rocks with a generally low iron content.

SUGGESTIONS FOR PROSPECTING

The search for additional ore deposits of possible economic interest will require exploration techniques involving detailed mapping on a large scale, supplemented with magnetic surveys as pointed out by Warner and others (1960). In the search for copper deposits, primary exploration might be aided by geochemical techniques, such as water and soil sampling. Large parts of the quadrangle, such as the area north and east of Thorne Bay, appear on the basis of the present study to offer little promise of economic deposits; and other areas, such as the area adjacent to the fault trending northwestward from the head of Kasaan Bay, seem to contain more than the average amount of disseminated sulfide minerals. The small sulfide-bearing pluton north of Lake No. 3 should be prospected in detail in the interest of outlining a large tonnage of low-grade ore.

In the search for copper deposits it would seem desirable to test with the diamond drill some of the new bornite prospects in the pyroxenite body at the salt chuck at the head of Kasaan Bay. The magnetic anomaly near the pluton north of Thorne Bay should be investigated.

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