UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

MINERAL RESOURCES OF GLACIER BAY NATIONAL MONUMENT, ALASKA

by

E. M. MacKevett, Jr., David A. Brew, C. C. Hawley,

Lyman C. Huff, and James G. Smith

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ABSTRACT

Glacier Bay National Monument, Alaska, contains concentrations of copper, molybdenum, nickel, gold, silver, titanium, iron, and a few other metals ranging in amount from greater-than-background to potentially significant deposits. Eight previously known and seven newly discovered deposits are considered to have possible economic potential; none of these deposits has been thoroughly explored. Approximately 70 other deposits or occurrences also are catalogued in the report, but are considered to have little economic potential. Non-metallic and industrial mineral occurrences have small economic importance. The potential for petroleum, mostly in off-shore sedimentary rocks of Tertiary age, is believed to be minimal.

The most important potential minable deposits in the area are the Nunatak molybdenum deposit and the Brady Glacier nickel-copper deposit. Other deposits of possible importance are the Alaska Chief and Margerie copper prospects, deposits associated with layered intrusive complexes in the Fairweather Range, beach placers near Lituya Bay, gold lodes near Reid Inlet and at Sandy Cove prospect, a copper-molybdenum deposit in the Bruce Hills, and several smaller base metal deposits.

The Monument is within the rugged St. Elias Mountains physiographic province. Five distinct geologic provinces are recognized. They are generally characterized by highly deformed, slightly to moderately metamorphosed Paleozoic through Mesozoic detrital clastic, carbonate, and volcanic rocks which are interrupted by belts of Mesozoic and Cenozoic(?) granitic and gabbroic rocks.

The investigations made in the summer of 1966 consisted of (1) reconnaissance geologic mapping, (2) systematic geochemical sampling, (3) examination of previously known mineral deposits and deposits discovered during field studies, and (4) analytical chemical investigations in the laboratory.

The approximately 2700 samples collected during the geochemical investigations consist mainly of stream sediments and of altered and mineralized rocks. Most of the samples were analyzed for total heavy metals in the field and subsequently by semiquantitative spectrographic methods in the laboratory. Additionally, many of the samples were assayed for gold, and a few were tested for specific elements by various analytical methods. The reconnaissance geologic mapping included several hundred miles of foot and boat traverses supplemented by helicopter-supported spot checking and airborne reconnaissance. The field and laboratory investigations were supplemented by data from the literature, but the combined data provide only a skeletal framework and a catalog of information about the occurrence and potential for valuable metals, non-metals, and organic fuels in the area.

SUMMARY AND CONCLUSIONS

The widespread occurrence of diverse mineral deposits in Glacier Bay National Monument has been known for many years. The National Park Service in November, 1965, requested that the Geological Survey study the known deposits and evaluate the overall mineral potential of the Monument as an aid in planning future development. This report presents the results of the Geological Survey's summer, 1966, studies, which are mainly detailed descriptions of individual mineral deposits and details of the geochemical sampling program. The most important results are presented briefly in this section of the report; background information on the geography, geology, and study methods used are found in the Introduction section (pages 19 to 34).

The chief metallic commodities of potential economic importance in Glacier Bay National Monument include copper, molybdenum, nickel, gold, silver, titanium, and iron. A few other metals might constitute byproducts or might form deposits in some favorable areas that are as yet unexplored or concealed. The belt of Tertiary sedimentary rocks that borders the Gulf of Alaska and probably occurs offshore is a possible host for petroleum, but the potential is low. The potential for nonmetallic deposits that are known in the Monument, such as coal, limestone, and dolomite, is minimal because of their low grades, impurities, cheaper availability elsewhere, and similar factors.

The deposits considered to have the best economic potential include eight that were previously known and seven that were found during our investigations. The previously known deposits are the Nunatak molybdenum prospect; the Brady Glacier nickel-copper prospect; titanium, iron, and copper deposits associated with the layered mafic intrusive rocks of the Fairweather Range; the Alaska Chief copper prospect; gold- and ilmenite-bearing beach placers north and south of Lituya Bay; the Margerie copper prospect; and gold lodes in the Reid Inlet area and at the Sandy Cove prospect (figs. 1 and 3A). The most attractive deposits found during our investigations include a copper-molybdenum deposit in the Bruce Hills; veins and altered zones north of White Glacier; base metal lodes near Mount Brack; and copper deposits south of Rendu Glacier, near Gable Mountain, east of Dundas Bay, and west of Tarr Inlet (figs. 1 and 3A).

The previously known deposits are described on the following pages in the order of their probable economic potential. The Nunatak molybdenum prospect and the Brady Glacier nickel-copper prospect are equally likely to be mined in the near future. The deposits that we found cannot be ranked without additional data, and, at this stage, all are considered to have about the same potential. They are all partly or largely covered by snow, ice, or surficial deposits, and satisfactory appraisals of their configurations and grades require physical exploration. These newly-found deposits are interesting because of their inferred sizes, their grades, and the possibility that concealed parts of some may be larger and richer than is apparent from the surface examination. These deposits would be regarded as exploration possibilities by most mining companies, but remoteness and difficult access are detrimental factors in most cases. Probably none of these newly-found deposits will prove to be of major importance, but they cannot be eliminated from consideration without exploration.

The investigations were thorough enough to conclude that most, if not all, sizeable mineral deposits exposed in the Monument east of the Fairweather Range have been found. Some of the geochemical anomalies detected in stream sediment samples from this same part of the Monument probably indicate the existence of concealed deposits. Most of the planned fieldwork in the Fairweather Range itself was prevented by bad weather, and only small parts of its eastern margin were examined; therefore our appraisal of the Range is severely limited by lack of data.

MINERAL DEPOSITS

Previously Known Deposits

Nunatak Molybdenum Prospect

Deposits at the Nunatak molybdenum prospect (numbered 1 on fig. 1, and 21 on fig. 3A) consist of abundant, closely-spaced molybdenite(MoS_2)-bearing quartz veins, minor molybdenite disseminated in hornfels, and a mineralized fault zone. The deposits have been described by Twenhofel (1946), and they were sampled and explored with two diamond drill holes by the U. S. Bureau of Mines (Sanford and others, 1949). Mining companies have conducted limited exploration at the prospect. The deposits are mainly in hornfels, but locally they occur in an intrusive igneous body mapped as quartz monzonite porphyry, which is exposed over a small area, and in a silicified zone near the edge of the igneous body. Pyrite(FeS_2), pyrrhotite($Fe_{1-x}S$), chalcopyrite($CuFeS_2$), and traces of silver are associated with the molybdenite in parts of the deposit.

Satisfactory estimates of the grade of the deposits will require bulk sampling. Likewise, adequate estimates of the reserves are contingent on determining the extent of the deposits.

Our reserve estimate for the closely-spaced molybdenite-bearing vein network, or stockwork, above sea level near Muir Inlet is 2,247,000 tons of material averaging 0.067 percent MoS_2 and 0.016 percent copper. Our estimate for the remainder of the stockworks and the fault zone deposit is 129,530,250 tons of material averaging 0.026 percent MoS_2 and 0.018 percent copper. The grades are based on assays of chip samples collected during our investigations. In addition about 18,000,000 tons of material similar to that in the second category above are inferred to underlie the steep cliffs near the southern end of the stockworks. Reserves that are comparable in tonnage and grade to those above sea level probably also occur below sea level.

Twenhofel (1946, p. 17, 18) estimated that the whole stockwork contained 8,500,000 tons of material averaging 0.125 percent MoS_2 and 91,500,000 tons of material averaging 0.080 percent MoS_2 and that the fault zone deposit contained 540,000 tons of material averaging 0.169 percent MoS_2. Twenhofel's grade estimates are based mainly on channel samples and may be more representative than ours; none of his samples were analyzed for copper.

Three diamond drill holes drilled by American Exploration and Mining Company in 1966 explored parts of the deposits between 400 feet above sea level and 300 feet below sea level. These cores indicate grades of MoS_2 similar to those in our and Twenhofel's samples.

The Nunatak molybdenum prospect contains a large reserve of low-grade molybdenum ore, and if the current trends in price and demand for molybdenum continue it may be minable in the near future.

Brady Glacier Prospect

The Brady Glacier nickel-copper deposits are exposed on two small nunataks in Brady Glacier (2 on fig. 1, 72 on fig. 3A). The prospect is covered by patented claims held by the Newmont Mining Company. Published descriptions of the deposits are based on meager information (Berg and others, 1964, p. 144, 155; Cornwall, 1966, p. 37). The deposits are localized near the base of layered gabbro and in adjacent peridotite that form part of the layered mafic and ultramafic igneous rock complex known as the Crillon-LaPerouse stock. The deposits consist of pyrrhotite($Fe_{1-x}S$), pentlandite($(Fe,Ni)S$), and chalcopyrite ($CuFeS_2$) that form disseminations, veinlets, and lenticular masses as much as 35 feet long and 5 feet in diameter. The prospect has been explored by 46 diamond drill holes, many of which were drilled through several hundred feet of ice in the nearby glacier.

The nunataks have not been systematically sampled, but examination of their rocks indicate that disseminated sulfides are present nearly everywhere. The amounts are small and the overall average grade of the nunataks would probably be less than 0.5 percent each of nickel and copper. Several of the sulfide masses in the nunataks have been sampled and the assays show 2-3 percent nickel, 1-1.4 percent copper, and 0.25 percent cobalt. Individual massive sulfide lenses are small; however, 5 such bodies on the nunataks have lengths ranging from 15 to 35 feet and average widths of about 6 feet. The vertical extents of the lenses are probably comparable to these dimensions.

Diamond-drilling thus far has shown that low-grade nickel-copper mineralization is widespread in the gabbro-peridotite complex, but more drilling is needed to establish continuity of the higher-grade zones. By analogy with known commercial deposits of a similar nature elsewhere it is possible that, as the basal contact of the layered complex is approached at greater depth, higher grades of nickel and copper mineralization will be encountered. The information available to us is inadequate for making any reserve estimates, but the results of exploration may be considered sufficiently favorable to encourage mining the deposits.

Fairweather Range

The layered mafic and ultramafic rocks of the Fairweather Range include the Crillon-LaPerouse and the Astrolabe-DeLangle stocks of Rossman (1963a) and an inferred intrusive mass near Mount Fairweather (fig. 1). These rocks have been little explored and prospected. Descriptions of them and brief accounts of their mineral deposits (8 on fig. 1) are in Rossman (1963a) and in Kennedy and Walton (1946, p. 67-72).

Some layers in the layered complexes are known to contain large amounts of ilmenite in low-grade concentrations and lesser amounts of titaniferous magnetite. These and similarly mineralized layers that undoubtedly occur elsewhere in the complexes are a potential resource of titanium and iron. Minor amounts of vanadium are associated with the ilmenite and magnetite and constitute a remotely possible byproduct. Pods and lenses of massive sulfides, chiefly pyrrhotite($Fe_{1-x}S$) with subordinate chalcopyrite($CuFeS_2$), have been reported from some of the layers and contact zones of the complexes.

By analogy with other layered mafic and ultramafic intrusive masses, the poorly exposed and apparently largely concealed ultramafic rocks of the lower part of the complexes are possible hosts for chromite and platinum deposits. Likewise the peripheral and lower zones of the complexes may contain sulfide deposits rich in nickel and copper and possibly small amounts of platinum.

The little explored and prospected layered intrusive rocks of the Fairweather Range are potentially important because they contain known resources and are favorable hosts for a variety of mineral deposits. On the other hand, they occur largely in remote and rugged terrain where prospecting, exploration, and mining are difficult and costly.

Alaska Chief Prospect

The Alaska Chief copper prospect (3 on fig. 1, 29 on fig. 3A) consists of patented claims on a massive sulfide deposit in tactite, hornfels, and marble near a granitic mass. Workings at the prospect consist of a cleared and scraped area about 150 to 55 feet and an adit 40 feet long. The deposit is exposed throughout the cleared area and less extensively in the adit. The lateral extent of the deposit could not be ascertained because its surface exposures are surrounded by densely vegetated steep hillsides that lack outcrops. Likewise, little is known of its subsurface configuration. The deposit consists of pyrite(FeS_2), pyrrhotite($Fe_{1-x}S$), chalcopyrite($CuFeS_2$), bornite (Cu_5FeS_4), and sphalerite(ZnS), and their oxidized derivatives. Chip samples from the cleared area contained about 1 percent copper, as much as 4.377 ounces of silver per ton, and lesser amounts of gold and zinc. The deposits require drilling or similar exploration to determine their reserves. The prospect has been briefly described by Reed (1938, p. 72, 73) and by Wright and Wright (1937, p. 221, 222).

Placer Deposits Near Lituya Bay

Placer deposits that contain gold and other heavy minerals are distributed irregularly along the beaches for about 20 miles northwest of Lituya Bay and 15 miles southeast of the bay (7 on fig. 1, 87 and 88 on fig. 3A). Similar placers might be located just offshore beneath the Gulf of Alaska. The deposits consist of concentrations of heavy minerals in modern bare beach sands and in older beach sands whose surfaces are covered by vegetation. The deposits have been worked intermittently since the early 1890's. Between 1894 and 1917 they produced about $75,000 worth of gold (Mertie, 1933, p. 135). Their production since 1917 has been minor. A little platinum has been recovered from the deposits. The placer deposits also contain concentrations of ilmenite and, to a lesser extent, of magnetite. The deposits have been investigated by Rossman (1957) and by Thomas and Berryhill (1962, p. 37-40); both of these investigations stressed their ilmenite content. They could be worked under favorable economic conditions for gold, and they also constitute a potential resource of titanium, and possibly iron.

Margerie Prospect

The Margerie copper prospect (4 on fig. 1, 19 on fig. 3A) is in granitic rock and hornfels. Its deposits consist of pyrrhotite($Fe_{1-x}S$)-chalcopyrite ($CuFeS_2$) lenses, copper-bearing altered zones about 6 feet thick, and thin quartz veins. All of the examined deposits appear to be too small or too lean to be exploitable, but the prospect has been little explored and indications of mineralization are widespread in the general vicinity. The deposits were discovered in 1960 but have not been described in the geologic literature.

Reid Inlet Gold Area and Sandy Cove Prospect

The gold lodes of the Reid Inlet gold area (5 on fig. 1; see fig. 3A also), and the Sandy Cove prospect (6 on fig. 1, 7 on fig. 3A) occur in narrow nonpersistent quartz veins and in the contiguous altered wallrock. They are probably too small and too sporadically distributed to be minable now, but they probably would be amenable to small-scale mining during more favorable economic conditions.

The total value of gold production from mines in the Reid Inlet area was about $250,000 (Rossman, 1959, p. 39). The geology and ore deposits of the Reid Inlet area have been described by Rossman (1959). The Sandy Cove prospect was described by Reed (1938, p. 65-68).

Other Previously Known Deposits

Several other mineral deposits, such as those on Willoughby, Francis, and Marble Islands (Reed, 1938, p. 69-72), west of Rendu Inlet and on the southern part of Gilbert Island (Rossman, 1963b, p. 48-50) have been reported in the Monument. All of these probably have low potentials for mineral production.

Deposits Discovered During 1966

Several localities that contain mineral deposits of potential significance were discovered during the 1966 fieldwork (fig. 1). These deposits cannot be ranked without additional data, and no preference is implied by the sequence of the descriptions that follow. Most of these deposits are poorly exposed and require additional work for their satisfactory evaluation. Our brief examinations and limited sample data indicate that they warrant exploration.

The Bruce Hills deposits (9 on fig. 1, 34 on fig. 3A) are in and near a fault zone that cuts granitic rocks. They consist of stockworks of quartz veins, disseminations, and fracture coatings, and contain pyrite(FeS_2), chalcopyrite($CuFeS_2$), pyrrhotite($Fe_{1-x}S$), molybdenite(MoS_2), and malachite ($Cu_2Co_3(OH)_2$).

The deposits near Mount Brack (10 on fig. 1, 12 on fig. 3A) occupy veins and altered zones in metamorphic rocks. They consist of sphalerite(ZnS), galena(PbS), and probably a sulfosalt, and contain minor amounts of silver.

Deposits north of White Glacier (11 on fig. 1, 6 on fig. 3A) are localized in small altered zones that cut limestone and marble and in large altered zones that cut mafic volcanic rocks. The altered zones in the limestone and marble contain chalcopyrite($CuFeS_2$), particularly near intersections with dikes that cut the zones, and some altered zones in the volcanic rocks carry as much as 2 percent zinc.

A large mineralized altered zone is exposed in steep cliffs south of Rendu Glacier (12 on fig. 1, 15 on fig. 3A) near the contact between light-gray granitic rocks and metamorphic rocks. A sample of float from this zone contained 0.2 percent copper.

Mineralized joint coatings of unknown extent occur in coarse-grained dioritic rocks at Gable Mountain (13 on fig. 1, 14 on fig. 3A). The copper minerals in the joints comprise malachite($Cu_2Co_3(OH)_2$) and chrysocolla ($CuSiO_3 \cdot 2H_2O$). A composite grab sample from the deposit contained 0.1 percent copper and minor quantities of silver and molybdenum.

Low-grade copper deposits occur in a large altered zone east of Dundas Bay (14 on fig. 1, 31 on fig. 3A). The altered zone which is in quartz-rich metamorphic rock that locally is bounded by volcanic rocks, is as much as 300 feet wide and at least a mile long. Samples from the altered zone contained as much as 0.2 percent copper and traces of silver, molybdenum, and lead.

Disseminated sulfides and quartz veinlets that carry copper minerals occur in siliceous lenses within light-colored granitic rocks west of Tarr Inlet (15 on fig. 1, 63 on fig. 3A). A sample representative of the lenses yielded 0.1 percent copper.

Numerous other deposits, including a few that probably have potential equal to those described in the preceding paragraphs, were found during our investigations.

GEOCHEMICAL ANOMALIES

The geochemical sampling program found five areas containing significant anomalous metal contents in stream sediments, several areas with smaller anomalies, and also provided information about "background" concentration of elements in geologically different terranes. Although some of the anomalous areas were revisited and resampled in detail, none have been thoroughly evaluated; almost all, the five significant anomalies in particular, deserve further sampling and search for the causes of the anomalously high metal contents. The presently available data do not establish whether specific anomalies are derived from concealed mineral deposits with economic potential or from areas of widespread but nevertheless insignificant mineralization. Comparison of the geochemical maps with the mineral deposit maps shows that not all the known mineral deposits have geochemical anomalies detectible by methods used in this study; the various factors causing this are discussed in the main part of this report, the discrepancy does not lessen the importance of the anomalies that were mapped.

A significant geochemical anomaly (A on fig. 1) with as much as 150 ppm (parts per million) tungsten and 30 ppm tin occurs in stream sediments derived from light-colored granitic rocks and adjacent metamorphic rocks near the main arm of Dundas Bay. These samples were collected late in the fieldwork and there was no opportunity to resample the streams in the area. Geologically, the area is favorable for tungsten and tin deposits.

Another unevaluated significant anomaly is on the west side of Tarr Inlet (B on fig. 1) not far south of a described copper deposit (18 on fig. 3A). This anomaly contains 700 ppm copper, 200 ppm lead, 500 ppm tin, 1,000 ppm zinc, and anomalous amounts of other metals also. The anomaly is within a north-trending belt (fig. 3B) of mixed granitic and undifferentiated metamorphic rocks; this belt contains many small mineral deposits and the Reid Inlet gold area and appears favorable for base metal deposits.

Anomalously high total heavy metal, molybdenum, and strontium contents characterize an anomaly in stream sediments derived from a complex geologic terrane near Mount Merriam (C on fig. 1). Large iron-stained zones in hornfels and marble adjacent to intrusive granitic bodies there may be the source of the anomalous elements; these zones have not been sampled and the stream sediments have not been resampled in detail, so the anomaly is unevaluated but considered significant.

Sediments from several streams in the vicinity of Sandy Cove and Miller Peak (D on fig. 1) have anomalous total heavy metal, molybdenum, and strontium contents. These stream sediments have been resampled and the anomaly verified, but the source of the high metal content is not known. Granitic bodies intrude marble in this area and there may be either widespread low grade mineralization or hidden mineral deposits associated with the granitic rock-marble contacts.

Anomalously high chromium and copper values occur in the sediments of upper Berg Creek (E on fig. 1). This anomaly has not been resampled or evaluated, but the geology of the drainage area (fig. 3B) suggests that the metals may be derived from a volcanic terrane. This area is near the Monument boundary and the contiguous area outside the Monument has not been examined.

FAVORABLE AREAS

Specific areas in the Monument can be selected as being more favorable for mineral deposits than others from consideration of the distribution and characteristics of known mineral deposits, the results of geochemical sampling, and the geology. There is no certainty that these areas contain significant hidden mineral deposits, but they are more likely to do so than other areas. In the following discussion these areas are keyed to localities shown on figure 1.

The contact zones between granitic intrusive bodies and marble and other metamorphic rocks constitute favorable areas for several types of mineral deposits. Such contact zones are abundant in the Monument east of the Fairweather Range. Spatial and probably genetic relations exist between many of the known mineral deposits and granitic masses. In some cases, such as the Alaska Chief copper prospect and the Queen and Rendu Inlet iron deposits, the indications of genetic relations are strong.

Another association between mineral deposits and granitic rocks may be exemplified by the light-colored unfoliated granitic rocks that occupy a northwest-trending belt from Dundas Bay (near A on fig. 1) to beyond Johns Hopkins Inlet (fig. 3B). With the possible exception of the Reid Inlet gold deposits, which are quite distant, only a few mineral deposits are known to be associated with this belt. However, many metallic elements generally are concentrated during the late evolutionary stages of similar granitic rocks, and such rocks are associated with deposits of tin, molybdenum, tungsten, beryllium, gold, and other metals.

The layered gabbro and ultramafic rock complexes of the Fairweather Range and their border zones (2 and 8 on fig. 1) are favorable hosts for nickel, copper, iron, titanium, platinum, and perhaps vanadium deposits of various types. These complexes are probably more likely to contain significant undiscovered mineral deposits than any other favorable area in the Monument. However, exploration and development problems caused by the extremely rugged terrain and severe weather would be great. The beach and possible submarine placers on the Pacific Ocean shore west of the Fairweather Range (near 7 on fig. 1) contain iron- and titanium-bearing heavy minerals derived from the gabbro and ultramafic rock complexes as well as some gold and platinum. This area probably contains very large low-grade placer deposits.

A favorable belt of mixed rocks, including granitic intrusions and many kinds of metamorphic rocks, extends from the Brady Glacier northward past Reid and Johns Hopkins Inlets and along the west side of Tarr Inlet (from south of 5 north to 4 on fig. 1; fig. 3B). This belt contains many large iron-stained zones and many known mineral deposits, including those in the Reid Inlet gold area and the Margerie prospect. The marble and metamorphosed volcanic units are favorable hosts for deposits and are cut by at least two types of granitic intrusions.

In the Muir Inlet area and to the east is a structural zone with east to west trends (near 9 and 1 on fig. 1), instead of the north-northwest to south-southeast trends which typify the Monument as a whole (fig. 3B). The cause of these aberrant trends is not known, but the east-west zone is congruent with an area characterized by dikes and plugs of porphyritic intrusive bodies whose compositions are similar to many of the granitic rocks in the Monument. In places, as at the Nunatak molybdenum prospect, the country rock has been shattered by these shallow-depth intrusions. This area of congruent east-west trends and porphyritic intrusions contains most of the molybdenum deposits known in the Monument and is probably the most likely area in which to find hidden molybdenum-copper deposits.

A potentially favorable area (near E on fig. 1) is included in the eastern end of the area just described. Granitic intrusive rocks, metamorphic rocks somewhat similar to those near Muir Inlet, and a generally higher background content of metals in stream sediments all suggest that the area on both sides of the boundary in the northeastern part of the Monument may contain undiscovered mineral deposits of unknown size and significance.

* * *

Glacier Bay National Monument contains a few mineral deposits that are likely to be minable in the near future; some that may be minable in the more distant future, but which are not well enough known to be judged; some that probably would be minable with economic or technologic changes; and many that are insignificant. The economic potential for petroleum, coal, and nonmetallic commodities in the Monument is low.

INTRODUCTION

The U. S. National Park Service in November, 1965, requested that the U. S. Geological Survey study the mineral resources and mineral resource potential of Glacier Bay National Monument, Alaska. The purpose was to provide factual information for the use of the National Park Service in planning the future development of the Monument and for the public.

A Geological Survey field party investigated the mineral deposits of the Monument and their regional geologic setting during summer, 1966. Three concurrent methods of study were used. The most important method consisted of detailed field examination and sampling of previously known deposits and of new deposits found during the course of the overall investigation. The second method involved extensive collection and geochemical analysis of stream sediment samples from all major drainages. The third method was reconnaissance geologic mapping, which delineated the major rock units forming the host rocks of the mineral deposits, determined the bedrock compositions of the geochemically sampled drainage basins, and revealed new mineral deposits and areas favorable for deposits.

The investigation successfully covered almost all of the Monument, with only the high part of the Fairweather Range (fig. 2) and the Pacific coastal strip west of that range left unvisited. Eighty-eight mineral deposits, both newly-found and previously known, are described in this report. Of this number, sixteen are considered to be of greater economic interest than the rest; these deposits are described in detail in the text and also summarized separately on pages 1 to 18. Many insignificant mineral deposits were visited and sampled; their locations are given in this report although they are not described.

The geochemical sampling and analysis defined several significant geochemical anomalies, a few of which coincide with areas known to contain mineral deposits. Most of the anomalies have not been evaluated completely, due to lack of time, although some were re-sampled in detail.

The reconnaissance geologic mapping developed the regional framework of the mineral deposits and the background information essential in interpretation of the geochemical data. The mapping also contributed greatly to the knowledge of the regional geology of this part of northern southeastern Alaska.

PREVIOUS INVESTIGATIONS

Glacier Bay has attracted many geologists and glaciologists during the past 90 years mainly because of the rapid recession of the glaciers. Few of the earliest explorers and scientists came with economic interests in mind, but by 1892 some prospectors were in the area (Rossman, 1963b). In 1906 F. E. Wright and C. W. Wright (1937) studied the Johns Hopkins Inlet area and other parts of the Monument, and in 1919 J. B. Mertie visited the area. Buddington (Buddington and Chapin, 1929) visited the Monument in 1924. Somewhat later several Geological Survey geologists (Reed, 1938; Twenhofel and others, 1949; Kennedy and Walton, 1946) visited specific mineral deposits then of interest or under development. Economic interest in the Monument was lessened by prohibition of prospecting from 1924 to 1936.

In 1942, Twenhofel (1946) studied the Muir Inlet Nunatak molybdenum deposit in detail, and the U. S. Bureau of Mines sampled the deposit (Sanford, Apell, and Rutledge, 1949). In 1949 D. L. Rossman began geologic studies in the Monument. These studies are summarized in three reports (Rossman, 1959, 1963a, 1963b). In 1950-1951, J. F. Seitz studied the geology around Geikie Inlet (Seitz, 1959). Don J. Miller studied the Gulf of Alaska Tertiary province for several years; his mapping within the Monument was incorporated by Rossman (1963a) after earlier open filing (Miller, 1961). Reconnaissance studies in the Juneau 1:250,000 quadrangle part of the Monument were done in 1956-1958 (Lathram and others, 1959). A few mining companies, notably Fremont and Moneta-Porcupine, prospected in the Monument during the late 1950's and early 1960's.

PRESENT INVESTIGATION

The Geological Survey party, which made the studies reported here, was led by D. A. Brew and E. M. MacKevett, Jr., with Brew overseeing the operations and reconnaissance geologic mapping, and MacKevett the studies of mineral deposits and the mineral resource evaluation. In addition to Brew and MacKevett the party consisted of Drs. Arthur B. Ford, Charles C. Hawley, Lyman C. Huff, A. Thomas Ovenshine, Arthur S. Radtke (until July 9), James G. Smith (after July 13), geologists, and Mr. Raymond J. Wehr, physical science technician. Huff and Hawley coordinated the geochemical studies throughout the project. Dr. Henry C. Cornwall joined the project temporarily early in August to study the Brady Glacier deposit.

The U.S.G.S. R/V Don J. Miller, a 105-foot power barge manned by Robert D. Stacey, Master, Allen Z. Komedal, Chief Engineer, and John J. Muttart, Cook-Seaman, was used as base for the field operations. Helicopter support was a Bell G3B1, owned and operated by National Helicopter and Engineering Co., with Dan Ellis, Pilot, and Howard Grannell, Mechanic.

The party started field work May 24, 1966, and had excellent weather during May, June, and July. Frequent storms in August and early September hampered the studies, and the party left Glacier Bay on September 5, 1966.

The field studies were affected to a certain extent by the amount of snow cover present. Therefore, the sequence in which the different parts of the Monument were studied is significant. In late May the investigations covered shoreline and island exposures along the west side of Glacier Bay from Ripple Cove to Blue Mouse Cove; in June the northeastern and east-central parts of the Monument; in July the north-central, some of the northwestern, and the southeastern parts; and in August the south-central part, the west-central, and some of the northwestern areas. In general, the amount of snow diminished rapidly through June and early July, slowly in July and August, and in September the terrain above 4,000 feet was covered by new snow.

The results of the field studies are also a function of the way the data were gathered. All shoreline exposures within Glacier Bay and most of those along Icy Strait were traversed by slow-moving outboard-powered skiff, and frequent stops were made to examine the outcrops and obtain stream sediment samples. Ridges accessible by helicopter and suitable for walking were traversed by geologists and examined in detail. The rougher ridges were examined aerially from the helicopter and spot-landings for outcrop study purposes made wherever possible. Some streams were traversed on foot to gather sediment samples and bedrock information, but most were sampled with helicopter spot-landings.

The geochemical sampling program relied heavily on rapid analyses of the samples. All stream sediment samples were dried and sieved to -80 mesh on the barge immediately after collection, and the total heavy metals content (copper, lead, and zinc) was determined on a split by conventional field tests (Huff, 1951; see pages 36 to 37). The samples were then airmailed to the Analytical Services Branch laboratories of the U. S. Geological Survey in Denver, where spectrographic analysis for 30 elements was performed. Results were airmailed back to the field, usually arriving within 2 to 3 weeks from the time the sample was collected. Mineralized rock samples were in some cases screened by the total heavy metals test in the field before going to Denver for spectrographic analysis or assay.

Sections of this report were prepared by different authors and then combined after discussion and revision. D. A. Brew wrote the introductory material, geologic summary, and prepared the accompanying lithologic map. E. M. MacKevett, Jr., wrote all but one of the descriptions of the mineral deposits, incorporating geochemical material prepared by L. C. Huff. MacKevett was assisted by J. G. Smith in organizing data, by R. J. Wehr with laboratory studies, and S. R. Bartsch with drafting. H. R. Cornwall wrote the description of the Brady Glacier deposit; George Plafker is responsible for the summary of petroleum prospects in the Gulf of Alaska Tertiary province. C. C. Hawley prepared the maps showing the results of geochemical sampling and the discussions of geochemical anomalies. Hawley and L. C. Huff wrote the section discussing the geochemical sampling program. MacKevett and Brew wrote the summary and conclusions section.

GEOGRAPHY

Glacier Bay National Monument, Alaska, is an area of rugged glacier-clad mountains and steep-sided fiords within the St. Elias Mountains physiographic province in the northwestern part of southeast Alaska (fig. 2). Scenically and glaciologically it is one of the most outstanding parts of Alaska. The magnificent Fairweather Range culminates in Mount Fairweather (15,300 feet) and forms an awe-inspiring divide between the Gulf of Alaska, only 12 to 15 miles west of the range crest, and the deep fiords of Glacier Bay proper, as close as 8 miles east of the crest. The rapid recession of the glaciers in Glacier Bay has not only provided an unparalleled opportunity to study recessional glacial phenomena but has also exposed older glacial deposits and related features which are evidence for a complex sequence of relatively young glacial events.

The Monument is located some 100 miles west-northwest of Juneau, Alaska, (fig. 2) and is accessible only by water or air. Small boats can reach Glacier Bay from the Inside Passage waters by way of Icy Strait. Reaching the Pacific coastal part of the Monument involves an exposed and often rough run through Icy Strait and around Cape Spencer into the open ocean. Boating within Glacier Bay itself is less difficult and conditions are generally good during the summer months, although strong tides and sudden winds can abruptly change conditions. Charter float-equipped aircraft from Juneau and Haines reach the Bay in about an hour and can land in most fiords, except where icebergs are numerous. Ski-wheel aircraft have landed on several of the large glaciers. Regular daily air service is maintained to the permanent community at Bartlett Cove (Monument headquarters) during June, July, and August and to Gustavus (just outside the Monument) all year by Alaska Coastal Airlines.

The Monument has an area of about 3,900 square miles, excluding the water areas outside of Glacier Bay proper. Of this figure, 530 square miles (or about 14 percent) consists of the 50-mile-long Glacier Bay and its various arms and inlets. About 830 square miles (or 21 percent) are covered by glaciers. Much of the remaining 2,550 square miles is covered by snow all but 3 or 4 months of the year.

The land areas in the Monument are all mountainous except for a few broad plains underlain by glacial outwash in the southern and east-central parts. Four general types of mountains are found in the Monument, reflecting differences in total relief, glacial history, and vegetation development. Toward the north-northwest the lower, rounded summits and thickly-forested steep slopes, typical of the Chilkat Range and the southern parts of the Monument, give way to slightly higher, bare, serrated peaks and ridges which fall steeply into narrow, steep-gradient valleys. Still farther north, coalescing valley glaciers and icefields convert similar peaks and ridges to nunataks. In the highest parts of the Monument, the precipitous peaks of the Fairweather Range have impressive ice-fluted flanks which descend to heavily crevassed valley glaciers below.

The glaciers in the Monument range from small hanging types common on most peaks to the 240 square mile broad expanse of the Brady Glacier Icefield, but most are one- to three-mile-wide valley glaciers which head in cirques or icefields at 4000 to 6000 feet elevation and which descend almost to tidewater. The glaciers are in general quite crevassed and are easily traversed only early in the summer. The Brady Glacier Icefield and the Takhinsha Mountain Icefield are snow covered in their higher parts during most summers and are therefore more easily traversed.

At present, the ice in the glaciers may be as much as 1000-1500 feet thick in some of the deeper valley glaciers and as much as 1000 feet thick on the broader and higher icefields. Adjacent to nunataks and valley walls the ice thickness increases rapidly, but the bedrock surface may be very irregular locally. Except for some stagnant ice at low altitude all of the glaciers in the Monument are active, and there are signs that many are growing.

The fiords of Glacier Bay are steep sided and deep, with local depths greater than 1000 feet. Shallower areas are found only near the broad expanses of outwash deposits in the southern part of the Monument and over the small deltas associated with tidewater glaciers and the larger streams.

Most of the streams in Glacier Bay National Monument are small, have steep gradients, and drain areas of only a few square miles. In the southern part of the Monument, however, are several short but vigorous rivers draining relatively large areas. These rivers, most of their tributaries, and many of the other streams are swift and difficult to cross on foot. Almost all streams, regardless of size, were found to carry active stream sediment suitable for geochemical analysis.

The climate of the Monument is generally maritime in the southern and lower-altitude parts. Increasing altitude in the Fairweather Range, the presence of many glaciers, and the rain shadow effect of the Fairweathers tend to make the northern part of the Monument less humid and more like interior regions. No weather data are available for the northern or higher-altitude parts, but data are available for Cape Spencer and Gustavus (fig. 2). These data are summarized in table 1; they show that the months from February through July or August have the least precipitation, that the fall and early winter months have the most, and that the temperatures are in general mild in both summer and winter.

ACKNOWLEDGMENTS

The cooperation of the U. S. National Park Service Glacier Bay National Monument staff contributed greatly to the efficiency of the field operation. We would particularly like to thank Robert B. Howe, Superintendent, Charles Janda, Ranger, and Kenneth Youmans.

We also thank Newmont Mining Company and American Exploration and Mining Company for their cooperation in the appraisal of the Brady Glacier copper-nickel and the Muir Inlet Nunatak molybdenum deposits, respectively. L. F. Parker visited with Survey geologists in the field on one occasion, as did Lawrence Duff; both aided in locating prospects in the Reid Inlet area.

REGIONAL GEOLOGY

Knowledge of regional geology is important to this mineral resource appraisal in three ways: (1) the study of the rocks and their distribution aids the interpretation of the geochemical data; (2) knowledge of the geologic framework of the known deposits leads to geologic insights about particular environments that need to be carefully evaluated in areas where no deposits are yet known; and, (3) projection of known rock units from mapped areas into unmapped areas provides a basis for appraising the mineral potential of the unmapped areas.

The emphasis in this brief summary is on the gross lithic and structural framework of the Monument and no detailed stratigraphic information is presented. The lithologic map (fig. 3B) shows the major rock types and indicates the general geologic associations of the mineral deposits. [Figures 3A and 3B will be combined for final publication.] A geologic map is being prepared as a separate report.

Glacier Bay National Monument consists of five distinct geologic provinces, each of which is characterized by specific structural and lithologic features. The Coastal province lies west of the Fairweather fault (fig. 2). The Fairweather province is east of the Fairweather fault and extends eastward to the Brady Glacier. The Geikie province extends north-northwesterly through the center of the Monument. At its northern end, this province merges with the east-west trending Muir province. The Chilkat province occupies the south-eastern part of the Monument. The features which characterize these provinces are discussed below.

STRATIGRAPHY

The bedrock stratigraphic section in the Monument ranges from early Silurian through late Tertiary in age, with significant gaps in the late Paleozoic, late Mesozoic, and early Tertiary. The section is not well understood because of scanty fossil record, apparent abrupt facies changes, widespread metamorphism, and the disruption caused by intrusive bodies.

The Paleozoic part of the section crops out through the eastern half of the Monument and is particularly well exposed in the Chilkat province (fig. 3B). A stratigraphic thickness of 20,000 to 30,000 feet is estimated to be present. Detrital clastic rocks, mostly graywacke and argillite, of Silurian and possibly Devonian age are dominant. Some discontinuous nonfossiliferous limestones are also present. To the north these rocks appear to grade into a comparable section that contains significant amounts of volcanic rocks also. In the western and northwestern parts of the Chilkat province are exposures of thick reef limestones whose correlation with the rest of the section is uncertain. Carbonate and detrital clastic units of Middle Devonian age occur in the north-central and northwestern parts of this province, and also in the Muir province. The relations between the known Devonian rocks and the known Silurian rocks are obscured by structural complexities and poor fossil control.

The Paleozoic rocks throughout most of the Chilkat province are not greatly metamorphosed, except adjacent to intrusions. In the Geikie and Muir provinces these same rocks locally have been thoroughly metamorphosed, and it is difficult to correlate them with their less metamorphosed equivalents.

Mesozoic strata are found in the Coastal and Fairweather provinces along north-northwest trends similar to those in the Mesozoic rocks of nearby Chichagof Island. They include three gross units of unknown thickness: a) a low-grade metamorphic unit derived from mixed detrital clastic rocks and volcanic rocks, which is found only west of the Fairweather fault; b) a biotite schist unit; and c) an amphibolite unit. The schist unit is derived from a graywacke-shale sequence known to be of Jura-Cretaceous age on Chichagof Island and the amphibolite may be equivalent to volcanic rocks of probable Triassic age in that same area.

Tertiary strata unconformably overlie the metamorphosed Mesozoic strata in the Coastal province and consist of at least 12,000 feet of Miocene and Pliocene sandstone, shale, and minor volcanic rocks and conglomerate. The Tertiary strata probably extend offshore onto the continental shelf.

INTRUSIVE ROCKS

Intrusive rocks of probable late Mesozoic and perhaps Tertiary age dominate the Geikie and Muir geologic provinces and occur in all of the other provinces to a lesser extent. Some of the foliated granitic rocks discussed below may actually be metamorphic rather than intrusive, but they are closely associated with the granitics. The distribution of the different intrusive rocks is shown on figure 3B; it is apparent that most of the known mineral deposits are spatially related to intrusions.

Most of the intrusives in the Monument are mesozonal foliated granitic rock bodies. Hornblende quartz diorite, hornblende diorite, and biotite-hornblende quartz diorite are most common, but some biotite-hornblende granodiorite also occurs in foliated bodies. In practically every case, foliation is parallel to that in the adjacent metamorphosed country rocks, but local divergences are present. This relation suggests that these bodies were intruded before the end of the episode in which the country rocks were deformed. Most of the foliated granitic bodies contain and are locally bordered by areas of hornblende quartz diorite gneiss, which is commonly inclusion-rich and in some cases very heterogeneous.

Most of the mesozonal to epizonal unfoliated granitic rocks in the Monument are in the Geikie province, but isolated bodies also occur in the Fairweather, Muir, and Chilkat provinces. Because they all lack well-developed foliation, these granitic bodies are considered to postdate deformation. Compositionally, the unfoliated granitic rocks range from hornblende-biotite granodiorite to biotite granite. These bodies are generally free of distinctive border zones, but they do contain large hornfels inclusions. The intrusion at Johns Hopkins Inlet (figs. 2 and 3B) is unusual in that it is associated with very extensive and spectacular border zones of such inclusions.

A variety of dike rocks, ranging from aplites to lamprophyres, with andesites and diabases the most abundant, were mapped in the Monument. They are particularly common in the western and northwestern part of the Chilkat province and in the metamorphic rocks in the Muir province. Most of the dikes are probably relatively young and in many places have mineral deposits associated with them. The majority of dikes strike east or northeast, and they tend to occur in subparallel swarms.

A layered gabbro complex occupies a large part of the Fairweather province, and at least two other bodies of gabbro occur nearby. The gabbro in the synclinal structure of the largest complex is more than 30,000 feet thick. The regularly layered center of this mass is commonly bordered by a structurally complex zone of gabbro and ultramafic rocks; this zone locally contains important sulfide deposits. Other mineral deposits are known to occur within the layered portion.

STRUCTURE

Each geologic province in the Monument has characteristic structural features and two provinces--Muir and Chilkat--have unusual complications. Certain features, however, are common to the whole Monument; they are 1) a dominant north to northwest strike of all units and of planar structures within all units, 2) steep dips, and 3) repetition of section by large-scale folds. The major faults in the Monument also strike north to northwest, although there are minor local divergences from this pattern.

In the Coastal province the moderately- to gently-dipping Tertiary strata form two northwest trending synclines and one anticline and have also been displaced vertically by northwest-striking faults. Structures in the underlying Mesozoic rocks are not well known, but probably are similar to those in the adjacent Fairweather province.

The Fairweather fault, which separates the Coastal and Fairweather provinces, is part of a high-angle fault system that extends for over 280 miles from Yakutat Bay on the north to Chatham Strait and western Baranof Island on the south. The segment of the fault within Glacier Bay National Monument is near the central part of the system. The dominant fault movement is inferred to be vertical, with the west side down, but both historic displacement (Tocher and Miller, 1959) and inferred older movements further south (Loney, Brew, and Lanphere, 1967) suggest that a right-lateral component is also present.

Steeply-dipping, north- and northwest-striking foliation characterizes the Fairweather province, and the map units apparently are repeated by large folds. The emplacement of the large gabbro bodies had little structural effect on the country rock, except close to the contact.

The Geikie province is characterized by parallel north- and northwest-striking foliations in the country rocks and in the numerous granitic bodies. The distribution of country rock units implies complex folding, but the intervening intrusive masses make exact analysis difficult. In the northwestern part of the province northwest strikes and steep westerly dips of contacts suggest that most of the rocks in the province may be stratigraphically below units mapped in the adjacent Fairweather province. Geikie province also contains a prominent north-northwest striking zone of discontinuous faults.

The structures in the Muir province are very similar to those in the Geikie province, but contacts and foliations strike west to northwest and dip moderately to steeply to the north. These attitudes in the country rocks may be related to the configuration of the major intrusive bodies, but they may also represent pre-intrusion attitudes in part. In any case, the abrupt change from northerly trends near Muir Inlet to westerly trends only a few miles to the north suggest that one or more major structural discontinuities are involved. The distribution of map units in some areas between intrusive masses suggests that large folds, overturned to the south, may be present.

The same abrupt change in strike has been mapped in the northern part of the Chilkat province, near Tidal Inlet. There the situation is complicated by an east-west fault zone and, further to the east, by an important high angle reverse fault that brings relatively simply folded Devonian strata over more highly folded Silurian(?) rocks. Outside the area of these complications the rocks in the Chilkat province are characterized by northwest strikes, moderate to steep northeast dips, and large amplitude folds overturned to the southwest.

GEOCHEMICAL STUDIES

Geochemical studies in Glacier Bay National Monument consisted of the collection, analysis and subsequent interpretation of more than 2,700 samples including (1) 1,200 stream sediment samples, (2) 1,000 altered or mineralized rock samples, (3) 500 soil samples, (4) 30 unaltered and unmineralized background level samples, and a few (5) panned stream concentrate samples, (6) water samples, and (7) glacial moraine samples. The resulting basic data and preliminary interpretations provide only a skeletal framework, and we believe that further geochemical interpretation of these data is possible. In particular, the relations between bedrock lithic types and metal content of locally derived stream sediments should be considered in detail. The following interpretations are preliminary and incomplete.

Stream sediment samples provide the greatest amount of available geochemical data on the composition of the rocks and surficial deposits and on abnormal accumulations of metals, which might indicate the presence of undiscovered buried mineral deposits. The density of stream sediment samples varies greatly because large areas in the Monument have glacial rather than normal stream drainage. In areas of normal drainage, there are more than one sample per square mile; the samples are much more widely spaced in the glacier-covered areas.

The results of the stream sediment studies are given in figures 4 to 15 and tables 4 to 8. The concentrations of total heavy metals, chromium, copper, lead, molybdenum, and nickel are shown on individual maps and one map summarizes other elements such as arsenic, beryllium, bismuth, cadmium, silver, strontium, tin, tungsten, and zinc, which were detected in anomalous amounts. Complete analytical data are given for several promising areas on separate maps and in tables. The analytical data derived from other samples are incorporated in the sections on mine and prospect descriptions.

METHODS OF ANALYSIS

Most samples were analyzed twice, first by a field geochemical prospecting test for total heavy metals (hereafter referred to as THM) and then spectrographically in the U.S.G.S. Analytical Services, Denver, Colorado, laboratory by Nancy M. Conklin, J. C. Hamilton, R. G. Havens, Harriet G. Neiman, and A. L. Sutton, Jr. The results of the THM tests were available one or two days after sample collection and were used to guide further sampling. The results of the spectrographic analysis were available to the field party in two to four weeks.

The THM field test was made in a portable laboratory aboard the R/V Don J. Miller. The test is of the type described by Huff (1951) in which the sample is digested by heating with acid and the dissolved metal content determined by dithizone. This type of THM test extracts much more of the zinc, copper, and lead contained in the sample than does the commonly used cold citrate soluble THM test described by Hawkes (1963). The more complete extraction is of considerable importance at Glacier Bay because the oxidation of the rocks varies widely and more of the metal may be tightly bound than is the case in a more temperate or thoroughly weathered region. It should be emphasized that the THM test samples only the acid soluble part of the contained zinc, copper, and lead. The spectrographic method, however, measures essentially all the metal present. Both the spectrographic and THM tests are semiquantitative, but, within limits of error, comparison of the THM and spectrographic analyses permits assignments of some anomalies to copper, lead or zinc. For example, the THM test is especially sensitive to zinc, an element which has a poor spectrographic sensitivity (table 2). Stream sediment samples which have high values of THM and low spectrographic values of copper and lead are therefore believed to have anomalous concentrations of zinc.

The spectrographic method supplements the THM test because the latter does not detect elements such as chromium, molybdenum, nickel, tin, and tungsten. These and other elements are detected by spectrographic analysis if they are present in concentrations as high or higher than those listed in table 9. The sensitivity for elements such as cobalt, copper, chromium, molybdenum, and nickel is low enough to detect minor concentrations of these elements, but the sensitivity for gold, tungsten, and zinc is high enough so that these elements need to be markedly enriched to be detectable.

Two slightly different spectrographic methods were used; these are referred to on table 2 as the six-step and direct reader methods. The six-step method is similar to that described by Myers, Havens, and Dunton (1961) in that the concentrations are measured visually from photographic plates; it differs in that concentrations are reported the six-step geometrical array, 1, 1.5, 2, 3, 5, 7, etc., instead of the three-step array, 1, 3, 7, etc. The direct reader method refers to a direct reading spectrograph in which the concentrations are measured automatically by photomultiplier tubes. The two methods are comparable in sensitivity and accuracy for most of the elements sought (table 2).

In addition to routine THM and spectrographic analyses, many mineralized rock samples were analyzed for molybdenum and gold in the Denver laboratory by sensitive chemical methods.

SAMPLING AND SAMPLE PREPARATION

Stream sediment samples were collected from both large and small streams. Most of the streams sampled were flowing, but some samples were taken from the dry beds of intermittent streams. Clayey and silty sand was collected; this material is generally present in considerable abundance in the major streams, but may be very scarce in steep, small, or intermittent stream courses. However, some clayey and silty sand may be found even in small streams in pockets behind boulders. The samples were placed in water resistant paper bags, then dried at about 100° F. After drying, the sample was sieved at -80 mesh and that fraction was analyzed--first by the field THM test, then spectrographically.

ANOMALOUS AND BACKGROUND VALUES

Every region is characterized by a range of content values for each element; the average of these values is the background value. In many cases the median value is taken as background. Most samples have about this concentration, but a few will have much higher or much lower concentrations and these values are considered anomalous. High values are of special economic interest because they indicate areas of enrichment which may, in turn, be due to the presence of ore bodies. Most regions are underlain by many rock types and because each rock type has a characteristic element content, background values are not constant. Therefore, any group of anomalous values must be interpreted with consideration of such variations.

The results of this geochemical investigation are reported (figs. 4 to 10) in ranges of concentration, each range being identified by a specific symbol. The data shown on the maps suggest patterns of element distribution.

Total Heavy Metals

Analyzed stream sediment samples from Glacier Bay National Monument contain from 20 to 1000 ppm of zinc, copper, and lead extractable in hot acid. Based on a set of samples from 915 localities (fig. 4), which includes the average values from some duplicate analyses, the median THM concentration is about 25 ppm. About 75 percent of the samples contain less than 60 ppm, 90 percent less than 100 ppm, and 95 percent less than 120 ppm. The samples with 120 or more ppm THM are considered markedly anomalous.

Copper

Copper ranges from about 5 ppm to about 700 ppm in stream sediment samples from the Monument. Based on the set of 636 samples (fig. 5) analyzed by the six-step method, the median copper content is about 40 ppm. Approximately 95 percent of the samples contain less than 100 ppm; and the samples that contained 100 ppm or more copper are considered markedly anomalous.

Lead

Lead was not detected by spectrographic analysis in the majority of Glacier Bay stream sediment samples. The median value is therefore less than the spectrographic detectibilities (table 2), although it may be approximately the detectibility of the direct reader method (4 ppm). Based on 636 samples (fig. 6) analyzed by the six-step method about 85 percent of the samples contain less than 10 ppm, and 94 percent less than 15 ppm. The values above 15 ppm are considered markedly anomalous.

Molybdenum

Molybdenum is not reported in the majority of spectrographic analyses, but its median value may not be much less than the 3 ppm detectibility of the six-step method. In some areas many samples showed values by the direct reader method of 5-10 ppm; these values are below the general detectibility of the method and therefore were not considered in the statistical analysis. They may, however, indicate areas of slightly anomalous molybdenum content and are given on the detailed maps (figs. 11 to 15). In a group of about 1000 samples molybdenum exceeded 10 ppm in only 36 samples (fig. 7). All values above 10 ppm are considered anomalous.

Chromium

The chromium content of stream sediments in the Monument ranges from less than 5 ppm to about 2000 ppm (0.0005 to 0.2 percent). Based on a group of 957 samples (fig. 8), the median concentration is about 60 ppm and about 90 percent of the samples contain less than 100 ppm chromium. About 98 percent of the samples contain less than 200 ppm chromium. Samples with 200 ppm or more chromium are considered markedly anomalous.

Nickel

Nickel ranges from about 3 ppm to 700 ppm in stream sediments in Glacier Bay National Monument. Based on the 636 samples (fig. 9) analyzed by the six-step method the median value is about 15 ppm nickel. About 90 percent of the samples contain less than 30 ppm, and about 95 percent less than 40 ppm nickel. Values of 40 ppm or more are considered markedly anomalous.

Other Elements

Based on the 636 samples (fig. 10) analyzed by the six-step method, the median cobalt concentration in stream sediment samples is between 10 and 15 ppm, and about 90 percent of the samples contain less than 20 ppm cobalt. Cobalt is not shown on the maps as it generally tends to vary directly with nickel.

Any tin and tungsten values detected by the spectrograph were considered anomalous and are shown on figure 10, along with any detected values of a group of rare elements including silver and arsenic. Values of strontium greater than 1000 ppm were considered anomalous and are also shown on figure 10; although strontium is not an ore metal or common in ore minerals, it is shown because it apparently indicates additive metamorphism.

UNALTERED ROCKS

Rocks in Glacier Bay National Monument contain differing amounts of trace elements, depending on their origin, lithology, and major element composition. Many samples would be required to define exactly the trace element geochemistry of the bedrock units, but spectrographic analyses (table 3) of 31 apparently unaltered and unmineralized rocks provide a basis for some generalizations.

Limestones probably have lower trace element contents than any other rock type common in the Monument. The range in concentration in 4 analyzed samples is 0-3 ppm cobalt, 5-30 ppm chromium, 3-20 ppm copper, and 0-15 ppm nickel. No lead or zinc were detected. Streams draining unaltered limestone terranes should therefore have a low content of these metals. Three analyzed samples of detrital clastic sedimentary rocks contain as much as 15 ppm cobalt, 70 ppm chromium, 100 ppm copper, and 30 ppm nickel, indicating that streams draining unaltered detrital clastic rock terranes should carry these metals in considerable abundance.

Of the igneous rocks in the Monument, the diorite-granodiorite-quartz diorite suite was the most adequately sampled and analyzed. The average (arithmetic mean) concentration of selected elements is compared below with values for similar rocks reported by Turekian and Wedepohl (1961):

	Ba	Co	Cr	Cu	Ni	Sr
High calcium granitic rocks						
(1) granodiorites, etc. of Glacier Bay	506	12	14	40	5	443
(2) Average of Turekian and Wedepohl (1961)	420	7	22	30	15	440

Based on only three samples, the leucocratic granitic rocks (which are mainly adamellites) have an appreciably different trace element suite, including trace amounts of lead. Semiquantitative analysis shows that one sample contains 7 ppm beryllium and a trace of lithium, elements characteristic of some leucocratic granites which have associated ore deposits.

More mafic rocks, such as hornblendite and gneissic garnetiferous diorite, generally contain higher concentrations of the elements cobalt, chromium, copper, and nickel. Mafic dikes, including lamprophyres, locally contain very high concentrations of these elements, particularly chromium and nickel. The mafic dikes are locally abundant and probably contribute important amounts of these metals to stream sediments.

CAUSES OF ANOMALOUS VALUES

Anomalous concentrations of metallic elements occur in stream sediment samples from various parts of Glacier Bay National Monument; some of these concentrations indicate the presence of mineralized rocks and are discussed in the next section of this report (pages 43 to 52). In a few places similar anomalous concentrations indicate unusual amounts of metals contained in the country rocks or, directly or indirectly, the effects of glaciation.

Swarms of mafic dikes are the probable source of anomalous concentrations of metallic elements in some parts of the Monument. Such dike swarms comprise up to 40 percent of the bedrock in some areas. Some of the dikes contain unusual amounts of elements such as chromium and nickel, and most are bordered by thin baked and bleached rock with abundant thin carbonate veinlets. Erosion of the dike and contact zone rocks provides material relatively rich in metallic elements to the streams; hence, the presence of anomalous nickel and chromium in the stream sediments probably indicates the presence of dike swarms rather than ore deposits.

Aggrading glacial streams accumulated metal concentrates that may or may not be indicative of bedrock mineralization upstream. Some glacial outwash stream sediments show small but real concentrations of a suite of elements including iron, titanium, lanthanum, chromium, niobium, vanadium, yttrium, and zirconium. These concentrates were caused by a lag effect; the fast-moving glacial streams selectively carried off light minerals, and left the heavy minerals that contain this suite of elements. The same suite of metals was found in panning concentrates, which indicates the validity of the proposed mechanism.

RESULTS OF GEOCHEMICAL STUDIES

The geochemical studies show both many local concentrations of metals in stream sediments and systematic geographic distributions for individual elements. Some of the distribution patterns are related to mineral deposits in the bedrock, some to metal-rich country rocks, some to lag concentrates, and others are not clearly related to any of these. The distribution of anomalous values are shown in figures 4 to 15 and are discussed below with reference to known geologic features. The interpretations given are necessarily brief and further development of the detailed relations between stream sediment metal contents and bedrock composition of the drainage basins involved would be possible in some instances.

Total Heavy Metals

Anomalous THM values are widely scattered at Glacier Bay (fig. 4). Some of them cannot be assigned to any distinct mineralized zone and are interpreted to be the result of widely scattered but individually small centers of hydrothermal alteration and mineralization.

Inspection of the map shows that THM values are generally higher in the relatively unmetamorphosed and dominantly detrital clastic Chilkat Province than in the dominantly metamorphic and granitic Geikie or Muir Provinces (fig. 2). Within the Chilkat Province there are noticeable concentrations of anomalous THM values near the head of Excursion River, near Miller Peak and Sandy Cove, northwest of Tidal Inlet near Mount Merriam. The areas near Miller Peak-Sandy Cove and Mount Merriam are underlain by a variety of sedimentary rocks cut by small stocks and are discussed under "Areal Descriptions" (p. 48 to 52).

Anomalously high samples near the head of Excursion River are close to a prominent fault zone, which controls the north-northwest course of the river, and are probably related to mineralization along the fault zone, such as that known at the head of Adams Inlet. Farther east, additional subparallel faults are suggested by prominent topographic alinements. Some of the anomalous samples, particularly those in uppermost Berg Creek, show high copper and chromium contents also.

Isolated anomalous values scattered through the Chilkat Province are probably related to additive contact metamorphism or related mineralization. Isolated anomalous THM values east, west, and south of Snow Dome are related to an abundantly iron-stained contact zone with small magnetite masses adjacent to a granodiorite stock. An isolated anomalous THM value north of the Nunatak molybdenum prospect probably reflects copper and zinc added during molybdenum mineralization. High THM values north and south of White Glacier probably result from the zinc and copper deposits (6 on fig. 3A) known in the area.

In the Geikie Province, high THM values are concentrated near Dundas Bay. Many of these values are due to high copper contents, and they are discussed either with copper deposits or in the descriptions of the geochemical results in the eastern and western Dundas Bay areas. The Reid Inlet gold area is not marked by any conspicuous THM anomaly even though the gold deposits contain some sphalerite, which should contribute zinc to the streams. One anomalous high and several moderately high values of THM (60-119 ppm) are found in the Reid Inlet area, however. A very metalliferous stream sediment (1000 ppm) was found north of the area in Tarr Inlet.

Only a small number of stream sediment samples were obtained from the Muir Province because of dominant glacial drainage. The region seems to have a low THM content.

Copper

The copper distribution pattern (fig. 5) resembles that of the THM distribution, particularly in the generally higher metal values of the Chilkat Province in comparison to the Muir and Geikie provinces. The pattern in not, however, identical with THM; part of the difference is because the THM test is most sensitive for zinc and less sensitive for copper and lead, hence high THM does not necessarily indicate high copper. The difference between THM and copper values is very noticeable at the head of Excursion River and in the Miller Peak-Sandy Cove area. At both of these places only part of the THM anomalies is due to copper and an appreciable part is due to zinc, as is shown by comparison of the THM and the copper, zinc, and lead spectrographic analyses. In other places, as in uppermost Berg Creek east of Adams Inlet, anomalies barely discernible in THM are obvious in copper.

No copper anomalies were found in the Muir Province although it should again be noted that this area is extensively covered by glaciers and has few flowing streams.

The Geikie Province contains several conspicuous copper anomalies, even though the background copper content is lower here than the Chilkat Province. The largest anomaly is east of Dundas Bay where copper ranges up to 300 ppm in streams draining a large altered and mineralized area (fig. 3A). Near the head of Taylor Bay copper and THM values are high in a small creek draining across a gold prospect (Rossman, 1963b, plate 1). Most of the Reid Inlet gold area does not contain copper anomalies, but stream sediments collected east and west of the central part of the area do have anomalous copper contents. An isolated stream sediment sample on the west side of Tarr Inlet contained 700 ppm copper. A single sample from near the south end of the peninsula between Tarr and Rendu Inlets shows a barely anomalous value, but may be significant as it lies near a locally magnetite-bearing batholithic contact zone.

Lead

The distribution of lead resembles that of THM, but the correlation with the copper pattern is less marked. The data indicate broad areas of anomalous lead concentration in the southern part of the Chilkat Province and in the northern and southern parts of the Geikie Province (fig. 6).

Lead is somewhat enriched in two samples south of Snow Dome, one of which was marked by an anomalous THM value; these values are probably derived from mineralization in a nearby contact zone. Lead also furnishes one of the few geochemical clues to the Reid Inlet gold area; anomalous amounts of lead are present in drainages on the Lamplugh Glacier side of the area. Galena present in the gold deposits probably explains the anomalous values.

A small lead and THM anomaly north of Marble Mountain may be related to hydrothermally altered limestone country rock. The highest lead value found (200 ppm) is from the west shore of Tarr Inlet and coincides with anomalous values in THM, copper, and other metals. Slightly enriched values of lead (16-24 ppm) occur in drainages entering the south side of Johns Hopkins Inlet and also east of the Tarr Inlet about due east of the 200 ppm anomaly noted above. At both places the streams drain leucocratic granitic rocks, which are the only unmineralized rocks in the Monument that contain spectrographically detectable lead (table 3).

Molybdenum

The largest area of anomalous molybdenum content is in the northernmost Chilkat Province near Mount Merriam. Other areas of possible significance are near Miller Peak and Sandy Cove, and at the head of Dundas Bay. The spectrographic analyses indicated only markedly anomalous values of molybdenum because of the relatively poor sensitivity (10 ppm). As a result, no regional molybdenum background was detected (fig. 7).

Detailed soil sampling (fig. 30) disclosed anomalous molybdenum values near the Nunatak molybdenum deposit. The stream sediment sampling program did not detect the deposit, probably because of the recent glacial erosion which stripped off all enriched soil and because of the diluting effect of the surrounding extensive outwash deposits.

Chromium and Nickel

Chromium (fig. 8) and nickel (fig. 9) have a distribution pattern that generally resembles the pattern for copper (fig. 5). As is the case with all of the metallic elements discussed, chromium and copper are regionally most abundant in the Chilkat Province.

The largest chromium anomaly in the Chilkat Province is in upper Berg Creek. This area, which is also the site of a copper anomaly, is underlain by mixed volcanic and detrital clastic rocks, and some iron-stained zones cropout nearby. The chromium anomaly may persist downstream to Adams Inlet. Another chromium anomaly, which is traceable downstream, was detected along a tributary on the west side of Queen Inlet. The anomaly originates in an area where limestone and limy sandstone are intruded by granitic rocks.

Two anomalous and several moderately high chromium values near Mount Wright apparently are caused by a mafic dike swarm, and isolated values elsewhere may mark mafic dikes. Nickel is also markedly enriched near Mount Wright.

Other Elements

Anomalous amounts of tin, tungsten, strontium, silver, and other metals are recorded on figure 10. Tungsten was found only in two samples at the head of Dundas Bay, near exposures of leucocratic granitic rocks. Tin was noted there and at several other places, the most significant being the 500 ppm content of the highly anomalous stream sediment sample in Tarr Inlet.

Silver was found in amounts ranging from 1 to 10 ppm at several scattered localities, including the Tarr Inlet sample and a sample south of Margerie Glacier. Strontium is markedly enriched in two areas, the Miller Peak-Sandy Cove area and the Mount Merriam area. Both of these areas are also characterized by relatively high THM and molybdenum values.

Areal Descriptions

More detailed geochemical data are available for some of the areas of the Monument in which mineral deposits are known or in which one or more geochemical anomalies were detected. Areas for which more complete data exist are at (1) western Dundas Bay, (2) eastern Dundas Bay, (3) Miller Peak-Sandy Cove, (4) Mount Merriam, and (5) Reid Inlet.

Western Dundas Bay Area

Scattered anomalous values of THM, beryllium, copper, molybdenum, tin, and tungsten occur in the western Dundas Bay area (fig. 11). Some of the high THM values are caused mainly by anomalously high copper concentrations, others by zinc.

Tungsten- tin -molybdenum anomalies occur in two streams entering the head of Dundas Bay (Samples 12 and 13, table 4, fig. 11). The tungsten content of these samples is unusually high, and molybdenum and tin are also noticeably enriched. The headwaters of the stream of sample 12 drain an area near the contact of older granitic rocks and a leucocratic pluton, and it seems probable that the source of the anomaly is mineralization along or near the contact.

The composition of the leucocratic pluton itself is reflected in the beryllium and lead content of stream sediment samples from areas underlain by the pluton (14, 15, 17, 18, and 20, table 4). The beryllium content of these samples is not high in terms of estimated crustal abundance, but because beryllium is generally present in the Monument in concentrations of less than 1 ppm, the 2-3 ppm concentrations represent enrichment. Similarly, the lead content of these samples is only 15 ppm, a level that is not markedly anomalous around Glacier Bay; however, lead contents are generally low in this area so 15 ppm is a local anomaly. Except for the 120 ppm THM value of nearby sample 12, the area with anomalous tungsten does not have anomalous THM content.

Samples that show anomalous values of THM interpreted to be due primarily to zinc or copper, are concentrated in a small area on the west side of Dundas Bay, near samples 56, 59, 60, and 65 (table 4). The high THM values of samples 56 and 59 are probably caused by zinc, as spectrographic determinations show no lead and near background values of copper. One markedly anomalous sample (number 68, 200 ppm THM) is related to an abandoned cannery, as also evidenced by 0.1 percent tin (not shown on table 4).

Anomalous THM and copper values are also found in an unnamed stream draining into the head of Taylor Bay (samples 77 and 78, fig. 26, table 4) from an area of gneissic rocks. Rossman (1963b) reported a gold prospect in the drainage.

Eastern Dundas Bay Area

A small area east of Dundas Bay and not far north of Icy Strait contains two THM anomalies (fig. 12). The first, near the shore, contains both high THM and copper values and occurs in an altered zone. The metal content of the zone ranges from 100 to 300 ppm copper and as much as 30 ppm lead (samples 2, 3, 4, 4A, and 5, table 5). This occurrence is described more completely under copper mineral deposits.

The second anomaly is about 3 miles further east; it contains high THM values (samples 8, 9, 10, and possibly 18, table 5). The most metal rich sample (no. 8) was taken from a stream bed that flows along the contact of an igneous pluton with limestone country rock. Near sample 18 on Icy Strait, limestone exposed along the beach contains jasperoid masses as much as a foot across. This THM anomaly is partly due to zinc, because the THM values in samples 8, 9, and 10 are in excess of the total of copper plus lead.

Miller Peak-Sandy Cove Area

The Miller Peak-Sandy Cove area is on the east side of Glacier Bay, north of the mouth of Beartrack River and south of Mount Wright (fig. 13). The area contains the Sandy Cove gold-copper prospect, which is immediately to the east of sample locations 41 and 41A. In addition, there are several small areas of anomalous metal content. These are discussed starting at the northwest part of the map.

Stream sediment samples collected south of Mount Wright, particularly samples 1 through 13 and 19, 22, and 23 (table 6), are generally characterized by anomalous or relatively high values in THM, copper, chromium, and nickel. The area is mainly underlain by fine-grained detrital sedimentary rocks, subordinate limestone, and amygdaloidal basalt or andesite, which are all cut by numerous mafic dikes. Our interpretation is that the anomalous metal values probably are derived from the dikes or small-scale vein mineralization in the baked and altered walls of the dikes.

Streams further east (samples 14 and 15) drain a mixed sedimentary terrane which includes limestone, and the THM values may reflect mostly zinc from mineralized carbonate rocks like those known to exist near White Glacier (fig. 3A).

Similar mineralization may exist to the south and southeast of samples 28 to 38, where the anomalous or relatively high values of THM and trace amounts of lead may be derived from a mixed sedimentary terrane.

A group of samples in a tributary stream east of the Beartrack River (particularly samples 56 through 69) show relatively high or anomalous values of THM and copper. The bedrock in the stream drainage is graywacke and argillite and the origin of the THM and copper values is unknown.

Samples in the southwestern part of the area locally show anomalous values of THM, copper, molybdenum, and strontium. These values are probably related to a pluton near Miller Peak. Samples 92 and 99 show anomalous concentrations of copper and molybdenum, respectively.

Mount Merriam Area

There are no mines or prospects in the geologically complicated Mount Merriam area (fig. 14, 3B), but there are many stream drainages containing anomalous concentrations of THM and molybdenum and some outcrops of unprospected mineralized rock. The high THM values seem to be due to zinc, for neither lead nor copper are abundant. The area is similar to the Sandy Cove-Miller Peak area in having numerous high strontium values, showing additive contact metamorphism in the hornfelses and marbles around the granitic stocks.

The highest concentrations of molybdenum are found in a small part of the area east of Composite Island (samples 8, 13, 14, 20, and 21, table 7). Some of these samples also have high THM values, which, however, are not confined to this small area. Molybdenum is present in greater than detectable quantities in all samples from the Mount Merriam area.

Reid Inlet Gold Area

The Reid Inlet gold area (figs. 3A, 15, and tables 8, 11 and 12) contains the main gold deposits of the Monument, but it is not well marked by geochemical patterns.

The mixed greenstone and granitic terrane west of Lamplugh Glacier has a distinct copper anomaly, and several of the samples, notably 8, 9, and 16 (table 8) east of Reid Inlet also contain anomalous amounts of copper. Most of the area, however, seems characterized by less than background amounts of copper. As the gold generally is accompanied by galena, lead might be expected to be abundant, but only locally is this the case (table 8, samples 1, 2, 3, 4), although a greater sample density might have given a stronger pattern. Gold was found by panning in Ptarmigan Creek below the LeRoy mine and is visible in vein material elsewhere, so the Reid inlet area seems to be an example of an area in which an old-fashioned prospecting method--panning--is more satisfactory than geochemical methods.

MINERAL DEPOSITS

GENERAL STATEMENT

Deposits of gold, silver, molybdenum, iron, nickel, titanium, copper, and other metals are known from Glacier Bay National Monument. Some of these deposits have been mined or explored on a small scale, but many of them are essentially unexplored. Two of the deposits, the Brady Glacier nickel-copper deposit and the Nunatak molybdenum deposit, have been investigated in some detail. The term "mineral deposit" is used broadly in this report to include anomalous concentrations of ore metals. The deposits described range from small insignificant mineral occurrences to some deposits that apparently are large or rich enough to warrant exploration.

Our field investigations stressed evaluation of deposits of metallic commodities and involved examining (1) all known mines and prospects, (2) the many deposits discovered during the current investigation, and (3) some of the mineralized areas found by geochemical sampling. The mines and prospects were sampled and, in most cases, mapped in detail. The discoveries made during the current investigation were sampled and their apparent sizes and probable grades were appraised. We tried to establish the geological setting of the geochemically anomalous areas.

The current reconnaissance investigation provides information on the nature and distribution of the mineral deposits in the Monument and a basis for delineating additional target areas favorable for ore deposits. The study is not detailed enough to provide evaluations as to the economic feasibility of developing and mining a specific deposit, either currently or in the future. Such evaluations would require more extensive investigation and physical exploration, metallurgical and cost analysis surveys, and other studies necessary to establishing the feasibility of present or future mining.

The examinations were limited by such factors as time, difficult access, and the poor exposures of some of the deposits. Evaluating the mountainous 3,900 square mile Glacier Bay National Monument in only $3\frac{1}{2}$ months necessitated cursory examinations of many deposits. Access was impeded by rough terrain that required time-consuming climbs and descents and by locally dense brush. Foul weather was another obstacle, and low clouds and inclement weather prevented much of the contemplated work in the higher parts of the Fairweather Range. Many of the deposits are partly covered and obscured by snow, ice, and vegetation, or by diverse post-ore rocks and rock debris which prevent satisfactory estimates of their size and extent. Despite these limitations the coverage for most of the Monument is good, and we believe that most large or significant deposits that crop out east of the Fairweather Range were examined. The results of the geochemical sampling program provide a basis for evaluating the sizeable tracts of the Monument where bedrock is covered. However, significant undiscovered deposits which might be found by extensive and thorough prospecting, using modern geophysical and geochemical methods, may exist in the Monument, particularly in covered parts or in the Fairweather Range. Exploration of some known deposits may reveal larger and(or) richer ore bodies than those indicated by the surface examinations.

This report describes most of the known mineral deposits within the boundaries of the Monument. The exceptions are the ilmenite-rich deposits that are widely distributed in the mafic layered intrusives of the Fairweather Range (Rossman, 1963a) but were not examined during the current investigations. Only a few ilmenite localities are discussed specifically because the limited geologic information concerning them indicates that they are similar. However, comparable ilmenite-rich deposits are probably extensive and widespread throughout the mafic layered intrusives.

The following part of this report consists of descriptions of the known metal-bearing mineral deposits within the Monument. These descriptions are based largely on field and analytical data obtained during the current project, but they also include pertinent information obtained from previous investigations. The parts of this report describing nonmetallic commodities and petroleum are based mainly on previous investigations.

In anticipation of queries about the selection of material included in this section of the report, it should be emphasized that all deposits which were examined in detail are reported on here. All of the field and analytical data obtained are given for each of these deposits. Many other occurrences of metallic minerals were also noted, sampled, and analyzed, but were deemed wholly insignificant because of limited grade or size and are therefore not described. The locations of such samples also are shown in figure 3a. We have neither included nor excluded data arbitrarily.

METALLIC COMMODITIES

Metallic commodities in the Monument include the following groups: base and miscellaneous metals, precious metals, and iron and ferroalloy metals.

The most important known deposits in the Monument are the Nunatak molybdenum prospect (21), the Brady Glacier nickel-copper prospect (72), the Alaska Chief copper prospect (29), the Margerie copper prospect (19), the gold deposits of the Reid Inlet gold area and the Sandy Cove prospect (7), the placer gold deposits on the beaches near Lituya Bay (87, 88), and several iron and titanium deposits associated with the layered intrusives of the Fairweather Range.

Locations of deposits that contain anomalous concentrations of one or more of the metallic commodities are shown in figure 3A. Numbers or letters, shown in parentheses in the text, refer to the deposit locality number or letter shown on figure 3A next to the circles. Each circle in figure 3A indicates a discrete deposit or a group of deposits. Analyzed samples that contain only background concentrations of ore metals are shown by solid dots or solid dots with a cross in figure 3A; their analyses are not included in this report. Individual deposits are described under the commodity that would most likely yield the major mineral values, and these descriptions are referenced in descriptions of other lesser commodities in the deposit.

Base and Miscellaneous Metals

Anomalous concentrations of the following base and miscellaneous metals were found in the Monument: antimony, arsenic, bismuth, cadmium, copper, lead, tin, and zinc. Except for copper and zinc none of these elements appear to occur in significant quantities, although a few, notably lead, may be considered possible byproduct metals. Minor occurrences of radioactive minerals have been reported from the Monument, and these are also discussed briefly.

Antimony

Antimony is a minor constituent of several of the copper deposits, the Rendu Inlet silver deposit (37), and the silver-lead-zinc deposits near Mount Brack (12). Only two of our samples contained detectable antimony; one from the Mount Brack deposits contained 7,000 ppm antimony (table 9), probably as a constituent of a lead-bearing sulfosalt. The other, from the Francis Island copper deposit (28), contained 200 ppm antimony (table 9).

Tetrahedrite, a copper-antimony sulfide, has been reported from the prospect on the west side of Willoughby Island (27) (Reed, 1938, p. 72), from the Rendu Inlet silver prospect (37) (Buddington, 1924, unpublished notes) (Rossman, 1963b, p. 48, 49), and from Blue Mouse Cove on the south shore of Gilbert Island (42) (Rossman, 1963b, p. 50). Buddington (1924, unpublished notes) also reported jamesonite from the prospect on the west side of Willoughby Island and noted that an ore sample from there contained 25 percent antimony. L. F. Parker (oral communication, 1966) states that one of his samples that was assayed by the State (then Territorial) Division of Mines and Minerals contained several percent of antimony. This sample was from the north side of Johns Hopkins Inlet near locality (64), but none of our samples from that general vicinity contained antimony.

Arsenic

Arsenic was detected in samples from many localities in the Monument. It is particularly abundant in the Reid Inlet gold area (fig. 3A) as a constituent of arsenopyrite that is associated with the gold lodes. Arsenic was also found in the Mount Brack argentiferous base metals deposits (12), the Margerie copper prospect (19), on the west side of Tarr Inlet (17), and at a locality west of McBride Glacier (10).

Most of the accessible Reid Inlet gold deposits contain arsenic, which occurs commonly or entirely in arsenopyrite. The arsenic content of samples from the LeRoy mine (B) (table 11) is as much as 20,000 ppm. Samples from the Rainbow mine (C) (table 11) contained as much as 1,500 ppm arsenic, and those from the Monarch mines (E) (table 11), the Incas mine (G) (table 11), and the Rambler prospect (L) (table 11), respectively contained maxima of 7,000, 20,000, and 50,000 ppm arsenic. Minor amounts of arsenopyrite are reported from the gold quartz veins of the Sunrise prospect east of Reid Inlet (Reed, 1938, p. 64). An unidentified arsenic mineral was collected from a narrow vein on the eastern shore of Reid Inlet (Rossman, 1959, p. 57). Arsenopyrite is also a probable accessory mineral in the unsampled and inaccessible gold lodes near Reid Inlet. Their geologic settings are similar to those of nearby arsenic-bearing deposits.

Two samples from the Mount Brack deposits (12) (table 9) contained 7,000 and 30,000 ppm arsenic respectively. These samples represent complex silver-bearing base metal deposits, but the mineral host for the arsenic was not determined. A sample from a quartz vein at the Margerie copper prospect (19) (table 9) carried more than 10 percent arsenic. Another sample from the same vein contained 50,000 ppm arsenic, and a sample from a nearby altered zone revealed 2,000 ppm arsenic. Arsenic at the Margerie prospect is incorporated in arsenopyrite. An altered zone on the west side of Tarr Inlet (17) (table 9) south of the Margerie Glacier contained 5,000 ppm arsenic. Arsenic in quantities of 7,000 and 15,000 ppm was detected from a deposit localized at a facies change between marble and phyllite west of McBride Glacier (10) (table 9).

Löllingite, an iron di-arsenide, was questionably identified from the prospect on the northeast side of Willoughby Island (26) (Reed, 1938, p. 70, 71). Minor amounts of arsenic are reported in spectrographic analyses of the tactite that crops out south of Mount Merriam in the Mount Fairweather D-2 quadrangle (Rossman, 1963b, p. 41).

Many of the arsenic-bearing deposits are associated with gold and silver, and, as often is the case, the arsenic minerals may serve as useful indicators in prospecting for those precious metals.

Bismuth

Small amounts of bismuth were detected in samples from 12 localities (fig. 3A, tables 9 and 11). The highest bismuth analyses were 500 ppm from the Sandy Cove gold-copper prospect (7), 300 ppm from the Margerie copper prospect (19), 200 ppm from the Alaska Chief copper prospect (29), and 150 ppm from the Francis Island copper prospect (28). No bismuth-bearing minerals were identified, but bismuth is probably a minor constituent of some of the sulfides or sulfosalts.

Cadmium

Cadmium was detected from four localities in the Monument (tables 9 and 11): the Mount Brack argentiferous base metal deposits (12), sulfide lenses southwest of Red Mountain (20), the LeRoy mine (B), and the copper-zinc deposits north of White Glacier (6). The most cadmium found, 1,000 ppm, was in a sample from the LeRoy mine. Cadmium proxies for zinc geochemically, and all of the cadmium-bearing samples contained larger amounts of zinc than cadmium. Probably most of the cadmium is a minor constituent of sphalerite, but possibly some of it forms the cadmium sulfide, greenockite.

Copper

Distribution

Copper minerals are widespread and locally abundant throughout the Monument (fig. 3A). Among the previously known deposits whose major commodity is copper are those on the west side of Tarr Inlet (18), at the Margerie prospect (19), on Willoughby Island (26) (27), on Francis Island (28), at the Alaska Chief prospect (29), and at several localities in the Fairweather Range (78) (80) (82). In addition copper constitutes a potential byproduct at the Brady Glacier nickel-copper deposit (72), the Nunatak molybdenum prospect (21), the Sandy Cove gold-copper prospect (7), and the Rendu Inlet silver prospect (37).

Most of the discoveries resulting from our investigations contain anomalous concentrations of copper. The most significant of these are north of White Glacier (6), near Gable Mountain (14), south of Rendu Glacier (15), near Dundas Bay (31), in the Bruce Hills (34), west of Shag Cove (49), and west of Tarr Inlet (62) (63).

Types of Deposits

The copper lodes occur in diverse types of deposits in several different geologic environments. They include (1) altered zones, which are mainly mineralized fault zones, (2) massive sulfide bodies, (3) veins, (4) fracture coatings, (5) local disseminations, (6) contact-metamorphic deposits, and (7) low-grade copper-bearing amygdaloid. A clear distinction of type is impossible for many deposits because of intergradation of types. Typical examples of these types are described below.

Deposits in altered fault zones are best exemplified by those east of Dundas Bay (31). The massive sulfide deposits are diverse and include replacements in metamorphic rocks as at the Alaska Chief prospect (29), the nickel-copper lenses in gabbro at the Brady Glacier prospect, and the cupriferous pyrrhotite-rich lenses(?) at the Margerie prospect (19). The copper-bearing veins are widely distributed but are generally narrow. They are dominantly quartz veins, but some contain moderate quantities of calcite. The gold-bearing veins at the Sandy Cove prospect (7) carry good copper values, and many other veins in the Monument are enriched in copper. Networks of closely spaced veins and veinlets in bleached and altered metamorphic and granitic rocks form deposits that are similar to some porphyry coppers at the Nunatak molybdenum prospect (21), parts of the Bruce Hills deposit (34), and at and near the southwestern end of Gilbert Island (44) (45). Copper minerals coat fractures at the deposit at Gable Mountain (14) and at a few other deposits. Disseminated copper minerals were noted in granodiorite in the Bruce Hills (34), in siliceous lenses west of Tarr Inlet (63), in hornblendite dikes near Dundas Bay (58), and in hornfels at a few localities near Johns Hopkins Inlet (75) (76). Copper minerals are subordinate constituents of some of the skarns as at the Queen Inlet magnetite deposit (40) and the deposit south of Abyss Lake (54). A very lean copper deposit is localized in the amygdaloid on the north shore of Adams Inlet (5).

In general, the deposits range in size from isolated veins and lenses only a few inches thick, through sulfide bodies a few tens of feet in minimum dimension, to extensive networks of veins and mineralized zones that are several hundred feet wide. The deposits are in many different geologic settings, but most of them are in or near intrusive rocks.

Chalcopyrite is the dominant copper mineral in almost all of the deposits. Bornite or tetrahedrite are the chief ore minerals in a few of the deposits and subordinate associates of chalcopyrite in several others. Secondary copper minerals, chiefly azurite, malachite, and chrysocolla, are sparsely distributed in a few of the lodes.

Descriptions of the Deposits

Mount Young Area.--Several small base metal and silver deposits occur near Mount Young (fig. 3A) (1). Only two of our samples from these deposits showed anomalous amounts of metals, and in these the minor zinc and silver values outweigh those of copper. However, the deposits are discussed under copper because some of them contain chalcopyrite, and because copper minerals have been reported nearby.

The deposits are in a geologically complex area characterized by a variety of metamorphic rocks, small granitic plutons, and mafic dikes. The best analyses were from a sample consisting of sulfides, chiefly pyrite, replacing metavolcanic rocks and from a sample of altered hornfels and slate (table 9) (1). These contained as much as 1,500 ppm zinc and slightly anomalous amounts of silver, chromium, copper, molybdenum, and lead. The deposits consist of short quartz veins that commonly are less than 6 inches thick, and numerous altered zones commonly about 2 feet thick which were traceable for only a few tens of feet because of contiguous ice and snow. A few altered zones are as much as 10 feet thick and are exposed for about 100 feet. The altered zones transect metavolcanic rocks, schist, hornfels, slate, and marble; a few zones are localized along the margins of mafic dikes that cut the metamorphic rocks. The altered zones consist of hydrous iron sesquioxides, carbonate minerals, and quartz along with subordinate pyrite, traces of chalcopyrite, probably a secondary zinc mineral, barite, and clay minerals.

The quartz veins are best developed in the schist. They also occur in the other metamorphic rocks, along the margins of dikes, and as ladder veins within the dikes. Commonly the veins contain minor amounts of pyrite and, rarely, traces of chalcopyrite. Assays of samples from three of the quartz veins all showed less than 0.0015 ounce per ton gold.

Several iron-stained ankeritic altered zones between 5 and 30 feet thick cut mostly granitic rocks near locality (2) about 3.5 miles northwest of Mount Young (fig. 3A). Samples from these zones contained slightly anomalous amounts of copper and molybdenum (table 9) (2) and less than 0.0015 ounce per ton gold.

Copper minerals have been reported near Mount Young and from a few miles west of Mount Young (Lathram and others, 1959, their nos. 18 and 20).

The deposits near Mount Young that were examined are too lean to be of economic importance, but the abundant indications of weak mineralization and the fact that much of the bedrock is concealed by snow and ice might warrant additional prospecting during a relatively snow-free summer or by geophysical methods.

East of Casement Glacier.--Several altered zones cut the granitic rocks near the southeast edge of Casement Glacier (fig. 3A) (4). These zones are 5 to 30 feet thick and probably are mineralized fault zones. They are best developed near contacts between the granitic rocks and hornfels. The zones contain scattered pyrite and an array of oxidized gangue minerals. Analyses of representative samples of these altered zones show only slightly anomalous amounts of copper and molybdenum (table 9) (4).

Many conspicuous altered zones as much as 50 feet thick occur near Snow Dome, about 5 miles northeast of locality 4 (fig. 3A). They are mainly localized near contacts between granitic rocks and hornfels. Samples collected from these zones were essentially barren of ore metals.

North Shore of Adams Inlet.--Weakly mineralized amygdaloidal lavas are exposed for about 500 feet along the north shore of Adams Inlet (fig. 3A) (5). A few steeply dipping mafic dikes cut the lavas. The lavas are flows of amygdaloidal and vesicular altered basalt as much as 15 feet thick. They are porphyritic with plagioclase (labradorite) phenocrysts in a highly altered very fine grained groundmass that probably originally was intergranular or intersertal. Phenocrysts constitute about a third of the rock and are as much as 6 mm long, but typically about 3 mm long. The altered groundmass is composed of iron-poor epidote, actinolite, and lesser amounts of calcite, dolomite, and chlorite. Minor amounts of pyrite are scattered throughout the lavas.

All of the lavas are weakly mineralized with sulfides. Most of the sulfides are localized along fractures, and generally they are most abundant near the dikes. The sulfides probably formed during the low-grade metamorphism of the lavas and consist of pyrite and trace amounts of chalcopyrite and pyrrhotite(?). Extensive sampling showed that the lavas are very low in metal content (table 9) (5). All of the samples contained slightly anomalous amounts of copper; one sample contained 300 ppm cobalt. Most samples contained trace amounts of molybdenum, and silver and tin were each detected in one sample.

The mafic dikes are also altered basalts, but they are more intensely altered than the lavas. They are porphyritic and consist of medium-grained plagioclase phenocrysts in a highly altered very fine grained groundmass. The phenocrysts are probably oligoclase, and their cores are generally more altered than their rims. The groundmass is dominantly epidote and actinolite along with small amounts of calcite, chlorite, and leucoxene. Pyrite and subordinate ilmenite and magnetite are scattered throughout the dikes.

North of White Glacier.--Many mineralized zones are exposed north and northeast of a northward protruding lobe of White Glacier (fig. 3A) (6). These zones cut both limestone and the structurally overlying volcanic rocks. Some zones are near mafic dikes and a small granitic cupola that cuts the limestone. The altered zones in the limestone are less than 10 feet thick and generally not traceable for more than 100 feet. Those in the volcanic rocks are less numerous but larger and range from 2 to 200 feet in thickness; some of them can be traced for long distances.

The altered zones in the limestone contain abundant ankeritic carbonates and barite and lesser amounts of quartz, chlorite, pyrite, and copper minerals. Parallel sets of quartz veins between 1 and 4 inches thick transect some of the zones. Several zones are parallel to mafic dikes and a few are cut by mafic dikes. The sulfide mineralization commonly is strongest near the borders of the dikes. Thin pyritic lenses occur on bedding surfaces in the limestone contiguous to the altered zones. Analyses of samples from altered zones that cut the limestone are shown in table 9 (6) (nos. 66AMk-253 through 256B). These zones locally carry significant amounts of copper along with minor amounts of silver, zinc, and cadmium. Their gold content is negligible.

The altered zones in the volcanic rocks are conspicuously iron stained. A few locally contain abundant pyrite. A 6-foot long chip sample representative of one of these zones carried 20,000 ppm zinc (table 9) (4) (66AMk-257). The host mineral for the zinc was not identified. Gold values in samples from these zones were negligible.

The deposits north of White Glacier appear to be locally rich enough and large enough to warrant prospecting. A few altered zones south of White Glacier south of locality 8 were examined, but samples from them yielded negative results.

North of York Creek.--About fifteen widely spaced pyrite-rich veins and altered zones containing pods of pyrite cut the hornfels country rock north of York Creek (fig. 3A) (8). A sample representative of the hornfels consists mainly of quartz and tremolite with moderate amounts of plagioclase and minor biotite. Both the veins and the altered zones commonly strike between N. 10° E. and N. 40° E. and dip steeply. They both consist mainly of quartz and smaller quantities of pyrite, pyrrhotite, and dolomite. Most of the veins are about 6 inches thick. A sample representative of one vein (table 9) (8) contained 1500 ppm copper and small amounts of cobalt and nickel. Some of the altered zones are brecciated and some attain widths of about 50 feet. A chip sample across one of the altered zones (table 9) (8) carried 15 ppm of molybdenum. The deposits north of York Creek are too small or too lean to justify exploration.

Minnesota Ridge.--Copper minerals were found on Minnesota Ridge in a small outcrop within an extensive snowfield (fig. 3A) (13). The outcrop is composed of coarse-grained biotite-hornblende granodiorite or quartz diorite that is cut by a 3-foot thick porphyritic andesite dike. The deposit consists of pyrite, chalcopyrite, and secondary copper or iron minerals which were probably deposited as open space fillings along narrow joints with subordinate replacement of the adjacent wallrock. A sample of the richest-appearing mineralized material contained 700 ppm copper (table 9) (13). The size of the deposit is conjectural because of the snow cover, but the deposit is too low in grade to encourage exploration.

Gable Mountain.--Outcrops of coarse-grained dioritic rocks, probably quartz diorite, are exposed irregularly in a largely snow-covered area near Gable Mountain north of Carrol Glacier (fig. 3A) (14). The deposits consist of joint coatings of unknown extent. The chief copper minerals are malachite and chrysocolla. A composite grab sample from the deposits contained 1,000 ppm copper and small amounts of silver and molybdenum (table 9) (14). Remoteness, difficult access, and snow cover will inhibit the prospecting of these deposits.

South of Rendu Glacier.--A mineralized altered zone is exposed at altitudes near 4,000 feet in the cliffs south of Rendu Glacier (fig. 2) (15). The zone cannot be reached without a difficult rock climb, and consequently it was not examined closely. Based on aerial views the altered zone appears to be in mixed rocks near the contact with a light-gray granitic pluton. It is exposed over a surface approximately 50 by 200 feet. The margins of the zone are partly concealed, and its actual dimensions may be much larger. A sample of float from the altered zone carried 2,000 ppm copper (table 9) (15). A thorough examination of the deposit including detailed sampling is probably warranted despite the deposit's inhospitable setting and remoteness.

West Shore of Tarr Inlet.--Copper lodes occur on the west side of Tarr Inlet about a mile south of Margerie Glacier (fig. 3A) (18). The deposits are fairly extensive and consist of alteration zones between 1 and 8 feet thick and local disseminated sulfides in hornfels. Chalcopyrite is the dominant copper mineral, and it generally is associated with more abundant pyrite. A sample indicative of one of the best mineralized outcrops contained 1,500 ppm copper and minor amounts of bismuth, tungsten, and tin (table 9) (18). This locality is probably at or near two lode claims for copper that are held by the Kenney Presbyterian Home, but no workings or claim markers were found in the vicinity. Claims on copper lodes were reportedly staked in the general area prior to 1906 (Wright and Wright, 1937, p. 221). A stream sediment sample collected a few hundred feet south of locality (18) (see fig. 10) contained 700 ppm copper, 0.29 ounce per ton (10 ppm) silver, 10 ppm molybdenum, 10 ppm bismuth, 50 ppm cadmium, 30 ppm arsenic, 200 ppm lead, 500 ppm tin, and 1,000 ppm zinc. The mineralized zones are fairly widespread and further investigations of them might be worthwhile.

Margerie Prospect.--The Margerie prospect is in steep and rugged terrain south of Margerie Glacier at altitudes between 1,500 and 2,000 feet (fig. 3A) (19). The prospect is on several claims located in 1960 for the Moneta Porcupine Company. The deposits are in light-colored granodiorite and nearby high-rank metamorphic rocks, chiefly hornfelses. They consist of quartz veins, mineralized shear zones, and pyrrhotite-rich massive sulfide bodies. The quartz veins, which are as much as 2 feet thick, commonly strike northeast and dip gently south. Their chief sulfide minerals are arsenopyrite and chalcopyrite. Samples from the quartz veins carry as much as 2,000 ppm copper, more than 10 percent arsenic, minor amounts of bismuth, cobalt, and tungsten, traces of molybdenum, and as much as 0.145 ounce per ton (5 ppm) gold (table 9) (19).

The altered zones strike about N. 30° W. and dip steeply to the southwest. They are about 6 feet thick and strongly sheared. Many of the nearby joints are coated with the alteration products and probably contain minor quantities or ore minerals. The altered zones are profusely iron stained, and their constituent minerals were not identifiable megascopically. Samples from the altered zones contained as much as 700 ppm copper and 2,000 ppm arsenic along with slightly anomalous amounts of barium (table 9) (19).

The massive sulfides were not found in place, but judging from float they probably occur in the steep cliffs south of the prospect. The float is dominantly pyrrhotite associated with minor chalcopyrite, quartz, and an unidentified tungsten mineral. A sample of the massive sulfide contained 3,000 ppm copper and 3,000 ppm tungsten, the highest tungsten value of any of our samples (table 9) (19).

The examination of the prospect was brief because of inclement weather. The prospect and its environs warrant a more thorough examination.

Curtis Hills.--Several small mineral deposits were found in the recently deglaciated terrain west of the Curtis Hills (fig. 3A) (23). Hornfels is the dominant rock in the area; it is cut by a few steep mafic dikes and locally mantled by glacial drift and snow. The hornfels is composed largely of tremolite with lesser amounts of plagioclase, calcite, and quartz.

The deposits consist of narrow quartz veins, which are commonly less than 6 inches thick, and of altered zones, which generally are less than 2 feet thick. Many of the quartz veins are joint fillings. Pyrite is the only sulfide mineral recognized in both the veins and in the altered zones.

Some of the deposits contain minor amounts of copper and chromium (table 9) (23). Although the area is essentially virgin because of its recent denudation, the deposits in it appear to be too small and too lean to encourage prospecting.

North Marble Island.--North Marble Island (fig. 3A) (24) consists of massive white crystalline marble cut by a few mafic dikes. Most of the marble is fairly pure and consists of a mosaic of calcite crystals from 2 and 5 mm long. Some of the marble is dolomitic. The only sulfide mineral noted is pyrite that occurs disseminated in some of the dikes and in the silicified zones adjacent to the dikes.

Reed (1938, p. 69) reports sulfide bodies as much as $1\frac{1}{2}$ feet thick and 15 feet long in the marble near some of the dikes and small deposits locally along the dikes and in joints within the dikes. He states that the sulfide deposits contain pyrite, pyrrhotite, chalcopyrite, and covellite. Buddington (unpublished notes, 1924) reported a claim staked for nickel on North Marble Island. Rossman (1963b, p. 51) mentions a mass of sphalerite and magnetite that occurs in the limestone (marble) on North Marble Island.

South Marble Island.--South Marble Island (fig. 3A) (25) is composed of medium-grained white marble cut by numerous mafic dikes. The marble is fairly pure and consists almost entirely of an interlocking network of calcite crystals. The dikes are more numerous and thicker than those on North Marble Island. Most of them strike northwest and dip northeast at moderate angles. The largest dike is about 50 feet thick and is characterized by very fine grained chilled basaltic borders and by medium-grained gabbroic interiors. A thin section from the core of the largest dike reveals the rock to be equigranular with an average crystal size of about 2 mm. The thin section consists of about 55 percent labradorite and 30 percent pyroxene. The labradorite is slightly normally zoned. Both augite and pigeonite are present. Pyroxene rims are altered to green hornblende, which constitutes about 10 percent of the rock. Magnetite is a minor primary accessory mineral, and a little sericite is an alteration product of the plagioclase.

The mineral deposits are associated with the largest dikes and consist of disseminated pyrite within the dikes and pyrite-rich impregnations in the silicified wallrock near borders of the dikes. A few barren calcite veins cut some of the dikes. Samples from the deposits were all low grade and contained only slightly anomalous amounts of copper and nickel (table 9) (25). Reed (1938, p. 69) states that the sulfide mineralization on South Marble Island is similar to that on North Marble Island but appears to be less intense.

Willoughby Island.--Willoughby Island is underlain by massive light-gray limestone that has been locally converted to marble, and which is cut by many mafic dikes and by a few felsic dikes. Glacial drift mantles some of the northeastern part of the island. Both the mafic and felsic dikes are very fine grained. The 2 to 30-foot thick mafic dikes retain relict pilotaxitic textures, but their original glassy groundmasses have been devitrified. They consist of labradorite microphenocrysts and andesine microlites associated with an array of very fine grained minerals including chlorite, K-feldspar(?), cristobalite(?), opaque dust, and calcite. Their primary mafic minerals have been obliterated. Reed (1938, p. 72) reports that one of the mafic dikes from a prospect on the west side of the island consists mainly of andesine with considerable chlorite, quartz, pyroxene, and magnetite, and a little calcite. The felsic dikes consist chiefly of quartz and plagioclase.

Minor amounts of oxidized hydrothermally altered material occupies thin breccia zones contiguous to some of the mafic dikes and in the limestone and marble.

Two prospects are reportedly on Willoughby Island (Reed, 1938, p. 70), but despite an intensive search neither was found. One of the reported prospects is on the northeast side of the island at an altitude of about 750 feet (fig. 3A) (26), and the other is on the west side of the island at an altitude of about 450 feet (fig. 3A) (27). The northeast part of the island is covered with dense brush, and the western part of the island is rugged and in places covered with slide debris.

According to Reed (1938, p. 70, 71) the prospect on the northeast part of the island (26) is apparently a sulfide replacement of limestone. It was exposed over an area of 15 by 5 feet and for a height of 15 feet, and it consists of massive pyrite with subordinate chalcopyrite and löllingite(?). One end of the deposit was covered with talus (Reed, 1938, p. 70, fig. 5). At least three other similar deposits have been reported from the northeast part of the island.

The prospect on the west side of the island (27) is ambiguously reported to be both about 2 miles and about 1 and 1/4 miles south of the northwest tip of the island (Reed, 1938, p. 70, 71). The prospect is in marble near two intersecting lamprophyre (mafic) dikes (Reed, 1938, p. 71, fig. 6). The ore forms irregular pods or kidneys along intersections of the dikes and also thin veins along the dike contacts or along joints in the marble. It consists of chalcopyrite, pyrite, tetrahedrite, and an unidentified sulfide mineral. Reed (1938, p. 72) stated that prospecting downward along the dike intersections might be justified. Buddington (1924, unpublished notes) reported that ore probably from this deposit assayed 25 percent lead, 25 percent antimony, 1.74 ounces per ton gold, and 42 ounces per ton silver. It is not known whether this sample represents selected high-grade specimens or whether it is representative of the vein material. Buddington (1924, unpublished notes) also reported jamesonite from an unspecified locality on the west side of Willoughby Island.

Francis Island.--A copper-zinc-silver deposit is near the contact of quartz diorite and the predominantly marble country rock near the southwestern shore of Francis Island (fig. 3A) (28) (fig. 16). According to Buddington (1924, unpublished notes) a prospect was formerly located on the deposit, but the prospect site is now concealed by landslide debris. Outcrops are good in the near-shore cliffs, but they are sparse toward the interior of the island because of dense vegetation.

The quartz diorite is a coarse- to medium-grained rock that is hypidiomorphic granular in texture. It consists largely of plagioclase with calcic andesine cores and calcic oligoclase exteriors. Reddish-brown biotite and green hornblende are characteristic accessory minerals, and quartz is a minor interstitial component. Magnetite is a minor accessory mineral. Pyrite is sparsely distributed in some of the quartz diorite, and in places is altered to hematite. Narrow seams of tremolite are irregularly distributed in some of the marble, and its presence plus the coarseness of the marble indicates that a pluton probably underlies the island at shallow depths.

The quartz diorite intrudes the marble, and its irregular salients cut the marble in a few places (fig. 16). A contact-metamorphic aureole consisting of tactite and hornfels as much as 5 feet thick has formed in the marble adjacent to the intrusive. The tactite consists largely of garnet and pyroxene and the hornfels dominantly of tremolite and chlorite.

A brecciated, sheared, and silicified fault zone separates the quartz diorite and the tactite at the site of the deposit (fig. 16). The fault zone is as much as 10 feet wide, but it can be traced on the surface only for about 50 feet because of the cover. The ore minerals are irregularly distributed along the fault zone and comprise chalcopyrite, bornite, malachite, sphalerite(?), tetrahedrite(?), and chalcocite(?); all are associated with pyrite, secondary iron minerals and pyrolusite(?).

Samples from the fault zone contained as much as 7,000 ppm copper, 1,000 ppm zinc, 200 ppm antimony, 150 ppm bismuth, and 1.46 ounces per ton (50 ppm) silver (table 9) (28). Buddington (1924, unpublished notes) visited the prospect and reported that a small pocket of bornite with gold and silver values was found in the garnet-rich contact rock, and that a quartz diorite dike was locally impregnated with pyrite and pyrrhotite.

A semiquantitative spectrographic analyses of a soil sample collected during our initial examination of Francis Island contained abnormal amounts of copper, zinc, silver, and nickel and instigated the subsequent geochemical survey whose results are shown in figure 16. Total heavy metals tests of soil samples collected during the survey (fig. 16) indicate that the ore mineralization is localized along the fault zone near the probable site of the prospect. Prospecting the shear zone might be warranted, but indications are that the deposit is small.

Alaska Chief Prospect.--The Alaska Chief prospect is at an altitude of 1,150 feet in the mountains northwest of the mouth of Glacier Bay (fig. 3A) (20). The prospect was staked prior to 1906 and patented in 1924. It is on a densely vegetated steep hillside and formerly was accessible by a 2-mile-long trail from the beach. The trail is now badly overgrown and in disrepair. The prospect consists of a cleared and scraped area of about 150 by 55 feet in maximum dimensions and a short south-trending adit (fig. 17). Sulfide-rich bedrock has retarded reestablishment of vegetation in the cleared area. The Wrights (1937, p. 221, 222) report that a tunnel (adit) 130 feet long was driven from a point 60 feet beneath the surface workings, but neither the writers nor Reed (1938, p. 73), who examined the property in the 1930's, were able to find the tunnel.

The prospect is in calcareous contact rocks east of a granodiorite pluton that is associated with subordinate diorite. The intrusive contact and the bedding in the metamorphic rocks strike about N. 30° W. and dip steeply to the southwest. The metamorphic rocks are chiefly hornfels with subordinate tactite and marble. The hornfels consists mainly of plagioclase, quartz, amphibole, garnet, and chlorite. The tactite contains a similar mineral assemblage, but its dominant constituent is a grossularite-rich garnet. Reed (1938, p. 72) states that the contact rock consists mostly of zoisite and epidote with some chlorite and calcite, and that the marble carries considerable quantities of chlorite, orthoclase, and quartz. The Wrights (1937, p. 221) also report calcareous argillite in the vicinity of the deposits.

The deposit is exposed over the entire extent of the cleared area and intermittently in the adit (fig. 17). It consists of massive sulfide replacements of the metamorphic rocks. The Wrights (1937, p. 221, 222) state that some of the mineralization consists of calcite veinlets along bedding planes, and that the peripheral parts of the intrusive are locally mineralized. Reed (1938, p. 73) notes that mineralization less intense than that manifested in the cleared area extends over a wide area. Efforts to ascertain the extent of the deposit were unsuccessful because of the dense vegetation. The deposit's surface exposures locally consist of a gossan. Sulfide minerals in the deposit are pyrite, pyrrhotite, chalcopyrite, sphalerite(?) and bornite. Oxidized parts of the deposit contain malachite and a little azurite along with abundant secondary iron and manganese minerals. The gangue is predominantly calcite with lesser amounts of quartz.

Chip samples from the cleared area contained as much as 15,000 ppm copper, 700 ppm zinc, 0.232 ounce per ton (8 ppm) gold, 4.377 ounces per ton (150 ppm) silver, and minor to trace amounts of nickel, molybdenum, bismuth, and cobalt (table 9) (29), (fig. 17). A grab sample from the ore pile contained more than 10 percent copper, 1,000 ppm zinc, 2.917 ounces per ton (100 ppm) silver, and minor anomalous concentrations of cobalt, molybdenum, nickel, and bismuth (table 9) (29), (fig. 17). A soil sample collected below the cleared area contained 15,000 ppm copper, 1,500 ppm zinc, 1.46 ounces per ton (50 ppm) gold, 1.46 ounces per ton (50 ppm) silver, 300 ppm cobalt, 300 ppm bismuth, and 500 ppm nickel (table 9) (29), (fig. 17).

Reserve estimates at the prospect are contingent on estimates of the deposit's size and configuration, neither of which are known. The deposit is exposed throughout the cleared area, which is about 150 feet long and 30 feet in average width. Assuming that the deposit extends to 50 feet beneath the surface, which is a third of its exposed length, the deposit holds 225,000 cubic feet of indicated reserves (150 x 30 x 50). About 8 cubic feet of the sulfide-rich rock would weigh a ton, and therefore the indicated reserve is 28,125 tons. The grade of this reserve as inferred by the surface sampling is slightly better than 1 percent copper. If the deposit extends to a depth of 100 feet below the surface and additional reserve of 28,125 tons could be inferred. Likewise additional inferred reserves of unknown tonnage and grade exists beyond the lateral limits of the cleared area and beneath the 100-foot subjacent projection of the cleared area.

Negative factors to be considered in the reserve and grade estimates are that the sample taken from thc adit (table 9) (no. 66AMk-471) was lean, and that the surface samples consisted partly of gossan, which might be richer than the unoxidized ore.

Adequate reserve and grade estimates require additional exploration and more thorough sampling. The deposit justifies exploration on the basis of its indicated grade and the possibility that it is large. An exploration program consisting of diamond drilling and geophysical and geochemical methods to locate targets in the concealed areas probably is warranted.

East Side of Dundas Bay.--Two copper-bearing deposits were found on the east side of Dundas Bay (fig. 3A) (31) (32). One deposit (31) occupies an extensive altered zone in quartz semischist that has sharp contacts with adjacent metabasalt. The altered zone is between 100 and 300 feet wide and traceable for at least a mile. It strikes about N. 20° E. and dips steeply and contains sporadically distributed pods of sulfides within abundant secondary iron minerals and also a few quartz veins. The sulfides are mainly pyrite with minor chalcopyrite. Malachite stains a small part of the zone. Semiquantitative spectrographic analyses of samples from the deposit contain as much as 2,000 ppm copper and traces of silver, molybdenum, and lead (table 9) (31). The apparent size of the deposit makes it an exploration target even though its grade is somewhat low. The Wrights (1937, p. 222) state that a number of mining claims were located east of Dundas Bay for copper, lead, zinc, and gold.

The other deposit (32) is in cataclastic biotite-quartz diorite that has flaser structure. It consists of copper-bearing quartz veins between 1 and 2 inches thick that have formed along foliation planes. The extent of the deposit could not be determined because of poor exposures. A sample of the quartz veins contains 1,[illegible]00 ppm copper and 300 ppm molybdenum (table 9) (32), but the average copper and molybdenum contents of the deposit are much smaller because the values are in the quartz veins, which are spaced a foot or more apart.

Bruce Hills.--The Bruce Hills deposit is in the central part of the Bruce Hills north of Plateau Glacier (fig. 3A) (34). The deposit is in granodiorite near a steep fault zone that strikes N. 30° E. (fig. 18). Many of the rocks near the fault zone are shattered and brecciated, and several subsidiary faults diverge from the fault zone (fig. 18).

The part of the deposit that was examined occupies a spur that trends southwestward from the crest of the Bruce Hills. Rocks underlain by the fault zone are intensely shattered, heavily iron stained, and probably are mineralized, but they have not been tested by sampling. The granodiorite contains a few small roof pendants of hornfels and is cut by several andesite dikes that strike about N. 70° E. and dip to the southeast. Surficial deposits comprising glacial till and talus partly cover the bedrock (fig. 18). The heavily iron stained mineralized rocks are mostly altered granodiorite containing numerous sulfide-bearing thin quartz veins, disseminated sulfides, and mineralized fracture coatings. The ore minerals are associated with pyrite and(or) pyrrhotite and include chalcopyrite, molybdenite, malachite, and minor amounts of molybdite, sphalerite, and galena. Other minerals in the deposits include montmorillonite, chlorite, hematite, and goethite. Samples from the deposit carried as much as 3,000 ppm copper and 1,000 ppm molybdenum (table 9) (34).

The summit regions and north slopes of the Bruce Hills were largely snow covered at the time of the examinations, and the extent of the deposit to the northeast could not be determined. Likewise tracing the deposit to the southwest was precluded by cover, including snow and ice. A few small outcrops along the crest of the hills northeast of the area shown in figure 18 contain chalcopyrite and molybdenite and probably represent a continuation of the deposit. Probably the molybdenite occurrence in the north-central part of the Bruce Hills reported by Rossman (1963b, p. 49, 50) is a part of the deposit.

Forty-four soil samples were collected at 50 foot intervals along several traverses at and near the deposit. Some of the samples were analyzed by the citrate soluble cold total heavy metal test at the sample site, and subsequently all of the samples were analyzed for total heavy metals by our usual test (see p. 36).

In order to check the analytical results 24 of the samples also were analyzed by semiquantitative spectrographic methods. These analyses show that copper and molybdenum are the only ore metals present in abnormal amounts. From a comparison of the analytical results (table 10), the total heavy metal method is judged to be a satisfactory exploration guide for this geologic situation.

Figure 18 shows that the highest total heavy metal content, 600 ppm, was detected in a soil developed on talus about 20 feet west of a large dike. Many of the soil samples collected in this vicinity have total heavy metal contents between 160 and 200 ppm.

Because of the cover and the limited access little is known concerning its overall size and grade, but the results of our examination suggest the deposit is worthy of exploration.

West of Mouth of Rendu Inlet.--Several small altered zones crop out in bleached marble west of the mouth of Rendu Inlet (fig. 3A) (38). The altered zones strike northwestward and dip steeply. They are as much as 20 feet long and 1 foot thick and contain scattered sulfides, chiefly pyrite, and abundant secondary iron minerals. A sample from one of the altered zones contained 1,500 ppm copper, 1,000 ppm nickel, and 700 ppm cobalt (table 9) (38).

South of Tidal Inlet.--Several thin quartz veins occur in marble near the contact with hornblende diorite on the eastern shore of Glacier Bay south of Tidal Inlet (fig. 3A) (41). The marble is white and massive and near the contact it contains small amounts of wollastonite and garnet. Sulfide minerals in the veins include pyrite, chalcopyrite, and pyrrhotite(?). A sample representative of the veins carried 1,000 ppm copper, 300 ppm nickel, and 300 ppm cobalt (table 9) (41).

Blue Mouse Cove.--Three mineralized areas were examined on the southeastern part of Gilbert Island north of Blue Mouse Cove (fig. 3A) (42). The country rock is a complex assemblage of quartz diorite and younger granodiorite that has been cut by aplite and andesitic dikes. The first area, which is northwest of the easternmost tip of the island, is in a shear zone 12 feet wide adjacent to an andesitic dike. The shear zone consists of abundant quartz and dolomite and less abundant muscovite, secondary iron oxides, and an unidentified zinc mineral. The only anomalous sample from this zone (table 9) (42) contained 700 ppm zinc and a trace of silver.

The other areas are on the south shore of Gilbert Island north of Blue Mouse Cove. They contain several nearly parallel calcite veins and a quartz-calcite vein. The veins strike about N. 80° W. and dip between 75° NE. and vertical. The calcite veins are as much as 6 inches thick, and the quartz-calcite vein is a maximum of $1\frac{1}{2}$ feet thick. The veins contain minor amounts of pyrite and secondary iron minerals. None of the samples from the veins contained anomalous amounts of ore metals, and their analyses are not given. The quartz-calcite vein is probably the same vein that Rossman (1963b, p. 50) reports to contain tetrahedrite, pyrite, and some gold and silver. None of the three areas appear to be attractive for exploration.

Southwest Gilbert Island and Nearby Unnamed Island.--Copper-molybdenum deposits are sparsely distributed in the southwest part of Gilbert Island (fig. 3A) (45) and on the nearby small island to the south (fig. 3A) (44). The deposits have about the same potential for molybdenum as they do for copper. They consist of stockworks of numerous quartz veinlets in bleached and altered biotite-hornblende quartz diorite that is cut by alaskite dikes with minor aplitic phases. The quartz diorite is medium grained and has a hypidiomorphic granular texture. It consists of about 45 percent plagioclase (andesine), 30 percent blue-green hornblende, lesser amounts of quartz and red-brown biotite, and traces of zircon, sphene, apatite, epidote, and clinozoisite. The alaskite is strongly altered. It contains mainly plagioclase and quartz in near-equal amounts and about 15 percent of K-feldspar. Some of the plagioclase is albite. Other minerals form less than 10 percent of the rock and include chlorite, muscovite, biotite, and epidote.

Numerous east-striking, near-vertical faults with displacements of only a few inches transect the veinlets and their hostrock. Most of these faults contain gouge seams an inch or so thick. The veinlets generally are less than 3 inches thick. They commonly strike between N. 20° W. and N. 40° W. and dip northeastward at moderate angles. Minor amounts of chalcopyrite and molybdenite are localized near the borders of some of the veinlets. The bleached and altered zones are exposed in seacliffs as much as 60 feet high. The northernmost mineralized zone is exposed for about ½ mile along the face of the seacliffs and the southernmost zone for about 1/6 mile. These deposits probably include the few molybdenite-bearing veins near the western shore of Gilbert Island that were cited by Rossman (1963b, p. 49).

A selected specimen representative of the highest-grade material from the northernmost altered zone contained 7,000 ppm copper, 2,000 ppm molybdenum, and 0.292 ounce per ton silver (table 9) (45). More representative and more extensive samples from the stockworks of both altered zones were of much lower grade (table 9) (44) (45). Despite their large size the deposits are probably too low in grade to encourage exploration.

West of Shag Cove.--A sheared and altered zone approximately 65 feet wide occurs in quartzose rocks on the west side of Shag Cove south of Geikie Inlet (fig. 3A) (49). The zone strikes N. 50° E. and dips 75° NW. It contains numerous thin quartz veins and several sulfide-rich pods that have the same general trend as the major structure. The quartz veins contain pyrite. A chip sample representative of part of the altered zone with abundant quartz veins yielded low values (table 9) (49) (66AHx-32A). The largest visible sulfide pod is about 3 feet long and ½ foot thick. It consists of pyrrhotite with subordinate amounts of pyrite, chalcopyrite, azurite, and cuprite(?). A sample from this pod contained 3,000 ppm copper, 700 ppm zinc, 200 ppm cobalt, and a trace of silver (table 9) (49) (66AHx-32B). The chances of finding minable quantities of ore in the altered zone are remote.

West Arm of Dundas Bay.--A small island in the southern part of the west arm of Dundas Bay is composed of gneissic dioritic rocks that are cut by several hornblendite dikes that are as much as 10 feet thick (fig. 3A) (58). The dioritic rocks are locally garnetiferous. Some of the hornblendite dikes contain disseminations and impregnations of sulfide minerals, chiefly chalcopyrite. A sample of high-grade material from one of the dikes carried 10,000 ppm copper (table 9) (58). The dikes might be worthy of additional prospecting, but the chances of finding minable quantities of ore in them are poor.

West of Mouth of Tarr Inlet.--A zone of pegmatitic hornblende diorite about 8 feet thick cuts the dominant heterogeneous hornblende diorite west of the mouth of Tarr Inlet (fig. 3A) (62). In addition to the pegmatitic diorite the zone contains quartz-calcite veins about 10 inches thick and a few thin aplite dikes. Besides abundant quartz and calcite the veins carry chalcopyrite, pyrite, epidote, and chlorite. Fractures in the veins are coated irregularly with secondary copper minerals, chiefly chrysocolla. A sample of the veins contained 2,000 ppm copper (table 9) (62).

West of Tarr Inlet.--The leucocratic granitic rocks west of the medial part of Tarr Inlet (fig. 3A) (63) locally are altered and contain pale pink to green siliceous lenses. The lenses carry abundant disseminated sulfides and sulfide-bearing veinlets. The sulfide minerals are pyrite and subordinate chalcopyrite. A grab sample from one of the lenses contained 1,000 ppm copper, 300 ppm zinc, and a trace of silver (table 9) (63).

North of Johns Hopkins Inlet.--Several altered and mineralized zones are exposed in the steep cliffs along the north shore of Johns Hopkins Inlet (fig. 3A) (64). They are distributed intermittently from near the point opposite Lamplugh Glacier westward for about 4 miles. Because of their number, proximity, and similarity, they are represented by a single symbol in figure 3A. The altered zones near the eastern part of Johns Hopkins Inlet occur chiefly in septa of metamorphic rocks, mainly marble, within a dominantly dioritic terrane. Those near the western part are in greenstone, phyllite, or granodiorite, generally near intrusive contacts. A few of the altered zones are near mafic dikes.

The altered zones range from a few feet to several hundred feet in width and are exposed for lengths as much as 1,000 feet. They consist of assemblages of quartz, calcite and ankeritic carbonates, plagioclase (including albite) amphibole, muscovite, chlorite, barite, epidote, and secondary iron minerals. The zones locally contain lenses of sulfides and are cut by quartz and calcite veins. The sulfides are pyrite with very small amounts of chalcopyrite. The content of ore metals in the altered zones is low. The highest values that were obtained in any of our several chip samples from the zones were 1,000 ppm copper, and traces of molybdenum and silver (table 9) (64). The altered zones were examined by Reed during the 1930's (Reed, 1938, p. 58, 59). L. F. Parker (oral communication, 1966) reports that a sample from one of the altered zones contained several percent antimony.

Although some of the altered zones are large, all of them appear to be too low grade to encourage exploration.

South of Johns Hopkins Inlet.--A large altered zone has formed in the granitic rocks south of Johns Hopkins Inlet west of the Lamplugh Glacier (fig. 3A) (65). The altered zone is irregular in outline. It is as much as 100 feet wide and exposed for several hundred feet along its strike in the cliffs south of Johns Hopkins Inlet. The zone is cut by a few granitic dikes. Surfaces of the altered granitic rocks are coated by malachite, chrysocolla, and secondary iron minerals. A grab sample from the altered zone contained 1,500 ppm copper and 30 ppm molybdenum (table 9) (65).

East of Lamplugh Glacier.--A few sulfide-rich lenses are in hornblende diorite that crops out on the ridge east of Lamplugh Glacier in the Reid Inlet gold area (fig. 3A) (F). The hornblende diorite contains abundant mafic inclusions and is cut by several aplite dikes. The lenses are as much as 10 feet long and 1 foot in diameter. They consist almost entirely of pyrite. Semiquantitative spectrographic analyses of a sample from the largest lens disclosed 1,000 ppm copper, and traces of nickel, cobalt, and chromium (table 11) (F).

Southwest of Lamplugh Glacier.--Pyrite-bearing quartz veins as much as 10 inches thick cut hornfels west of the upper part of Lamplugh Glacier (fig. 3A) (67). The veins strike about N. 22° W. and dip nearly vertical. Wallrock contiguous to the veins is heavily iron stained and sparsely copper stained. Samples from the veins and the adjacent wallrock contained only minor anomalous amounts of copper and molybdenum (table 9) (67).

East of Reid Glacier.--Two altered zones, each about 10 feet thick, crop out east of the divide between Reid and Scidmore Glaciers at altitudes near 4,000 feet (fig. 3A) (69). The altered zones trend irregularly and cut fractured metamorphic rocks, mainly marble. A few quartz veins between 1 and 2 feet thick also transect the metamorphic rocks. The altered zones are conspicuously stained by reddish-brown secondary iron minerals, but they lack visible ore minerals. Samples from the altered zones carried negligible amounts of copper and molybdenum (table 9) (69) (66AMk-566, 567). The quartz veins contain small quantities of sulfide minerals. A sample from a quartz vein yielded 1,000 ppm copper (table 9) (69) (66AMk-568).

East of Hoonah Glacier.--Two mineralized areas crop out east of Hoonah Glacier near the southeast shore of Johns Hopkins Inlet. The first of these is about three quarters of a mile northeast of Hoonah Glacier (fig. 3A) (75). It consists of disseminated pyrite in hornfels and appears to be extensive. The hornfels locally is faulted and brecciated. A sample from this deposit contained insignificant amounts of copper and molybdenum (table 9) (75).

The second area is contiguous to Hoonah Glacier (fig. 3A) (77). It consists of a large altered zone several hundred feet thick that has formed in metamorphic rocks near their contact with granodiorite. The altered zone contains abundant pyrite disseminations and impregnations, mainly in biotite hornfels, and it is conspicuously iron stained. Only a small part of it was examined. Samples from the zone yielded minor amounts of copper and molybdenum (table 9) (77). Although the analyses indicated low contents of ore metals, a more thorough examination might find richer parts in the altered zone.

Fairweather Range.--Copper minerals have been reported from many localities in the Fairweather Range. Most of the known occurrences are in the southern part of the range near or in rocks of the Crillon-LaPerouse layered gabbro stock. Rossman and members of his 1952 field party (unpublished notes) mention copper-stained outcrops on both sides of North Crillon Glacier (fig. 3A) (78), from about 3 miles northwest of Mount Marchainville (fig. 3A) (82), and from a few other localities in the Fairweathers.

A 5-foot thick layer of gabbro that is exposed for several thousand feet along the south wall of the valley occupied by North Crillon Glacier (fig. 3A) (80) contains between 2 and 3 percent pyrrhotite and chalcopyrite (Kennedy and Walton, 1946, p. 71). Kennedy and Walton (p. 71) also report that many apparently similarly mineralized bands, including some much greater in thickness, crop out in the nearby cliffs. They also report (p. 71) that specimens collected by R. G. Goldthwait from the north wall of the South Crillon Glacier contained between 5 and 6 percent sulfide minerals, principally pyrrhotite and chalcopyrite. These specimens were from near the contact between the gabbro stock and schist. Many fragments of amphibole-quartz schist that are constituents of a moraine on North Crillon Glacier near altitudes of 2,000 feet are stained with copper carbonates (Kennedy and Walton, 1946, p. 71).

The copper deposits in the Fairweather Range are in very rugged terrain, and they have not been examined in detail. Samples are not available from any of them, and little is known about their size and tenor. Probably the deposits merit additional prospecting, but their remoteness and difficult access are serious impediments to any contemplated prospecting or mining.

Southwest Arm of Lituya Bay.--A gabbroic dike that cuts granitic rocks on the southwestern shore of the southeast arm of Lituya Bay (fig. 3A) (84) contains irregular veinlets and blebs of pyrrhotite (Kennedy and Walton, 1946, p. 71). Small amounts of chalcopyrite, which Kennedy and Walton (p. 71) estimate to constitute less than 1 percent of the rock, are associated with the pyrrhotite.

Other Deposits that Contain Copper.--In addition to those deposits that contain copper as their principal potentially economic commodity, several other deposits in the Monument are copper bearing. Among these are deposits at the Brady Glacier nickel-copper prospect (72), the Nunatak molybdenum prospect (21), the Sandy Cove gold prospect (7), and the Rendu Inlet silver prospect (37).

Chalcopyrite is an important constituent of the pyrrhotite-rich lenses, disseminations, and impregnations at the Brady Glacier nickel-copper prospect (fig. 3A) (table 15) (72). It is a minor constituent of the sizeable lodes at the Nunatak molybdenum prospect (fig. 3A) (21), and probably copper would be recovered if the deposits were mined on a large scale. Chalcopyrite and bornite are associated with gold-bearing quartz veins at the Sandy Cove prospect (fig. 3A) (7). Samples from this prospect contained as much as 5 percent copper (table 9) (7). Argentiferous tetrahedrite is the chief ore mineral at the Rendu Inlet silver prospect (fig. 3A) (37) (Buddington, 1924, unpublished notes; Rossman, 1963b, p. 48, 49).

Chalcopyrite and subordinate secondary copper minerals are minor constituents of many other deposits in the Monument, notably those of the Reid Inlet gold area (fig. 3A), near the head of Wachusetts Inlet (fig. 3A) (35), and the skarns east of Queen Inlet (fig. 3A) (40), south of Abyss Lake (fig. 3A) (54), and west of Rendu Inlet (fig. 3A) (39). A reported copper occurrence at Beartrack Cove on the east side of Glacier Bay (Wright and Wright, 1937, p. 221) was not found during our investigations. The Wrights (1937, p. 221) also report finding large masses of pyrrhotite with some copper (chalcopyrite?) in moraine deposits near Adams Inlet. They also mention (p. 221) copper claims on the mountain between Queen and Tidal Inlets.

Lead

The mineral deposits of the Monument generally are low in lead content, and none of the known deposits obstensibly could be worked for lead. Only two of the deposits, one reported from the west side of Willoughby Island (fig. 3A) (27) and the other near Mount Brack (fig. 3A) (12), contain lead in possible byproduct quantities. Buddington (1924, unpublished notes) reports jamesonite from an undisclosed locality on the west side of Willoughby Island. A sample, presumably from this locality and presumably of selected high-grade ore, contained 25 percent lead (Buddington, 1924, unpublished notes). A sample from the Mount Brack argentiferous base metal deposits, which are described under "zinc", contained 7,000 ppm lead (table 9) (12). Two other deposits whose principal commodity is zinc, the deposit southwest of Red Mountain (fig. 3A) (table 9) (20) and a deposit about a mile southwest of the Alaska Chief prospect (fig. 3A) (table 9) (30), contain minor amounts of lead. A few of the copper deposits contain trace to minor amounts of lead. Galena is a minor constituent of some gold-bearing quartz veins in the Reid Inlet gold area, notably those at the LeRoy mine (fig. 3A) (B). A sample from the LeRoy mine carried 1,500 ppm lead (table 11) (B). However, the Reid Inlet gold deposits are too small to permit recovering their base metals at a profit. Samples from the Sandy Cove gold prospect contained minor to trace amounts of lead (table 9) (7).

Radioactive Elements

No uranium or thorium minerals were found during our investigations, although radioactive minerals were looked for during the field examinations, and all samples were routinely checked with a Geiger counter. Rossman (1963b, p. 52) states that some of the altered zones near Sandy Cove contain between 0.001 and 0.003 percent U_3O_8. Seitz (1959, p. 116) reports that he checked the area that he mapped near Geikie Inlet for anomalous radioactivity, and that the results were negative. No favorable indications of uranium or thorium minerals were noted during the examinations. Possibly undetected deposits of these elements are in some of the leucocratic granitic rocks or in the altered zones.

Tin

No tin minerals were found and no significant anomalous concentrations of tin were detected in the rock and ore samples that were analyzed. The largest amount of tin that was found in these samples was 30 ppm in a sample from the Queen Inlet magnetite deposit (fig. 3A) (table 9) (40). Smaller amounts of tin were detected in samples from several other localities (table 9).

A tin and tungsten anomaly in stream sediments was revealed by geochemical sampling near the north end of Dundas Bay. Samples from this area contained 30 ppm tin and as much as 150 ppm tungsten (table 4) (nos. 12, 13). The provenance of the streams that yielded the anomalous samples consists partly of leucocratic granitic rocks, which are considered favorable for tin deposits, and prospecting the area seems justified.

Two stream sediment samples collected in the northern part of the Monument also contained anomalous amounts of tin. A sample collected on the west side of Tarr Inlet a few hundred feet south of locality 18 (fig. 3A) contained 500 ppm tin in addition to anomalous amounts of other metals (see pages 48 to 52). The second anomalous sample came from west of Lamplugh Glacier terminus; the sample contained 33 ppm tin, but only ordinary concentrations of copper, lead, and molybdenum.

Zinc

Distribution and Types of Deposits

Zinc is fairly widespread in the mineral deposits of the Monument. It occurs in seven deposits that are described under "Copper", in the Queen Inlet magnetite deposit, in a few lodes in the Reid Inlet gold area, and it is apparently the most important commodity in seven deposits that were found during the investigations. Most of the zinc deposits are in the eastern part of the Monument.

The zinc deposits are diverse in type and have formed in several geologic settings. They consist of veins, altered zones, disseminations, and local sulfide-rich replacements in a variety of host rocks. Sphalerite is the main zinc mineral in most of the deposits, but some deposits contain fine-grained encrustations of secondary zinc minerals. The best zinc deposits in the Monument appear to be near Mount Brack (12) (fig. 3A) and in an altered zone north of White Glacier (6) (fig. 3A) (described under "Copper") that carries 2 percent zinc.

Descriptions of Deposits

Nunatak on Casement Glacier.--An iron-stained altered zone is exposed on a small recently denuded nunatak on Casement Glacier (fig. 3A) (3). The nunatak consists of thin-bedded limestone, argillite, and hornfels. The altered zone is about 30 feet thick, and it contains several quartz-ankerite-barite veins that are less than 1 foot thick. The veins and the altered zone strike N. 58° W. and dip vertically. Pyrite is the only visible sulfide mineral in either the veins or the altered zone. The deposit is low in grade, and its only anomalous ore metal concentration consisted of 300 ppm zinc (table 9) (3).

Mount Brack.--The deposits near Mount Brack (fig. 3A) (12) consist of veins and altered zones in graywacke, limestone, hornfels, siltstone, and mafic dikes. The veins and altered zones strike north, and most of them dip east. Six veins were exposed at the time of our examination, and probably others are concealed beneath snow, which is widespread and perennial over much of the area. The veins are generally between 6 and 8 inches thick. They consist chiefly of quartz and calcite with locally abundant ankeritic carbonates, sulfides, and sulfosalts(?). Samples from the veins yielded higher values in zinc and most other ore metals than those from the altered zones. The vein samples (table 9) (12) (66AMk-315 and 66ABd-280) contained as much as 15,000 ppm zinc, 0.875 ounce per ton (30 ppm) silver, 7,000 ppm lead, 30,000 ppm arsenic, 7,000 ppm antimony, and 0.087 ounce per ton (3 ppm) gold. The presence of sulfosalts is inferred from the arsenic and antimony content of the samples.

Altered zones as much as 30 feet thick are fairly numerous near Mount Brack. They are composed principally of heavily iron-stained ankeritic carbonates, chlorite, quartz, and calcite and minor plagioclase and muscovite. Some of them enclose quartz-carbonate veinlets. Samples from the altered zones were lean, and their maximum zinc content was 700 ppm. Indications of mineralization are widespread, and the general area probably merits prospecting.

Southwest of Red Mountain.--Small pyrite-rich pods and impregnations occur in the Black Cap Limestone near a granodiorite cupola about 2½ miles southwest of Red Mountain (fig. 3A) (20). The largest pod is about 10 feet long and 1 foot in diameter. It consists largely of pyrite along with subordinate calcite and encrustations of a secondary zinc mineral, probably hydrozincite or smithsonite. A sample from the largest pod contained 7,000 ppm zinc, 500 ppm lead, 70 ppm cadmium, and a trace of silver. The deposits are too small to be of economic significance.

Southwest of Alaska Chief Prospect.--An altered shear zone that cuts granitic rocks about a mile southwest of the Alaska Chief prospect contains minor zinc values (fig. 3A) (30). The altered zone is about 3 feet wide. Its attitude is N. 30° W., 80° southwest. The granitic host rock at the deposit is granodiorite or quartz monzonite. A sample from the altered zone contained 1,500 ppm zinc, 300 ppm lead, and traces of molybdenum, bismuth, and silver (table 9) (30). The deposit is probably too lean to encourage exploration.

Hugh Miller Inlet.--Three thin pyrite-rich veins cut biotite-hornblende quartz diorite on the west side of Hugh Miller Inlet west of Gilbert Island (fig. 3A) (46). The veins strike between N. 40° W. and N. 55° W. and dip northeastward. A steep northwest-striking shear zone cuts the quartz diorite near the veins. The veins are heavily iron stained and consist of abundant pyrite and its alteration products and probably quartz, barite, and carbonate minerals. A sample from the veins yielded 1,500 ppm zinc, 70 ppm bismuth, and a trace of molybdenum (table 9) (46). Possibly the veins represent a fringe zone of the previously described extensive low-grade copper-molybdenum deposits that are exposed on nearby parts of Gilbert Island (45). The veins are probably too small and too lean to warrant exploration.

Mount Cooper.--Altered zones occur in iron-stained pyritic hornfels near a peak locally referred to as Mount Cooper, west of Lamplugh Glacier (fig. 3A) (66). They are best developed near fine-grained porphyritic dikes that cut the hornfels. A sample from one of the zones contained 300 ppm zinc, traces of molybdenum, and 15,000 ppm barium (table 9) (66). The dominant minerals in the altered zones are quartz, plagioclase, actinolite, and barite.

A large altered zone north of the ones examined was not sampled because of difficult access, but its composition is probably similar to the zone that was sampled.

Northwest Shore of Johns Hopkins Inlet.--Iron-stained hornfels crops out for several hundred feet along the northwest shore of Johns Hopkins Inlet and probably extends for many hundreds of feet to the northwest (fig. 3A) (76). The hornfels contains abundant finely disseminated pyrite, but apparently it lacks significant amounts of ore minerals. A sample of the hornfels carried 300 ppm zinc and traces of lead and molybdenum (table 9) (76).

Other Deposits That Contain Zinc.--Zinc is a constituent of several deposits whose major commodity is copper, gold, or iron, and these deposits are described elsewhere in this report. The zinc-bearing deposits that are described under "Copper" include those near Mount Young (1), north of White Glacier (6), at the Margerie prospect (19), on Francis Island (28), at the Alaska Chief prospect (29), near Blue Mouse Cove (42), and on the west side of Tarr Inlet (63). Sphalerite occurs in the gold-quartz veins at the LeRoy and Rainbow mines in the Reid Inlet gold area (B) (C). Minor amounts of zinc are associated with pyrite in contact-metamorphic rocks at the Queen Inlet magnetite deposit (40).

Samples from the Mount Young deposits contained as much as 1,500 ppm zinc (table 9) (1). A sample representative of a 6-foot wide altered zone north of White Glacier contained 20,000 ppm zinc (table 9) (6). Quartz veins at the Margerie prospect carry traces of zinc (table 9) (19). A selected sample from the Francis Island deposit yielded 1,000 ppm zinc (table 9) (28). Chip samples from the Alaska Chief prospect contained as much as 700 ppm zinc, and a grab sample from the ore pile contained 1,000 ppm zinc (table 9) (29). A sample from an altered zone near Blue Mouse Cove yielded 700 ppm zinc (table 9) (42). Zinc is a minor constituent of siliceous lenses west of Tarr Inlet that contain disseminated sulfides (table 9) (63). Samples from the LeRoy mine contained as much as 15,000 ppm zinc (table 11) (B), and a sample from the Rainbow mine carried 2,000 ppm zinc (table 11) (C). Samples from the Queen Inlet magnetite deposit have a very low zinc content (table 9) (40). Conceivably zinc constitutes a potential byproduct in a few of these deposits.

Precious Metals

Gold is the only precious metal that has been found in significant amounts within the Monument. Silver is a constituent of several deposits, and small amounts of platinum have been reported from a few of the placers.

Gold

Distribution and occurrence

Both lode and placer deposits of gold are widespread in the Monument (fig. 3A). The lode deposits are mainly in the Reid Inlet gold area (fig. 3A), but a few are known from elsewhere in the Monument, notably at the Sandy Cove prospect (fig. 3A) (7). The best known of the placer deposits are on the beaches north and south of Lituya Bay (fig. 3A) (87) (88).

The lode deposits commonly occupy narrow nonpersistent quartz veins in granitic or metamorphic rocks. A few of them are sporadically distributed in thin altered zones adjacent to the quartz veins. Minor amounts of gold occur in some of the larger altered zones in the Monument, and gold constitutes the main commodity of exonomic interest in a few of the altered zones. Gold is a minor constituent of a deposit that is localized along a facies change between marble and phyllite west of McBride Glacier (fig. 3A) (10). It is also a subordinate metal in some of the base metal deposits, as at the Alaska Chief prospect. The placer deposits comprise beach sands, outwash gravels, river and stream sediments, and a few residual placers.

Lode deposits

Reid Inlet Gold Area.--The Reid Inlet gold area includes the ridge south of Glacier Bay that is bordered by Reid and Lamplugh Glaciers and by Reid Inlet (fig. 3A). It also includes small parts of the terrain east of Reid Inlet and west of Lamplugh Glacier (fig. 3A). The area contains most of the gold lodes in the Monument and also one small copper deposit. Gold has been produced at six properties which are designated as mines, and there also are six prospects in the area. The total value of the gold produced from the mines is about $250,000. The Reid Inlet gold area has been examined by several geologists and mining engineers, and it is the subject of a detailed report by Rossman (1959). Our studies were facilitated by the results of the earlier investigations, and in most instances Rossman's maps have been used as bases for our sample localities and geologic data.

The Reid Inlet area is underlain chiefly by granodiorite and quartz diorite and by a few northwest-striking screens and septa of metamorphic rocks. Fine-grained mafic dikes are locally abundant in the area. Almost all of the Reid Inlet deposits occupy thin nonpersistent quartz veins; the remainder are sporadically distributed in narrow altered zones contiguous to the quartz veins. Iron stains on the veins and on altered rock near the veins permits them to be readily identified at a distance. None of the deposits appear to be amenable to large-scale mining.

Terry Richtmeyer Prospect.--A gold claim about 1,200 feet south of Glacier Bay and 2 miles west of Ptarmigan Creek is reportedly held by Terry Richtmeyer (Alaska State Division of Mines and Minerals, written communication, 1966) (fig. 3A) (A). We were unable to find the claim. It probably is on quartz veins in granitic rocks near their contact with hornfels.

LeRoy Mine.--The LeRoy mine is the largest mine in the Reid Inlet gold area. It is a little less than a mile south of Glacier Bay at altitudes between 950 and 1,000 feet (fig. 3A) (B). The mineralized veins at the mine were discovered in 1938 by A. L. Parker and L. F. Parker (Rossman, 1959, p. 38). The mine workings consist of four southwest-trending adits with subsidiary raises and stopes, and minor surface workings (fig. 19). The longest adit explores the LeRoy vein for about 240 feet.

The gold is in thin nonpersistent quartz veins and less extensively in narrow altered zones adjacent to the veins. The veins transect northwest-striking metamorphic rocks that dip steeply and form a screen between granitic masses. The metamorphic rocks consist of schist, slate, hornfels, and argillite and are differentiated into three units in figure 6. Petrographic studies of thin sections reveal that many of the rocks that were mapped as schist are schistose granodiorite that has been intensely sheared. With few exceptions the veins strike about N. 30° E. and dip between 50° and 80° northwest. About 15 veins are exposed on the property. Most of them are only an inch or two thick, but one of them, the LeRoy vein (fig. 19) attains a thickness of about 3 feet. The veins are characterized by pinching and swelling and by lack of continuity. The lack of continuity appears to be an intrinsic quality, but it is accentuated by faulting. The LeRoy vein, which has yielded the most production, apparently terminates southwestward near its contact with argillite (which Rossman (1959) considered to be a fine-grained mafic dike). The vein has been stoped throughout much of its extent both above and below the adit level. Some of the veins are strongly fractured and brecciated. Gold is distributed irregularly in the veins and uncommonly in the contiguous altered zones which generally are a few inches thick. The veins consist mainly of quartz along with minor amounts of feldspars, calcite, and clay minerals. The sulfide minerals arsenopyrite, pyrite, galena, sphalerite, and chalcopyrite are minor constituents of most of the veins. Subordinate amounts of silver are associated with the gold. The veins have been extensively sampled, and the locations and gold values in samples that were collected during the 1966 investigations and during a previous examination by the Territorial Department of Mines are shown in figure 19. Additional analytical and descriptive data germane to these samples are shown in tables 11 and 12. The richest sample represents a 6-inch thick vein that is exposed at the surface and contained 10.34 ounces per ton gold and 7.40 ounces per ton silver (fig. 19) (table 12). Samples representative of the LeRoy mine lodes contained as much as 0.0045 ounce per ton (15 ppm) silver, 70,000 ppm arsenic, 1,000 ppm cadmium, 70 ppm copper, 1,500 ppm lead, and 15,000 ppm zinc, and 0.699 ounce per ton (24 ppm) gold (table 11) (B). About $100,000 in gold has been produced from the mine.

The LeRoy mine and vicinity were studied by geochemical methods to find out if soil sampling and analyses would aid in exploration for gold lodes in the Reid Inlet area. The original prospectors in the area relied heavily on panning to trace the gold-bearing veins. Where the veins are exposed panning works well, but throughout much of the area the veins are covered by soil and glacial deposits. Most of the veins contain more sulfide minerals, including galena, than gold. Rather than analyze the samples for gold, it was decided to determine their total heavy metal content, which would reveal any abnormal amounts of lead.

Eighteen soil samples were collected at 50-foot intervals along two horizontal traverses near altitudes of the lower and upper portals (fig.19). In addition 13 samples were collected from near the caved stope above the LeRoy adit. All the samples were collected within 250 feet of known gold-bearing veins and 11 were collected within 50 feet of known veins.

Analyses of the samples showed that none of them contained significant amounts of lead or more than 40 ppm total heavy metals. From these results it was concluded that the small amounts of lead in the ore could not be detected in soil diluted with glacial detritus, and that soil sampling methods that were used are not satisfactory for the Reid Inlet area.

Rainbow Mine.--The Rainbow mine is west of the mouth of Reid Inlet (fig. 3A) (C). The mine workings explore an altered fault zone about 1 foot thick that contains vein quartz. The fault zone, which is traceable on the surface for about a half mile southwestward from sea level to altitudes slightly more than 1,000 feet, strikes about N. 30° E. and dips between vertical and 70° SE. The workings consist of a southwest-trending adit about 180 feet long, a short crosscut, stopes above the adit level, and a small pit near the southwesternmost outcrops of the zone (fig. 20). The portal of the adit is in seacliffs about 15 feet above high tide level. The fault zone cuts granodiorite and small masses of alaskite. A shattered and brecciated quartz-calcite vein a few inches thick occupies the fault zone. The vein contains gold and an assemblage of sulfide minerals similar to those at the LeRoy mine. The altered zone, which is marked by abundant secondary iron minerals and gouge, also contains widely scattered gold.

Analytical results of samples from the Rainbow mine are shown in table 11 (C). The highest gold value found in any of our samples from the Monument, 10.211 ounces per ton gold, was detected in one of the samples from the mine. Besides gold, samples from the Rainbow mine carried as much as 2.043 ounces per ton silver, 1,500 ppm arsenic, 500 ppm lead, and 2,000 ppm zinc (table 11) (C).

The Rainbow mine probably is the second largest gold producer in the Reid Inlet area, but its production data are unavailable. The mine was worked during 1945 and shortly thereafter, and its ore was transported by barge and truck to the mill at the LeRoy mine.

The Rainbow mine is similar geochemically to the LeRoy mine, and the soil conditions are comparable. The Rainbow mine was sampled for the same purpose as the LeRoy mine; that is, to find out if analysis of the soil for lead could help trace the veins where they are covered by soil and glacial material.

Most of the 12 soil samples that were collected were from the hillside 10 to 50 feet below an outcrop of the vein, where detection of an anomaly seemed most likely. None of these samples contained more than 40 ppm total heavy metals. These results support the conclusions made for the LeRoy mine; namely, that the amount of lead in the soils is too small to be useful in tracing the veins.

Sentinel Mine.--The Sentinel mine is west of the mouth of Reid Inlet at altitudes near 900 feet (fig. 3A) (D). Ore at the mine is localized along a northwest-striking steep altered zone that cuts granodiorite. The altered zone is about a foot thick and consists of intensely altered and comminuted granodiorite that contains sparse impregnations of sulfides, abundant secondary iron minerals, and erratically distributed gold. Several other altered zones that are similar in attitude and character to the one at the mine are exposed on the hillside northeast of the property. A sample from one of these (table 11) (D) yielded negligible gold values. The mine has yielded a small undisclosed production of gold. It was worked by shallow surficial workings that are now obscured by overburden and vegetation.

Monarch Mines.--The Monarch mines are on the steep hillside west of Reid Inlet (fig. 3A) (E). The Monarch No. 1 mine is at an altitude of about 1,875 feet and the Monarch No. 2 mine at an altitude of about 1,500 feet. Both of the mines were worked from adits, and both probably produced minor amounts of gold.

The adit at the Monarch No. 1 mine extends for about 210 feet southward from its portal (fig. 21). A small overstope was excavated about 70 feet from the portal. The adit explores an altered zone between 1 and 5 feet thick within granodiorite. The zone strikes northward and dips steeply to the west. It contains quartz veins and lenses a few inches thick along with abundant gouge and breccia. The granodiorite wallrock is medium- to coarse-grained and hypidiomorphic granular in texture. It contains about 65 percent plagioclase, 15 percent quartz, and 10 percent K-feldspar. The rock is cut by microfractures and is altered, resulting in the obliteration of its primary mafic minerals and replacement of the original plagioclase by oligoclase. Its minor constituents and alteration products consist of sphene, allanite, calcite, chlorite, epidote, and opaque minerals. The veins and lenses, and less commonly the altered zones, contain sparsely distributed arsenopyrite, pyrite, galena, and gold. Calcite and clay minerals constitute the lesser gangue minerals. Samples from the mine showed low values in gold and other ore metals (table 11) (66AMk-337 through 66AMk-343).

Rossman (1959, p. 50) reports a few other gold-bearing veins near the Monarch No. 1 vein. One vein a few hundred feet west of the Monarch No. 1 vein crops out over a length of about 100 feet and is as much as 10 inches thick. Some of the partly decomposed weathered material at the surface of the vein has been mined. A small, rich stringer vein about 5 inches thick is exposed several hundred feet west of the south end of the Monarch No. 1 vein.

Workings at the Monarch No. 2 mine consist of a westward-trending crosscut adit about 120 feet long and two short drifts (fig.22). The workings are in granodiorite that is cut by a few quartz veins and by northward-striking mafic dikes and faults. The granodiorite at the Monarch No. 2 mine is less altered but slightly more deformed than its counterpart at the Monarch No. 1 mine. The quartz veins strike northward and dip nearly vertical. They are between 2 and 8 inches thick and are bordered by thin gougey selvages. The veins contain sparsely distributed calcite, sulfides, and minor amounts of gold (table 11) (E) (66AMk-344 through 66AMk-348). A few other small quartz veins are near the Monarch No. 2 property (Rossman, 1959, p. 51).

Incas Mine.--The Incas mine is west of Reid Inlet at altitudes near 1,000 feet (fig. 3A) (G). The Incas lode, which was one of the first discoveries in the Reid Inlet area, was staked by Joseph Ibach in 1924 (Rossman, 1959, p. 46). The mine consists of about 200 feet of underground workings (fig. 23) and several trenches that are now badly caved and sloughed. The deposits are localized in quartz lenses in an altered fault zone within granodiorite. The fault zone strikes northward and dips steeply. It is between 1 and 3 feet thick and traceable intermittently on the surface for about 1,000 feet. The granodiorite is medium grained and hypidiomorphic granular in texture. It contains about 60 percent plagioclase (sodic andesine), 20 percent quartz, 10 percent K-feldspar, and 10 percent alteration products, chiefly epidote and chlorite. Much of the granodiorite has been deformed cataclastically. The quartz lenses contain minor amounts of calcite and sulfides, chiefly arsenopyrite, and sporadically distributed gold. The altered zone consists of hydrothermally altered granodiorite and traces of gold and sulfides. Our samples from the mine revealed only minor amounts of gold and ore metals (table 11) (G).

Rossman (1959, p. 48) states that several other veins and altered zones crop out in the vicinity of the mine. He also believes that the mine has not been explored sufficiently for evaluation of its economic possibilities. The small production from the property was probably mainly from surficial workings.

Sunrise Prospect.--The Sunrise prospect includes several shallow pits and trenches on the hillside east of Reid Inlet at altitudes near 800 feet (fig. 3A) (H). Rocks at the prospect are marble and hornfels that strike northward and dip steeply. Subordinate fine-grained diorite or quartz diorite is also present. Several northeast-striking lamprophyre dikes, as much as 30 feet thick, cut the other rocks. The gold occurs principally in several subparallel narrow quartz-calcite veins whose attitudes are similar to those of the metamorphic rocks. The veins are between 2 and 12 inches thick and are discontinuous. Generally their outcrop lengths are between 20 and 40 feet. Pyrite is the only metallic mineral noted in any of the veins. Reed (1938, p. 64) reports that a 10 inch sample across one of the veins carried 0.08 ounce of gold per ton and 0.20 ounce of silver per ton. A sample from the largest vein at the prospect carried negligible values (table11) (H).

Thin altered zones are developed adjacent to some of the lamprophyre dikes, and these and nearby parts of the dikes carry minor amounts of pyrrhotite, pyrite, and arsenopyrite. Rossman (1959, p. 56) reports minor amounts of scheelite from a quartz vein near the Sunrise prospect.

Hopalong and Whirlaway Claims.--According to Rossman (1959, p. 56) two claims were staked on the Whirlaway and Hopalong veins on the west side of the ridge east of Reid Inlet. The claims are at altitudes near 1350 feet (fig. 3A) (I). The veins cut fine-grained diorite or quartz diorite. They strike northward and dip vertical and are as much as a foot thick. The veins pinch and swell, and throughout most of their exposures are only a few inches thick. They can be traced for about 60 feet along their strike. Besides quartz the veins contain abundant calcite, minor muscovite, uncommon pyrite and arsenopyrite, and probably erratically distributed gold. Our samples from them were essentially barren (table 11) (I). Rossman (1959, p. 56) states that a small amount of gold was recovered by sluicing the weathered surficial parts of the veins.

Galena Prospect.--The Galena prospect is west of Reid Inlet at an altitude of about 500 feet (fig. 3A) (J). Its workings consisted of trenches that are now obscured by sloughing and overburden. The prospect was staked in 1936 or 1937. The rocks at the prospect are granodiorite, subordinate schist, and a few lamprophyre dikes. The prospect is on a vein between 4 and 18 inches thick that was exposed over a length of about 60 feet (Twenhofel and others, 1949, p. 33). The vein consists of banded and vuggy quartz with fairly abundant pyrite, sphalerite, and galena. A sample representing a 12 inch width of the vein contained 0.16 ounce per ton of gold, 0.30 ounce per ton of silver, and 0.79 percent zinc (Reed, 1938, p. 63).

Highland Chief Prospect.--The Highland Chief prospect is at altitudes between 2,500 and 2,800 feet west of the head of Reid Inlet (fig. 3A) (K). Extensive snowfields, which persist throughout most summers, covered most of the prospect area during our examination. The rocks that were exposed consist of amphibolite, schist, and marble that are locally penetrated by granodiorite salients. The metamorphic rocks form part of a northwest-trending screen, and they dip steeply. None of the reported quartz veins at the property were exposed. According to information quoted in Rossman (1959, p. 54) the main quartz vein at the prospect is as much as 6 feet thick and contains considerable free gold. Rossman (1959, p. 54) reports that other steep northwest-striking quartz veins near the prospect contain gold. These are alledged to be as much as 2 feet thick and traceable for as much as 700 feet along strike. The prospect is probably one of the most promising in the Reid Inlet area, but its exploration and development have been curtailed by the near-perennial snow cover.

Rambler Prospect.--The Rambler prospect is on the steep hillside east of Lamplugh Glacier (fig. 3A) (L). The prospect consists of a few small surficial pits on quartz veins, mainly within leucocratic granodiorite. The granodiorite contains a few small screens of metamorphic rocks, and it is cut by a few northeast-striking steep mafic dikes. The quartz veins commonly strike between N. 60° E. and East and dip steeply. They are mainly only an inch or two thick, but in places they attain a thickness of 3 feet. Most of the veins pinch and swell conspicuously. Typically, the veins are exposed for less than 200 feet along their strikes and are bordered by narrow altered zones. The veins consist of quartz, calcite, feldspars, barite, scattered sulfides (mainly arsenopyrite, pyrite, and galena), and traces of gold. All of our samples from the veins yielded low gold values (table 11) (L). High-grade samples rich in gold reportedly have been collected at the prospect (Rossman, 1959, p. 55; Lawrence Duff, oral communication, 1966).

Other Lode Deposits in the Reid Inlet Area.--Several other gold-bearing lodes have been reported from the Reid Inlet area, but they were not examined during our investigations. These include the A.F. Parker prospect and a few unexplored quartz veins.

The A.F. Parker prospect is about two thirds of a mile northwest of the LeRoy mine at an altitude of 850 feet. The prospect was staked in 1938 and worked by a 20 foot-long adit with a production of 7 or 8 tons of ore (Twenhofel and others, 1949, p. 33, 34). The prospect explores irregular quartz veinlets that are localized in a fault zone cutting granodiorite. The veinlets are between ½ and 1 inch thick within a gouge zone about 10 inches thick. The fault zone strikes N. 70° E. and dips 86° SE. At the face of the adit it is truncated by a fault that strikes N. 66° E. and dips 64° NW (Twenhofel and others, 1949, p. 34). The quartz veinlets contain galena and pyrite and a little free gold.

Rossman (1959, p. 55, 56) reports a few other quartz veins in the Reid Inlet area that probably contain gold. These veins are little explored, but they are probably similar to the better-known quartz veins in the area.

South of Lituya Bay.--Rossman (1959, p. 57, 58, and his fig. 9) reports zones of hydrothermally altered rocks south of Lituya Bay and west of Crillon Glacier (fig. 3A) (85). These zones are reddish yellow and are developed in Tertiary volcanic and sedimentary rocks. They are readily susceptible to erosion, and their best outcrops are in stream banks, ravines, or gulleys. Most of the zones are essentially barren, but some of them contain gold. Their highest analyzed gold content was 0.24 ounce per ton (Rossman, 1959, p. 58, and his fig. 9). The zones are numerous and extensive and have been scarcely prospected. Conceivably parts of them carry higher gold value than indicated by Rossman's samples, and they probably merit additional prospecting.

Sandy Cove Prospect.--The Sandy Cove prospect is northeast of Sandy Cove, an embayment of the eastern part of Glacier Bay, at altitudes near 110 feet (fig. 3A) (7). The prospect consists of three claims that probably were staked during the 1930's. It was explored by a northeasterly-trending adit about 110 feet long and by a few surficial workings. The prospect is on a south-facing hillside that is partly covered by vegetation and soil. The ore deposits are localized in a series of northward-striking steep quartz veins and in the contiguous altered wallrock (fig. 24). Surface exposures of the veins and the altered zones are strongly oxidized and colored reddish brown by widely dispersed hydrous iron oxides. Most of the veins are in monzonite or quartz monzonite that forms small masses intruding marble, which is the dominant rock near the prospect. Reed (1938, p. 66) considered the intrusive rock at the prospect to be monzonite; our petrographic studies indicate it is a quartz monzonite. The rock is medium-grained hypidiomorphic granular and consists mainly of plagioclase that is zoned from sodic andesine to calcic oligoclase. It contains about 25 percent K-feldspar, between 10 and 15 percent each of quartz and green hornblende. Minor accessory minerals and alteration products in the rock include sphene, apatite, allanite, epidote, chlorite, muscovite, calcite, pyrite, and magnetite. The quartz monzonite and monzonite are locally silicified near the altered zones and quartz veins.

The quartz veins range from 1 to 12 inches in thickness; and the altered zones are as much as 10 feet thick. Most of the quartz veins are lenticular and discontinuous. Some of them are in an en echelon pattern. In addition to quartz their gangue minerals include ankeritic carbonates and probably barite. Sulfide minerals which locally comprise the bulk of the veins consist of pyrite, chalcopyrite, and bornite. In places the sulfide minerals have been oxidized to malachite, chrysocolla, and diverse hydrous iron minerals. Gold is distributed erratically in the veins. The altered zones carry minor amounts of gold and sulfides.

Samples from the prospect contained as much as 0.96 ounce per ton (33 ppm) gold, 50,000 ppm copper, 1.46 ounce per ton (50 ppm) silver, 50 ppm molybdenum, 500 ppm bismuth, and 150 ppm lead (table 9) (7). The richest samples were from near the face of the adit (fig. 24) (table 9) (7). The other veins and altered zones appear to be leaner in ore minerals than the ones exposed in the adit. Reed (1938, p. 68) reports gold and silver assay results for 39 samples that were cut in the adit. These samples contained as much as 0.51 ounce per ton gold and 2.4 ounces per ton silver. Their average content was 0.11 ounce per ton gold and 0.6 ounce per ton silver, and their median content was 0.04 ounce per ton gold and 0.3 ounce per ton silver. Reed (1938, p. 68) also reports that 4 tons of selected ore from near the portal of the adit contained 0.37 ounce per ton gold and 0.15 ounce per ton silver. Rossman (1963b, p. 52) detected between 0.001 and 0.003 percent U_3O_8 in samples from some of the altered zones near Sandy Cove.

Soil samples were collected at the Sandy Cove prospect in an effort to trace the vein that is exposed near the portal of the adit. A soil sample from just west of the adit contained 220 ppm total heavy metals, whereas one from just east of the adit contained only 20 ppm total heavy metals (fig. 25). Samples collected across the trend of the vein both to the northwest and to the southeast contained only background concentrations of heavy metals.

Glacial till from the hillside above the prospect dilutes the residual soil and interferes with the application of geochemical techniques. In spite of this dilution the soil samples collected close to or just downhill from mineralized areas seem to be geochemically anomalous. The lack of anomalous samples across the trend of the vein is interpreted as indicating that the vein pinches out near the surface both northwest and southeast of the adit. A sample collected downhill from the dump contained 480 ppm total heavy metals; this sample is believed to be contaminated by ore metals from the dump and not to have any significance in prospecting.

The sampling and mapping disclosed several other veins northwest of the adit which yielded geochemical anomalies by soil sampling. Rock sample 66AHf-280B, which had a copper content of 1,000 ppm (table 9) (7), was collected near a soil sample that contained 240 ppm total heavy metals. A soil sample collected near a vein west of sample 66AHf-280B contained 320 ppm total heavy metals. The veins appear to form an en echelon pattern that trends northwestward, and based on the geochemical studies several of them merit further exploration.

The Sandy Cove deposits don't appear to be large enough or rich enough to encourage mining under current conditions. Possibly they would be amenable to a small-scale mining operation under more favorable conditions.

Copper is a possible byproduct in the ore. Further exploration of the prospect should attempt to find richer and larger lodes, possibly near intersections with cross cutting structures. The Wrights (1937, p. 221) note old claims near Sandy Cove that were allegedly staked on pyrrhotite-rich lodes that contain some copper and nickel.

West of McBride Glacier.--Gold is a minor constituent of altered zones west of the middle part of McBride Glacier (fig. 3A) (10). The altered zones are near an irregular interfingered contact that marks a facies change between marble and phyllite. Small irregular masses of limy silicate rocks are near the contact. About 10 separate altered zones are present. They are less than 2 feet thick and less than 100 feet long and are essentially conformable with the bedding, which strikes about N. 85° E. and dips 25° NW. The altered zones are pervaded by intense iron staining derived from the alteration of their ankeritic carbonates and sulfide minerals. They also contain arsenopyrite and traces of gold. Samples from the zones carried as much as 15,000 ppm arsenic, 500 ppm copper, and 0.087 ounce per ton gold, (table 9) (10).

East of Lower Brady Glacier.--Several small gold-bearing quartz veins crop out in the mountains west of Dundas Bay nearly east of the terminous of Brady Glacier (fig. 3A) (55). The veins are in mafic gneiss and diorite. They commonly are only a few inches thick and are exposed for short distances along their strikes. The veins presumably contain small amounts of gold, but no gold is visible in the hand specimens. A sample from one of the veins yielded negligible amounts of gold and other ore metals (table 9) (55). The area has not been prospected thoroughly, and it may contain undiscovered gold-bearing veins of interest.

West of Dundas Bay.--Rossman (unpublished notes) mentions a lode gold occurrence on the north shore of the peninsula between Dundas Bay and its west arm (fig. 3A) (57). The deposit was not found during the 1966 fieldwork. It probably consists of small gold-bearing quartz veins in dioritic rocks.

Russell Island.--Two thin gold-bearing quartz veins occur in an altered zone near the northeastern tip of Russell Island (fig. 3A) (61). The altered zone is about 3 feet thick and transects biotite-hornblende granodiorite. The veins and the altered zone strike N. 17° E. and dip vertically. The veins are between 2 and 5 inches thick. Neither the veins nor the altered zone can be traced for more than about 25 feet on the surface because of cover. Besides quartz the veins contain fairly abundant calcite and minor pyrite. A sample of the veins carried 0.844 ounce per ton gold and traces of silver and lead (table 9) (61).

Other Lode Deposits.--Gold is a minor constituent of many of the deposits that are described elsewhere in this report, particularly some of the copper lodes (table 9). The Wrights (1937, p. 221) refer to gold occurrences in the schist belt south of Adams Inlet that were unsuccessfully explored during the early days. They also (p. 222) mention some old and presumably abandoned gold claims in the hills between the east and west arms of Dundas Bay. Buddington (unpublished notes, 1924) notes that a claim was staked for gold at Dundas Bay, but no specific information concerning this claim is available. Buddington (unpublished notes, 1924) further reports that specimens that contained free gold were found in the moraines of Johns Hopkins and Brady Glaciers.

Placer Deposits

Placer gold deposits are fairly widespread in the Monument, but the only significant producers are the beach placers north and south of Lituya Bay (fig. 3A) (87) (88). The placers include beach sands, stream deposits, old alluvial terrace and bench placers, glacial outwash, and minor residual placers that are associated with some lodes in the Reid Inlet area. No significant placer gold deposits were discovered during our investigations. Descriptions of the known placer deposits in the Monument follow.

South of Wood Lake.--Rossman (1963b, p. 50) reports that placer gold has been mined from glacially derived gravels south of Wood Lake in the upper part of the Dundas River drainage basin (fig. 3A) (52). The exact location of these deposits could not be ascertained. The general region has been deglaciated fairly recently, and probably its streams contain local auriferous placers.

Dundas River.--According to records of the Alaska State Division of Mines and Minerals nine placer gold claims on the Dundas River are held by the Jimmie Martin estate. Little is known about the claims, but they are probably in the vicinity of locality (53) as plotted on figure 3A.

Outwash of Brady Glacier.--According to information cited in Rossman (1963b, p. 50, 51) placer mining of the outwash in front of Brady Glacier was carried on for some time during the early part of the century. The gold in these deposits is very fine grained and floury and difficult to recover. Probably attempts to mine it were of short duration and yielded only small amounts of gold.

Oregon King Consolidated.--Thirty-six placer claims, mainly on the beaches west of La Perouse Glacier (fig. 3A) (81), are held by the Oregon King Consolidated organization, (Alaska State Division of Mines and Minerals, written communication, 1966). The deposits have been explored intermittently during recent years and probably include a few stream and terrace deposits as well as the beach placers.

Lituya Bay.--The most extensive and best known placer gold deposits in the Monument are in the beach sands near Lituya Bay (fig. 3A) (87) (88). Auriferous sands are distributed irregularly along the beaches for about 20 miles northwest of Lituya Bay and about 15 miles southeast of the bay. They have been worked intermittently for many years. Mertie (1933, p. 133) states that mining by Americans near Lituya Bay commenced in 1894. The heyday of the mining was in 1896 when between 150 and 200 men were engaged in working the placer deposits. Between 1894 and 1917 the placers produced about $75,000 worth of gold (Mertie, 1933, p. 135). A small amount of platinum was recovered also. Production since 1917 has been small.

The minable placers are formed largely by the reworking of older gold-bearing deposits, particularly of poorly consolidated terrace, bluff, and bench deposits near the seashore. This process is abetted by large waves generated during storms, and the most favorable periods for mining are shortly after storms. Most of the gold in the deposits has been recycled and reconcentrated during several stages and also has been transported by glacial processes. Consequently it is extremely fine grained and floury and difficult to recover. The deposits were worked by fairly primitive methods, including Long Toms and sluice boxes, and undoubtedly a sizeable amount of the gold was not recovered.

The pay streaks generally are less than a few feet thick. They are in black sands that are rich in garnet and contain ilmenite, magnetite, and other heavy minerals that were concentrated by washing and gravity settling. The sparse platinum in the placers is very fine grained like the gold.

Rossman (1957) examined the beach deposits during 1952 and the following descriptions are taken from his report. The beach deposits overlie bedrock, glacial outwash, and moraines. All of them, except the modern bare beaches, are partly covered by alluvial fans, glacial outwash, or swamp deposits. The beach deposits include modern bare ocean beaches, tree-covered modern beaches, and older tree-covered beaches. The beaches that lack vegetation are between a few tens of feet and 1,000 feet wide. The tree-covered beaches are between 800 and 2,700 feet wide. Upper parts of all the bare beaches contain concentrations of heavy minerals that form deposits as much as several hundred feet wide and a few miles long. The vertical range of the heavy sand concentrations in the bare beaches is not known. Most cut banks show layers of heavy minerals to depths of about 6 feet. The tree-covered beaches also contain concentrations of heavy minerals on their upper surfaces, but little is known of the extents and depths of these deposits. The main heavy minerals of all of the beach sands, in general order of decreasing abundance, are garnet, pyroxene, ilmenite, amphibole, magnetite, staurolite, epidote, rutile, sphene, and zircon. The light fractions of the dark sands include quartz, feldspar, mica, calcite, and small rock fragments. Rossman was mainly concerned with the economic potential of the ilmenite in the sands. The heavy mineral sands near Lituya Bay were also investigated by the U. S. Bureau of Mines, mainly with emphasis on their iron and titanium content (Thomas and Berryhill, 1962, p. 37-39).

Mertie (1933, p. 135) reports that attempts to mine some of the bench and terrace deposits were largely unsuccessful. The Wrights (1937, p. 223) note that the counteraction of waves and stream currents near the mouth of a stream about 4 miles northwest of Lituya Bay is effective in concentrating heavy minerals.

The beach deposits near Lituya Bay are a potential source of additional gold production along with minor amounts of platinum and possibly ilmenite. They could be worked on a small scale under favorable economic conditions, or possibly some of them could be worked on a large scale by dredging. Little is known concerning the possibility of offshore placer deposits near Lituya Bay. The presence of such deposits is conceivable, but the likelihood of finding them in economically exploitable quantities in the near future is probably remote.

Other Placer Deposits.--Small amounts of gold have been recovered by mining the residual and weathered material that overlies some of the gold lodes in the Reid Inlet area. Surficial parts of many of these lodes essentially constitute residual placers. Gold is sparsely distributed in colluvium and in stream placers in the Reid Inlet area but probably in quantities too small to be exploited.

Many of the streams throughout the Monument undoubtedly contain small concentrations of placer gold, but the likelihood of significant gold production from them is small. The extensive glacial outwash and other fluvio-glacial deposits in the Monument likewise probably contain widely dispersed gold. Attempts to find concentrations of gold in these deposits were unsuccessful, and it is unlikely that they contain minable placers.

Platinum

Platinum is a rare constituent of some of the beach placers near Lituya Bay, especially those south of the bay (Mertie, 1933, p. 134), but no lode sources of platinum are known in the Monument. By analogy with known platinum deposits, such as those in the Bushveld complex and at Sierra Leone in Africa, or in the Stillwater complex in Montana, the platinum is probably a minor constituent of the mafic and ultramafic layered complex that forms the Crillon-La Perouse and the Astrolabe-DeLangle stocks in the Fairweather Range. The platinum would most likely be associated with certain ilmenite-rich layers within these rocks or with some of their sulfide deposits. However, platinum has not yet been found in rocks of the Fairweather Range. Platinum, along with several other metals, should be prospected for in the little-explored layered mafic and ultramafic rocks because these rocks are assuredly the source of the placer platinum.

Silver

Silver is a subordinate metal in many of the gold and base metal deposits in the Monument, and in only one prospect, near Rendu Inlet, is silver a major commodity. The known silver minerals in the Monument are minor constituents of veins, altered zones, and replacement bodies. They include argentiferous tetrahedrite, jamesonite, and native silver. Besides the Rendu Inlet prospect (fig. 3A) (37), silver has been reported from the Reid Inlet gold lodes, the Sandy Cove gold prospect, a prospect in the northwest part of Willoughby Island, near Blue Mouse Cove on Gilbert Island, and from the Nunatak molybdenum prospect. The richest silver value in our samples are 4.377 ounces per ton (150 ppm) from the Alaska Chief prospect, 2.043 ounces per ton (70 ppm) from the Rainbow mine in the Reid Inlet area, 1.46 ounces per ton (50 ppm) from the Sandy Cove prospect, 1.46 ounces per ton (50 ppm) from Francis Island, 0.875 ounce per ton (30 ppm) from the base metal lodes near Mount Brack, and 0.583 ounce per ton (20 ppm) from the copper deposits north of White Glacier (tables 9 and 11). Rossman (1963b, p. 49) states that a quartz-rich sample from a gulley northeast of the Nunatak molybdenum prospect carried 7.07 ounces of silver to the ton, but our samples from the Nunatak molybdenum prospect (table 13) carried only trace amounts of silver.

Small amounts of silver are associated with gold in most of the placer gold deposits in the Monument. The high degree of mineral comminution in many of the placers, particularly the recycled and glacially derived ones, inhibits recovering substantial amounts of silver from them.

Rendu Inlet Prospect

The Rendu Inlet silver prospect has been known for many years. According to Buddington (unpublished notes, 1924), it consists of two claims that were patented about 1892. The prospect is at an altitude of 30 feet on the west side of Rendu Inlet about 3 miles northwest of the mouth of the inlet (fig. 3A) (37). Its workings consist of a short westward-trending adit that is caved at the portal. Recent slide material covers most of the outcrops and precluded a satisfactory examination of the prospect. The deposits are mainly in an ankeritic carbonate-quartz vein about 6 inches thick and in contiguous altered wallrock a few feet thick. The vein and altered zone both strike N. 85° E. and dip 65° SE. White bleached marble forms the hanging wall of the deposit, and the foot wall is a dioritic dike that is about 20 feet thick and intrudes marble. A 4-inch thick quartz-calcite vein occupies a steep northwest-striking fault that offsets the northeast-striking vein a few inches. The only indication of ore mineralization exposed at the time of our examination was locally intense iron staining. Samples from the prospect were low in grade and lacked silver (table 9) (37). Buddington (unpublished notes, 1924) states that argentiferous tetrahedrite occurs on the claims. Rossman (1963b, p. 48, 49) found a specimen that contained tetrahedrite and wire silver along fractures in quartz. It is concluded that these ore minerals are sporadically distributed in the veins. Several similar-appearing veins and altered zones are along the west side of Rendu Inlet near the prospect. Samples from these zones were barren, but possibly diligent prospecting would detect small amounts of silver and copper minerals in them.

Iron and Ferroalloy Metals

The iron and ferroalloy metals discussed here include iron, chromium, cobalt, manganese, molybdenum, nickel, titanium, tungsten, and vanadium. Deposits of these metals include the two that have the best potential for mining in the near future, the Brady Glacier nickel-copper deposit and the Nunatak molybdenum deposit, as well as a few that merit exploration.

Iron

Several iron deposits are within the Monument, but none of them appear to be large enough or rich enough to be mined currently. The deposits include several magnetite-rich skarns, concentrations of magnetite and ilmenite in the layered mafic rocks of the Fairweather Range, beach placers that contain magnetite and ilmenite, and an alleged hematite deposit of uncertain genesis and type. Although they are locally rich, all of the known skarn deposits seemingly contain insufficient amounts of ore to be exploited. The layered mafic rocks of the Fairweather Range and the placer deposits northwest and southeast of Lituya Bay constitute a low-grade resource of iron along with their more important titanium.

Descriptions of Deposits

East of Dundas Bay.--Rossman (unpublished notes) mentions an iron deposit at an indefinite location east of Dundas Bay and north of Icy Strait (fig. 3A) (33). Little is known about the deposit, but judging from the local geology it probably is in skarn near the contact between granodiorite and limestone. A magnetic disturbance reported from the north side of Lemesurier Passage near locality (33) (U.S. Coast and Geodetic Survey Chart 8202) probably is also attributable to a magnetite-rich skarn deposit.

Buddington (unpublished notes, 1924) reports claims for hematite at an altitude of 1,700 feet in the mountains between Dundas Bay and the next cove to the east. No additional information is available on these claims, and they were probably abandoned many years ago.

West of Rendu Inlet.--Magnetite-rich skarn deposits are distributed irregularly in the southern part of the peninsula west of Rendu Inlet (fig. 3A) (39). The deposits are in small pods of tactite or skarn near the contact between quartz diorite and marble or within the quartz diorite (fig. 26). The deposits appear to be small, but much of the nearby bedrock is covered by surficial deposits and the size and distribution of the magnetite deposits cannot be estimated accurately. The skarn and tactite consist of garnet that is rich in grossularite, associated with calcite, quartz, chlorite, epidote, and with concentrations of magnetite. The marble is massive, coarse grained, and calcite rich. The quartz diorite is medium-coarse grained and contains abundant hornblende. A few mafic dikes as much as 6 feet thick cut the other rocks, and some of them contain small pyrite-rich blebs and pods near their contacts.

Two magnetometer traverses were made across the marble-quartz diorite contact and for several hundred feet into the quartz diorite terrane (fig. 26). These revealed local magnetic anomalies as much as 5,500 gammas (fig. 26). The quartz diorite has a fairly high magnetic background, but the anomalous magnetic values that were detected in it are attributed to pods of magnetite-rich skarn or tactite or possibly to local magnetite-rich segregations. Except for iron, samples of the skarn and tactite lacked significant amounts of ore metals (table 9) (39).

Queen Inlet.--Masses of tactite that locally contain sufficient magnetite to be termed skarn crop out in seacliffs along the east shore of Queen Inlet east of Composite Island (fig. 3A) (40). The tactite bodies are as much as 20 feet thick and intervene between alaskite and coarse white marble (fig. 27). Porphyritic felsic volcanic rocks are associated with some of the alaskite. In addition to magnetite the tactite contains abundant garnet, quartz, calcite, hornblende, pyroxene, chlorite, and sporadically distributed veins and pods of sulfide minerals, chiefly pyrite. Some of the veins are rich in albite. A few steeply dipping mafic dikes as much as 15 feet thick cut the other rocks. Several steep faults, apparently with minor offsets, are exposed in the seacliffs.

The alaskite is a hypidiomorphic-granular medium-grained rock that is slightly altered. It is prevailingly light gray, but some of its feldspars are altered to milky white masses. The alaskite contains between 50 and 65 percent oligoclase, between 20 and 30 percent quartz, minor K-feldspar, and subordinate amounts of magnetite and alteration products including calcite, epidote, actinolite, and chlorite. Some of the alaskite is cut by veinlets and minute fractures.

The porphyritic volcanic rocks are yellowish white. They contain abundant phenocrysts of plagioclase (sodic andesine) and quartz in a microcrystalline groundmass composed largely of plagioclase microlites, quartz, and albite(?). Minute crystals of pyrite and magnetite are widely dispersed throughout the rock. Calcite veinlets transect some of the volcanic rocks.

The coarse, white marble consists predominantly of calcite. The mafic dikes are dark-gray to black altered porphyritic andesites. They contain about 70 percent plagioclase (andesine) that forms phenocrysts between 1 and 2 mm long and which also is the dominant groundmass mineral. Other minerals in the rock are chlorite, actinolite, magnetite, and pyrite.

A magnetometer traverse along the beach contiguous to the seacliffs revealed magnetic anomalies greater than 1,000 gammas along projections of the tactite bodies (fig. 27).

The hillsides east and northeast of the seacliffs are largely covered by glacial deposits. Outcrops on these hillsides consist mainly of felsic siliceous rocks that were mapped as alaskite but which also include some siliceous porphyritic volcanic rocks. The alaskite and the volcanic rocks are cut by steep mafic dikes that contain sparsely distributed pods and thin veins of sulfides, chiefly pyrite. The petrography of these rocks is analogous to their counterparts that are exposed in the seacliffs. A magnetometer survey along a traverse extending southwestward from an altitude of 1,740 feet to near the beach was made to trace the magnetite deposits inland and to find concealed deposits (fig. 28). This survey revealed anomalous magnetism to 1,300 gammas in some areas that are covered by glacial drift; this probably indicates concealed magnetite-rich lodes similar to those exposed in the seacliffs.

Semiquantitative spectrographic analyses of the skarns showed major amounts (>10 percent) of iron, as much as 300 ppm copper, 300 ppm cobalt, 30 ppm tin, and traces of molybdenum and nickel (table 9) (40) (nos. 66AMk-298A, -298B, -299, -303). Similar analyses of pyrite-rich pods, veins, and altered zones contained abundant iron and as mucb as 300 ppm copper, 70 ppm cobalt, 30 ppm tin, and traces of molybdenum and lead (table 9) (40) (nos. 66AMk-305, -321, -323, -324). Analyses of an 18-foot long chip sample taken across the richest-appearing magnetite deposit in the seacliffs revealed 23.4 percent total Fe as Fe_2O_3, 38.5 percent SiO_2, 7.0 percent Al_2O_3, 0.11 percent P_2O_5, 1.54 percent S, 0.36 percent TiO_2, and 30 ppm As.[1/]

The known iron deposits east of Queen Inlet are too small and too lean to warrant economic interest, but possibly intensive prospecting might lead to the discovery of larger and richer deposits near the known ones.

West of Blackthorn Peak.--Seitz (1959, p. 117) reports a magnetic anomaly near the divide of Geikie Glacier west of Blackthorn Peak (fig. 3A) (51). The anomaly was detected from an airplane from an altitude of about 2,500 feet above the ground. Outcrops are poor in the vicinity of the anomaly because of extensive ice and snow. Probably the anomaly indicates a magnetite-rich skarn deposit, but conformation of the nature of the deposit and its size and grade would require drilling or other physical exploration.

1/ Fe_2O_3 determined by atomic absorption by W. D. Goss
SiO_2, Al_2O_3, and TiO_2 determined colorimetrically by G. T. Burrow
P_2O_5 determined volumentrically by L. F. Rader
S determined by induction furnace by Dorothy Kouba
As determined colorimetrically by E. J. Fennelly

East of Brady Glacier.--Magnetite deposits were found in the hills east of the lower part of Brady Glacier about 3 and 3/4 miles south of Abyss Lake (fig. 3A) (54). The deposits are at an altitude of about 1,350 feet. They consist of several steep lenses of magnetite-rich skarn that strike northwestward. The lenses are bordered by marble and by small masses of leucocratic granodiorite. The lenses are as much as 30 feet long and 10 feet in thickness. They comprise abundant magnetite and garnet, subordinate quartz and calc-silicate minerals, and minor pyrite and chalcopyrite.

Semiquantitative spectrographic analyses showed that samples of the skarn contained major amounts of iron and 1,000 ppm copper (table 9) (54). Magnetometer readings of as much as 5,000 gammas were obtained on some of the skarn outcrops. Although some of the skarn bodies are rich enough to constitute iron ore, they are too small to be exploited. Development of the deposits is contingent on the unlikely possibility of discovering concealed skarn bodies that contain large tonnages of magnetite.

Fairweather Range.--The layered mafic and ultramafic rocks of the Fairweather Range contain a large low-grade iron resource along with appreciable amounts of other metals, notably titanium. These rocks form the Crillon-LaPerouse and the Astrolabe-DeLangle stocks of Rossman (1963a) and probably a similar, but unexplored mass near Mount Fairweather. Four localities where the layered rocks are known to contain concentrations of iron minerals are shown in figure 3A (73, 79, 80, 83). Undoubtedly many other localities in the Fairweather Range contain similar deposits, but the Range has been only cursorily prospected, chiefly because of its formidable terrain and difficult access.

The iron deposits in the Astrolabe-DeLangle stock are represented in a general way by locality (73) in figure 3A. Rossman (1963a, p. 44, 45) reports that some layers in the stock contain concentrations of ilmenite, and that other layers contain as much as 20 percent titanium-bearing magnetite. At most places the contact zones of the stock also contain titanium-bearing magnetite. Most of the layers that carry much magnetite or ilmenite crop out over a "stratigraphic" thickness of about 1,000 feet near the top of the mountain that forms Astrolabe Peninsula. The iron- and titanium-rich layers are between 1,100 and 2,000 feet in altitude and appear to persist through the mountain. Rossman (1963a, p. 45, table 8) shows magnetite and ilmenite contents of some rocks from the Astrolabe-DeLangle stock.

Several iron-stained layers that are signaled by bright red outcrops have been reported from the Crillon-LaPerouse stock (Rossman, 1963a, p. 42, 43) (Kennedy and Walton, 1946, p. 71). A few of these are represented in figure A (79, 80, 83). Most of these layers contain fairly abundant ilmenite and subordinate pyrrhotite and chalcopyrite. The layers have not been prospected thoroughly, and probably some of them and some of the other layers in the stock also contain concentrations of magnetite.

The presence of layered mafic intrusive rocks near Mount Fairweather is indicated by float on the moraines of the Fairweather Glacier. Presumably these unexplored rocks have magnetite and ilmenite contents similar to the Crillon-LaPerouse and the Astrolabe-DeLangle stocks.

Placer Deposits.--The beach placers north and south of Lituya Bay that were described under "Gold" contain concentrations of ilmenite and some magnetite. The largest known placer concentrations of these heavy minerals in the Monument are between 2 and 13 miles south of Lituya Bay (Rossman, 1963a, p. 46). Rossman (1957, table 1) reported on the magnetite and ilmenite content of the beach placers. His samples contained as much as 10 percent magnetite and 21 percent ilmenite, but their average content of these minerals was considerably less. The probability of iron being recovered from these deposits is remote.

Chromium

No chromium lodes are known to occur in the Monument, but chromite float has been reported on glaciers in the Fairweather Range (Goldthwait, in Kennedy and Walton, 1946, p. 71, 72). The largely unexposed ultramafic rocks that are inferred to form the lower parts of the layered intrusive complexes of the Fairweather Range are potential hosts for chromite deposits. Trace amounts of chromium were found in almost all of our samples from the Monument, and anomalous quantities of chromium were found in a few of the samples (tables 9, 11, 13, and 15). The largest amounts of chromium detected in the samples were 1,500 ppm from near Mount Young (table 9) (1), 1,000 ppm from peridotite at the Brady Glacier prospect (table 15, CSN-1) (72), and 700 ppm from the Curtis Hills (table 9) (23).

Cobalt

Cobalt is a potential byproduct of the nickel-copper deposits at the Brady Glacier prospect, but no discrete cobalt minerals have been identified in the deposits. Samples representative of the richest ore at the prospect contained an average of 0.25 percent cobalt. Cobalt is probably a minor constituent of similar sulfide deposits that may be associated with the layered mafic and ultramafic complexes of the Fairweather Range. Minor amounts of cobalt were detected in almost all of our analyzed samples from the Monument, and anomalous amounts of cobalt were detected in a few of them (tables 9, 11, 13, and 15). The anomalous concentrations of cobalt are as much as 2,000 ppm in massive sulfides from the Brady Glacier prospect (table 15) (72), 700 ppm from west of Rendu Inlet (table 9) (38), 300 ppm from north of Adams Inlet (table 9) (5), the Queen Inlet magnetite locality (table 9) (40), and the Alaska Chief prospect (table 9) (29), and 200 ppm from Shag Cove (table 9) (49).

Manganese

Manganese is widely associated with most of the mineral deposits, but no potentially exploitable manganese deposits are known from the Monument, and the likelihood of discovering such deposits is remote. Manganese-stained oxidized zones are conspicuous in outcrops of several deposits, particularly the base metal replacement lodes and altered zones. Samples from several of the deposits contained between 2,000 and 7,000 ppm manganese (table 9). The most notable of these are from Francis Island (table 9) (28) and the Alaska Chief prospect (table 9) (29).

Molybdenum

Distribution

Many mineral deposits that contain molybdenum are known in the Monument. They include one important prospect, the Nunatak prospect (fig. 3A) (21); a few deposits, such as those in the Bruce Hills (fig. 3A) (34) and near the southwestern part of Gilbert Island (fig. 3A) (44), (45), that contain molybdenum and copper of near-equal potential; several small molybdenite deposits; and some deposits whose analyzed samples revealed trace to minor amounts of molybdenum.

Molybdenum is widely distributed throughout much of the eastern and northeastern parts of the Monument where widespread, but generally small, molybdenum content characterizes many of the metalliferous deposits. The molybdenum deposits are particularly abundant in parts of the Mount Fairweather D-1 and D-2 quadrangles (fig. 3A).

Types of Deposits

The molybdenum deposits commonly are localized in metamorphic rocks near granitic masses or within the granitic rocks themselves. They form stockworks, disseminations, veins, mineralized fault zones, fracture coatings, and uncommonly they are parts of contact-metamorphic zones, dikes, or amygdaloidal lavas. The largest known molybdenum deposits in the Monument consist of swarms of closely spaced veins and veinlets that are termed stockworks. Except for minor amounts of molybdite in the Bruce Hills copper-molybdenum deposit (34), molybdenite is the only molybdenum mineral in the deposits.

Descriptions of Deposits

Casement Glacier.--Molybdenite-bearing float was found on lateral moraines fairly high on Casement Glacier (fig. 3A) (9) by members of the Ohio State University field party sponsored by the Institute of Polar Studies (Colin Bull, written communication, 1965). The float reportedly also contained some copper carbonates.

Van Horn Ridge.--Numerous claims for molybdenum are on Van Horn Ridge east of the head of Muir Inlet (fig. 3A) (11). A few of the claims have been explored by shallow pits and trenches. The deposits are in iron-stained altered zones in north-striking hornfels that dips steeply and in granodiorite. Most of the altered zones are along faults. Typically they are a few feet wide and do not persist along strike. The altered zones are weakly mineralized. Samples from them contained as much as 200 ppm molybdenum and traces of lead (table 9) (11).

West Side of Tarr Inlet.--Many iron-stained altered and brecciated zones are exposed in the cliffs west of Tarr Inlet south of Margerie Glacier (fig. 3A) (17). These zones are between 1 and 5 feet thick and cut granodiorite or less commonly, hornfels. A few of them are near the edges of felsic dikes. The altered zones are lean in ore metals. Samples from them contained as much as 100 ppm molybdenum, 5,000 ppm arsenic, and 1,000 ppm barium (table 9) (17).

Nunatak Prospect.--The largest known molybdenum deposits in the Monument are at the Nunatak prospect east of Muir Inlet (fig. 3A) (21). The deposits are mainly in the northern part of "the Nunatak", an isolated knob about 1,100 feet high that is surrounded by water and periglacial debris. Prior to regression of the nearby glaciers, "the Nunatak" was surrounded by ice and was a true nunatak. The deposits were located in 1941 (Twenhofel, 1946, p. 12), and since then they have been explored intermittently. They were investigated and described by a U. S. Geological Survey field party under the direction of W. S. Twenhofel (1946) and by the U. S. Bureau of Mines (Sanford, Apell, and Rutledge, 1949). During the summer of 1966 they were explored with three diamond drill holes by the American Exploration and Mining Company. Our field examination consisted of checking Twenhofel's geologic map, and of collecting numerous chip samples, soil samples, and a few pertinent rock and mineral specimens.

Deposits at the prospect consist of stockworks of molybdenite-bearing quartz veins, uncommon disseminated molybdenite, and a mineralized fault zone. They are mainly in hornfels, but locally they occur in quartz monzonite porphyry and in silicified zones near the edge of the porphyry (fig. 29).

Geology.--The following descriptions of the rocks at the Nunatak prospect are largely from Twenhofel's (1946) report. The oldest rocks are dark-blue thin-bedded limestone with subordinate shale that crops out in the southwestern part of "the Nunatak" (fig. 29). These rocks are conformably overlain by a thick sequence of hornfels, which Twenhofel (1946, p. 12) differentiated into three units (fig. 29). The hornfels consists chiefly of orthoclase and clinozoisite with some diopside, garnet, quartz, and oligoclase. The lower hornfels unit is characteristically thin bedded and contains a few limy beds. The middle unit is also thin bedded and contains many beds that are rich in clinozoisite. The upper hornfels unit is thick bedded.

Small dikelike masses of quartz monzonite porphyry cut the hornfelses (fig. 29). Numerous postore andesitic dikes cut the hornfels, limestone, and quartz monzonite porphyry. Surficial deposits, chiefly of glacial origin, cover parts of "the Nunatak." Outcrops of the quartz monzonite porphyry are locally bordered by siliceous zones as much as 15 feet thick.

The quartz monzonite porphyry consists of phenocrysts of oligoclase and less abundant hornblende, biotite, and quartz in a microcrystalline groundmass that contains K-feldspar, quartz, and plagioclase. The phenocrysts are commonly euhedral and 3 to 4 mm long. Accessory minerals in the rock are magnetite and sphene. The alteration products include actinolite and epidote. Numerous quartz-rich veinlets cut the rock. Samples of the porphyry that were studied petrographically contained less K-feldspar than a normal quartz monzonite; this fact, along with the characteristic microcrystalline groundmass, indicates that the rock should be classified as rhyodacite porphyry.

The andesitic dikes are dominantly hornblende andesite porphyry and some dacite porphyry. They are altered porphyritic rocks with pilotaxitic groundmasses. They contain between 50 and 60 percent plagioclase (sodic andesine), which constitutes the dominant mineral in both their phenocrysts and groundmasses. Hornblende is both a phenocryst and groundmass mineral and forms between 10 and 15 percent of the rock. Other primary minerals that are minor constituents of the andesitic rocks include biotite, pigeonite, magnetite, and apatite. The secondary minerals include actinolite, chlorite, epidote, and calcite.

The dominant structural grain at "the Nunatak" is shown by north-striking beds that dip eastward (fig. 29). In the western part of "the Nunatak" the beds are folded into an open anticline. Bedding is obscure near the quartz monzonite porphyry. Several steep faults, apparently with minor offsets, are exposed at the prospect (fig. 29). These faults commonly strike north or northeast. The myriad fractures that developed in the quartz monzonite porphyry and the hornfels prior to the intrusion of the andesitic dikes were mineralized to form the stockworks of quartz-molybdenite veins.

Ore deposits.--The ore deposits consist of stockworks of closely spaced quartz veins and veinlets that contain almost all of the known molybdenum reserves, mineralized fault zones, and less common fracture coatings and disseminations. The stockworks are widely distributed throughout the northern part of "the Nunatak" extending from near the summit westward and northwestward to Muir Inlet (figs. 29 and 30). They consist of myriad closely spaced quartz veinlets less than an inch thick and thin quartz veins that are as much as 18 inches thick but commonly are less than 6 inches thick. The stockworks are mainly developed in the hornfels, but they have formed in the quartz monzonite porphyry also, particularly in its partially silicified peripheral zones. The stockworks are best exposed in the cliffs contiguous to the shoreline of Muir Inlet throughout a lateral extent of about 800 feet (figs. 29 and 30). There they consist of hundreds of N. 70° W.- to west-striking quartz veins and veinlets that dip nearly vertical. The veins and veinlets are cut by many steep, northeast-striking fractures that are occupied by clayey gouge as much as 2 inches thick and less common barren quartz and calcite. In places the transecting fractures offset the veins a few inches. Poorly developed near-horizontal fractures also cut some of the quartz veins and veinlets. Many of the quartz veins and veinlets contain molybdenite, generally as selvages or thin films along their borders, but unusually as scattered disseminations within the quartz. Molybdenite also forms rare thin films along some joint surfaces near the stockworks. Diamond drill cores reveal quartz-free molybdenite along fractures in some of the hornfels and as very fine disseminations in some of the quartz monzonite porphyry.

Besides quartz and molybdenite the veins contain minor to trace amounts of pyrite, pyrrhotite, chalcopyrite, tetrahedrite, bornite, enargite, alunite, K-feldspar, epidote, albite, malachite, and chlorite. The copper minerals occur mainly near the margins of the stockworks, and their distribution indicates a crude lateral zoning of the deposits. Thin altered zones, which are next to some of the veins contain phlogopite, montmorillonite, calcite, and feldspars.

Rossman (1963b, p. 49) reports that a grab sample of mineralized quartz-rich rock that was collected from a gulley on the northeast side of "the Nunatak" contained 0.04 ounce of gold per ton and 7.07 ounces of silver per ton. Silver was detected in only two of our samples (table 13). Minor amounts of both gold and silver were found in some of the cores from the American Exploration and Mining Company diamond drill holes (Robert Garwood, oral communication, 1966).

The fault deposits are largely confined to the steep, north-striking fault that extends northward from the lake north of Nunatak Cove (fig. 29), but they are also weakly developed in some of the lesser faults at the prospect. They mainly differ from the stockworks by containing molybdenite deposited along fractures within fault zones.

Satisfactory estimates of the grade of the deposits will require bulk sampling. Likewise, adequate estimates of the reserves are contingent on determining the configuration of the deposits. Indications that the deposits extend to considerable depths are: a) that they are exposed throughout a large vertical range, b) that the richest exposures of ore are in seacliffs that border Muir Inlet, c) that a company diamond drill hole was mainly in mineralized rock to its bottom approximately 300 feet below sea level, and d) that a Bureau of Mines diamond drill hole penetrated uniformly mineralized rock continuously to its bottom 158 feet below sea level.

Our investigations included collecting 58 chip samples from the stockworks, 3 chip samples from the fault zone, and 98 soil samples (fig. 30). The chip samples were between 20 and 120 feet in length and had sample intervals between ½ and 5 feet. All of the chip samples were analyzed colorimetrically for molybdenum and by semiquantitative spectrographic methods for 29 elements including molybdenum (table 13). The soil samples were analyzed by semiquantitative spectrographic methods.

For the purpose of estimating reserves, that part of the Nunatak deposit above sea level was divided into two blocks; block I contains the richest-appearing ore and includes the part of the stockwork extending from Muir Inlet to the 300-foot contour, and block II comprises the rest of the stockwork and the fault zone deposit, except for the small, inaccessible, and unsampled southern part of the stockwork (fig. 30).

Our reserve estimates for all the known mineralized areas above sea level follow. Grades are based on analyses of chip samples collected during our investigations.

Indicated reserves	Area (square feet)	Projected depth (feet)	Tons 1/	Grade (percent MoS_2)	Grade (percent Cu)
I. Stockworks near Muir Inlet below 300-foot contour	149,800	150	2,247,000	0.067	0.016
II. Remainder of the stockworks and the fault zone deposit	2,252,700	575	129,530,250	0.026	0.018

1/. Based on the assumption that 10 cubic feet of ore weighs 1 ton.

In addition, about 18 million tons of reserves similar in grade to the indicated reserves in II are inferred to underlie the steep cliffs near the southern extremity of the stockworks. Reserves that are comparable in tonnage and grade to those above sea level probably occur in that part of the deposit below sea level.

Twenhofel's (1946, p. 17, 18) reserve estimates are based on the results of drilling and sampling by the U. S. Bureau of Mines during 1942 and on his geologic mapping. The Bureau of Mines program consisted of drilling two diamond drill holes totalling 285 feet and collecting and analyzing a total of 249 chip, drill core, and channel samples. Sixteen samples were from the fault zone and 233 from the stockwork (Sanford, Apell, and Rutledge, 1949). The average molybdenum content of 177 samples from the part of the stockwork mapped as containing conspicuous molybdenite was 0.075 percent (Twenhofel, 1946, p. 17). Fifty-six samples that were collected from parts of the stockwork mapped as containing inconspicuous molybdenite contained an average of 0.048 percent molybdenum (Twenhofel, 1946, p. 17). The samples from the fault zone contained an average of 0.12 percent molybdenum (Twenhofel, 1946, p. 17).

A summary of Twenhofel's (1946, p. 17, 18) reserve and grade estimates follows.1/ Twenhofel's grade estimates were based partly on channel samples and may be more accurate than ours.

	Surface area (square feet)	Projected depth (feet)	Estimated tons2/	Estimated grade (percent MoS_2)
Fault deposit	18,000	300	540,000	0.169
Stockworks	2,170,000	500	8,500,0003/ 91,500,0004/	0.125 0.080

1/ These samples were not analyzed for copper, a possible byproduct.
2/ Based on the assumption that 10 cubic feet of ore weighs 1 ton.
3/ Estimated from surface mapping to contain conspicuous molybdenite.
4/ Estimated from surface mapping to contain inconspicuous molybdenite.

Three diamond-drill holes drilled by the American Exploration and Mining Company and associates during 1966 explored the lower part of the stockworks to a depth of 313 feet below sea level. The locations of the drill holes are shown in figure 29, but other data from the drilling is considered privileged information by AMEX and could not be released at the time this report was prepared. In general, the results of the drilling corroborate the size and grade of the stockworks as indicated by the surface exposures.

The Nunatak molybdenum prospect contains a large reserve of low-grade ore, and if the current trends in price and demand for molybdenum continue, it may be minable in the future.

Geochemical Studies.--Ninety-eight soil samples and six water samples were collected at the Nunatak prospect to determine if geochemical methods could trace the molybdenum mineralization beyond areas that are known to contain molybdenite. The soil samples were collected from a traverse along the crest of "the Nunatak" and along other traverses in the medial and lower parts of "the Nunatak" (fig. 30). Water samples were collected from two glacial lakes on the west side of "the Nunatak". For comparison four water samples also were collected from creeks in the Glacier Bay area far from known molybdenum mineralization.

Soils from outside the mineralized area contained less than 5 ppm molybdenum and less than 30 ppm copper. During the ridge crest traverse many anomalous samples that contained between 10 and 29 ppm molybdenum were collected south of the area that is shown as mineralized on the geologic map (figs. 29 and 30) and from sites where close examinations of the rocks revealed no molybdenite. Some of the molybdenum may have been transported by glaciers from north of "the Nunatak"; however, it is believed that much of this molybdenum is of local derivation. Both molybdenum and copper are present in abnormal amounts in soils near the southern end of the crest of "the Nunatak" where minerals containing these metals have not been identified in the nearby bedrock.

Samples collected along the east base of "the Nunatak", except those near the extreme northern tip, have only background molybdenum and copper contents (less than 5 ppm and 30 ppm, respectively). However, on the west side of "the Nunatak" most of the samples contain anomalous values. The highest metal content in this group (910 ppm molybdenum and 270 ppm copper) occurs in sample 64 (fig. 30). The samples indicate that the soils with high molybdenum and copper contents extend irregularly southward beyond the area mapped and are mineralized as far south as the eastern tip of the larger lake (figs. 29 and 30). These high values confirm the southern extension of the geochemical anomaly and also the presence of copper in the southern part of the anomaly, which was indicated by the ridge crest sampling.

Several types of soil are present and available for sampling along the base of "the Nunatak." Of these the oldest is slightly weathered glacial till composed of gray mud and rounded glacial erratics. After deglaciation a series of alluvial talus cones formed; these are composed in part of glacial materials and in part of sand and angular pebbles of the local rock. Where talus cones of several different ages are recognizable, the younger ones contain the most local rock. The relative ages of the cones can be identified from their physiographic relations as the older ones are being dissected and the younger ones are still being formed.

For comparative purposes samples of two different kinds of soil were taken at several sample sites. The results in table 14 show that large differences exist in the molybdenum and copper contents of these closely-related soils and that the younger soil at a given site commonly contains much more of these metals than the associated older soil.

All soil samples from the Nunatak area composed entirely of glacial till have a low metal content. Samples collected along the two traverses that extend westward (fig. 30) are, except sample 61, composed entirely of till and all have low metal contents. Sample 61, which contains 230 ppm copper, is the only sample from these traverses which is composed in part of local bedrock.

The two samples of lake water from the Nunatak area were dried to a residue and analyzed spectrographically. One sample contains the remarkably high concentration of 7,000 ppm molybdenum. The other residues contain 700 ppm molybdenum, which is high by comparison with the soil samples. These analyses show that molybdenum is fairly soluble in the surficial environment. Even though the places in the area where waters could be sampled are limited, the possible use of water analyses in prospecting appears to deserve more study here. Because plants are likely to absorb molybdenum from the ground water study of the molybdenum content of the local plants seems desirable also.

Adams Inlet.--Buddington and Chapin (1929, p. 330) report that molybdenite occurs in fractures in metamorphic rocks on the north side of and near the entrance to Adams Inlet (fig. 3A) (22). This occurrence was not found although the general area was examined in some detail. Possibly it is the same locality as the copper-bearing amygdaloid with trace amounts of molybdenum that crops out about 1½ miles from the entrance to the inlet (5).

Wachusett Inlet.--A molybdenite-bearing quartz vein crops out in recently deglaciated rocks near the head of Wachusett Inlet (fig. 3A) (35). The vein is between 1 and 12 inches thick and is exposed for about 75 feet along its strike. It strikes N. 34° E. and dips 85° SE. The vein cuts quartz diorite, which has been intruded by andesitic and pegmatitic dikes, and contains quartz, pyrite, molybdenite, chalcopyrite, and secondary iron minerals. A sample from the richest part of the vein carried 7,000 ppm molybdenum, 15,000 ppm copper, 700 ppm zinc, and 0.0045 ounce per ton (15 ppm) silver (table 9) (35). The deposit is too small to be exploited, but it is rich enough to encourage exploration for similar, but larger, deposits in the vicinity, particularly since the nearby terrain has been recently exposed and is essentially unprospected.

Triangle Island.--Rossman (1963b, p. 49) reports that a few hundred pounds of molybdenite, which constituted the entire deposit, was mined in one day from Triangle Island, in the north part of Queen Inlet (fig. 3A) (36). Examination of the island, which is a seagull rookery, failed to reveal any molybdenite or signs of workings. The island is composed of fine-grained granodiorite that is cut by a few east-striking aplitic dikes that commonly dip north at about 50 degrees.

Geikie Inlet.--Buddington and Chapin (1929, p. 329, 330) report specimens of molybdenite float from near Geikie Inlet. Reed (in Smith, 1942, p. 178) reports claims on molybdenite-bearing tactite at a rather high elevation near the head of Geikie Inlet, probably near locality 50 in figure 3A. A brief examination failed to disclose any molybdenite or signs of workings in the general vicinity. Buddington (1924, unpublished notes) reports that molybdenite ore was obtained from near Geikie Inlet in 1918.

Brady Glacier.--Float specimens of molybdenite-bearing quartz veins have been reported from Brady Glacier (fig. 3A) (56), (Buddington, 1924, unpublished notes; Buddington and Chapin, 1929, p. 329, 330; Smith, 1942, p. 177). No specific information is available on the locations of the float specimens, and we were unable to find similar ones. The Brady Glacier moraines contain diverse rocks that were derived from a large and geologically complex area. Among these rocks are felsic granitic types that are favorable hosts for some molybdenum deposits.

Ridge West of Rendu Inlet.--A swarm of thin quartz veins and subordinate thin quartz-rich pegmatite dikes cut granitic rocks on the ridge west of Rendu Inlet (fig. 3A) (60). The veins and dikes have diverse attitudes, but they generally strike northward and dip steeply eastward. The veins commonly are spaced several feet apart and are between ½ and 3 inches thick, commonly less than 1 inch thick. The veins and dikes occupy a zone about 25 feet wide. The veins and quartz-rich parts of some of the dikes contain scattered sulfide minerals including molybdenite, chalcopyrite, pyrite, and pyrrhotite. The deposits appear to be too small and too dispersed to justify exploration.

Other Molybdenum Deposits.--Molybdenum is a constituent of many other deposits in the Monument, particularly some of those that are noteworthy for their copper contents. Molybdenum occurs in significant amounts in copper deposits in the Bruce Hills (fig. 3A) (table 9) (34) and near the southwest part of Gilbert Island (fig. 3A) (table 9) (44, 45). It occurs in lesser amounts in deposits east of Dundas Bay (fig. 3A) (table 9) (32) and southwest of Lamplugh Glacier (fig. 3A) (table 9) (67) and in minor to trace amounts in many other deposits that are indicated in figure 3A and tables 9 and 11.

Molybdenum was detected in trace to minor amounts in several samples that are not particularly noteworthy for their contents of other metals. These samples represent deposits that are best regarded as occurrences with no economic potential, and they do not merit individual descriptions. Included among them are occurrences east of the head of Charpentier Inlet (fig. 3A) (table 9) (47), on the north shore of Geikie Inlet (fig. 3A) (table 9) (48), on the south end of the ridge west of Reid Inlet (fig. 3A) (table 9) (70), south of the head of Reid Inlet east of Brady Glacier (fig. 3A) (table 9) (71), on the south shore of Johns Hopkins Inlet west of Lamplugh Glacier (fig. 3A) (table 9) (74), and about 1/4 mile northwest of the Sandy Cove prospect.

Nickel

Nickel occurs in trace to moderate amounts in many of the sulfide deposits in the Monument, and it is the principal commodity in the major deposits at the Brady Glacier nickel-copper prospect. Most of the samples that contained nickel are from deposits that are described under "Copper". The highest nickel contents in these samples were 1,000 ppm from a pyrite-rich lens west of Rendu Inlet (fig. 3A) (table 9) (38) and 500 ppm from soil at the Alaska Chief prospect (fig. 3A) (table 9) (29). Many other deposits, which are described under "Copper", contained between 100 and 300 ppm nickel. These include the deposits near Mount Young (fig. 3A) (table 9) (1), north of White Glacier (fig. 3A) (table 9) (6), north of York Creek (fig. 3A) (table 9) (8), in the Curtis Hills (fig. 3A) (table 9) (23), on the shore south of Tidal Inlet (fig. 3A) (table 9) (41), on South Marble Island (fig. 3A) (table 9) (25), and on Francis Island (fig. 3A) (table 9) (28). Minor amounts of nickel were detected in samples from two deposits that lack notable concentrations of other metals. These are a deposit north of Mount Abdallah (fig. 3A) (table 9) (16) that consists of iron-stained hornfels, and a deposit west of the head of Lamplugh Glacier (fig. 3A) (table 9) (68) in altered zones that cut hornfels. Probably some of the unsampled pyrrhotite-rich lenses and veins that have been reported from the Fairweather Range are nickeliferous (Kennedy and Walton, 1946, p. 71).

Searchers for undiscovered nickel deposits should concentrate on the layered mafic and ultramafic complexes of the Fairweather Range, particularly their lower horizons and contact zones. Both of these environments are regarded as geologically favorable sites for nickel-copper sulfide lodes such as those at the Brady Glacier prospect.

Description of Deposits

Brady Glacier Prospect, by H. R. Cornwall.--Massive and disseminated nickel-copper sulfides were discovered in 1958 by the Fremont Mining Company in three nunataks near the west edge of Brady Glacier in Mount Fairweather C-3 quadrangle (fig. 3A) (72). The sulfides occur at the southeast margin of a large lopolithic intrusion of gabbro and peridotite described by Rossman (1963a). The intrusion, called the Crillon-LaPerouse stock by Rossman, is 17 miles long and 8 miles wide and consists mainly of layered gabbro. The nickel-copper deposits occur near the base of the gabbroic intrusive in a zone where ultramafic rocks (peridotite) predominate. The following descriptions of the geology and ore deposits include some material that graciously was supplied by the Newmont Exploration Company.

Geology.--This mafic complex is intruded into amphibole and biotite schist which Rossman tentatively correlates with greenstone and graywacke units on Chichagof Island southeast of Brady Glacier. In the area of the Brady Glacier nickel-copper deposits, the mafic complex has intruded garnetiferous biotite schist. The minerals in this schist are quartz, plagioclase, orthoclase, and biotite with sparse porphyroblastic pink garnets.

According to Rossman (1963a) the Crillon-LaPerouse gabbroic intrusive has an exposed thickness of about 32,000 feet. The layers, ranging in thickness from less than one inch to tens of feet, are due to differences in grain size and in proportions of the principal minerals plagioclase, pyroxene, and olivine. The layers are trough-shaped, dipping away from the margins of the intrusive at angles of 70° or less.

In the nickel-copper-bearing nunataks on Brady Glacier the structures are much more complex and stratiform relations are less apparent. This is due in part to later intrusions and in part to postcrystallization faulting near the margin of the intrusive. The general relations of the rocks exposed in 1966 are shown in figure 31. Two of the three nunataks described by geologists of Newmont Exploration, Ltd. (written communication, 1961) were exposed in 1966--the High Nunatak and the Small Nunatak. In these exposures peridotite overlies fine- to medium-grained gabbro, in part layered, and the units dip 20-50° southeast toward the margin of the intrusive. These rocks are intruded by dikes and irregular bodies of gabbro, diorite, aplite, and possibly peridotite. A prominent shear zone strikes northeast parallel to the axis of the Small Nunatak and smaller faults run parallel to this in both nunataks. Several minor faults strike nearly north-south across the High Nunatak. The faults dip moderately to steeply east and southeast.

Peridotite is the predominant host rock for the Brady Glacier deposits. The peridotite most commonly consists of a mixture of forsterite (olivine) and enstatite (orthopyroxene). Augite (clinopyroxene) has been found in some specimens. Dunite consisting entirely of olivine is present but not abundant. The olivine crystals in the peridotite are rounded, 0.2-3.0 mm in diameter, and commonly surrounded by a matrix of poikilitic pyroxene. In most of the peridotite the pyroxene and, to a lesser extent, the olivine have been partly to completely altered to tremolite (amphibole), antigorite (serpentine) and minor epidote. The peridotite contains small amounts of chrome picotite (green spinel) and pyrrhotite ($Fe_{1-x}S$), pentlandite $(Fe, Ni)_9S_8$, and chalcopyrite ($CuFeS_2$). The peridotite contains lenses or schlieren as much as one foot thick of coarse gabbro and gabbro pegmatite, elongated parallel to layering where it is discernible.

Fine- to coarse-grained olivine gabbro is also a common host rock for the nickel-copper sulfide deposits. Plagioclase (An_{45-60}) is commonly fresh in crystals ranging from 0.1 to 2.5 mm. Augite is interstitial to the plagioclase in grains less than 0.5 mm. Some orthopyroxene is present; locally it is more abundant than augite. The pyroxene is moderately to completely altered to tremolite and antigorite. Forsterite (olivine) occurs in 0.1-3.0 mm grains and is partly to completely altered to tremolite and antigorite. A little epidote is present and small amounts of pyrrhotite, pentlandite, and chalcopyrite are disseminated through the rock.

Dikes up to 5 ft. or more of fine-grained gabbro, diorite, and aplite are quite common and tend to cross the layering of the peridotite and gabbro. The diorite is similar to the fine-grained gabbro but has more sodic plagioclase ($An_{\pm 40}$). The aplite has plagioclase phenocrysts (An_{35}) up to 2.5 mm long in a groundmass with grains less than 0.3 mm of euhedral biotite and anhedral plagioclase and quartz.

Ore Deposits.--The sulfides pyrrhotite ($Fe_{1-x}S$), pentlandite [$(Fe, Ni)_9S_8$], and chalcopyrite ($CuFeS_2$) occur in the host rocks described above as disseminated grains, veinlets, and lenticular masses up to 35 feet long and 5 feet in diameter. Most of the masses of solid sulfide are, however, much smaller. Large sulfide masses were mainly observed only near the northeast end of the Small Nunatak. The sulfide veinlets are commonly less than 1 mm thick and occur along fractures and fissures. Small lenticular masses also occur along the more prominent fissures and faults. The grains and small patches of sulfides are scattered through most of the host rock and occur in all types except the aplite. The disseminated sulfides appear to be most abundant in altered peridotite and gabbro pegmatite. Individual sulfide grains are commonly less than 2 mm in diameter.

The relative order of abundance of the sulfides is pyrrhotite, pentlandite, chalcopyrite. Pyrrhotite grains commonly have smaller peripheral grains of pentlandite and chalcopyrite. Pentlandite also occurs as lenticular blebs, 0.01-0.04 mm in diameter, in the pyrrhotite with more or less parallel orientation. These blebs probably formed by exsolution from the pyrrhotite during cooling of the rock. Chalcopyrite is more erratic in its distribution than the other sulfides and textural relations suggest that it may have formed slightly later. The pentlandite has been partly altered by weathering near the surface in the nunataks and upper parts of diamond-drill holes, to violarite (Ni_2FeS_4) and polydymite (Ni_3S_4).

Possibilities of Commercial Ore Deposits.--The Fremont Mining Company staked claims covering the Brady Glacier nickel-copper deposits in 1958. They sampled the nunataks and drilled 32 diamond-drill holes in 1958-1959 (written communication, 1959). In 1960-1961 Newmont Exploration, Ltd. (written communication, 1961), under an agreement with Fremont, drilled 14 more holes and did more mapping and sampling of the nunataks.

Disseminated sulfides are widely distributed throughout the nunataks. The amounts are small, however, and the overall average grade of the nunataks would probably be less than 0.5 percent each of nickel and copper. Several of the sulfide masses in the nunataks have been sampled and assays run 2 to 3 percent nickel, 1 to 1.4 percent copper, and 0.25 percent cobalt. Results of semi-quantitative spectrographic analyses of our ore and rock samples from the prospect are shown in table 15. Individual massive sulfide lenses are small; five such bodies on the nunataks, however, have lengths ranging from 15 to 35 feet and average widths of about 6 feet. The extent in depth is also probably comparable to these dimensions.

Diamond-drilling thus far has shown that low-grade nickel-copper mineralization is widespread in the gabbro-peridotite complex, but more drilling will be needed to establish continuity of the higher-grade zones. A large area about 1,000 feet in diameter beneath the glacier 1,000 feet southwest of the nunataks appears to contain 0.3 to 0.6 percent nickel and 0.2 to 0.4 percent copper in gabbro and peridotite; the depth of mineralization has not been determined. By analogy with known commercial deposits of a similar nature elsewhere it is very possible that, as the basal contact of the ultramafic complex is approached with greater depth, higher grades of nickel and copper mineralization will be encountered.

Several diamond-drill holes were drilled 200 to 700 feet south of the nunataks and these revealed somewhat higher grade mineralization than in the area described above. One hole intersected sulfide mineralization for over 100 feet with 1 percent nickel and 0.4 percent copper and another intersected over 100 feet averaging 0.7 percent nickel and 0.4 percent copper. The area surrounding the nunataks appears to offer the greatest promise for commercial ore bodies; more exploration is needed for a reliable evaluation.

Titanium

Distribution

Important amounts of titanium are in ilmenite-rich rocks of the layered mafic sequences of the Fairweather Range and, to lesser extents, in ilmenite-bearing beach placers north and south of Lituya Bay (fig. 3A). Titanium was detected in quantities of 10,000 ppm in samples from three other deposits examined during our investigations: Curtis Hills (fig. 3A) (table 9) (23), South Marble Island (fig. 3A) (table 9) (25), and east of Charpentier Inlet (fig. 3A) (table 9) (47). It was found in amounts between 2,000 and 7,000 ppm in many other deposits (fig. 3A) (table 9). These titanium values reflect host rocks that intrinsically have moderate titanium contents but are too lean to be of economic significance.

Descriptions of Deposits

Fairweather Range.--The ilmenite-rich gabbros of the layered intrusive complexes of the Fairweather Range constitute a large resource of low-grade titanium ore. The ilmenite deposits have not been studied in detail, and the limited information about them is from Rossman (1963a, p. 42-45) and from Kennedy and Walton (1946, p. 71). The layered intrusive masses of the Fairweather Range are the Crillon-LaPerouse and the Astrolabe-DeLangle stocks of Rossman (1963a) and an inferred and undefined stock near Mount Fairweather (fig. 3A). These masses have crude troughlike configurations that are shown by northwest-trending axes and inward-dipping layers. In the Crillon-LaPerouse stock, the largest of the layered masses, the layered sequence has a maximum exposed thickness of 32,000 feet and consists largely of gabbro. The ilmenite-rich layers represent magmatic deposits in which ilmenite was concentrated mainly by gravity settling. Four of the ilmenite deposits are shown in figure 3A (73), (78), (79), (80), and undoubtedly similar deposits occur elsewhere in the little explored range.

Rossman (1963a, p. 42) reports that the contact area of the Crillon-LaPerouse stock, 1½ miles southeast of Mount Lookout, probably contains between 10 and 25 percent ilmenite through a distance of several hundred feet, but that the lateral extent of the ilmenite-rich zone could not be determined because of extremely rough terrain. Rossman noted similar zones in the valley walls south of South Crillon Glacier. Layers of gabbro northwest of North Crillon Glacier contain between 7 and 10 percent ilmenite, and similar concentrations of ilmenite are near the southernmost exposures of the Crillon-LaPerouse stock (Rossman, 1963a, p. 42). Rossman also found a few layers that contain small concentrations of ilmenite and sulfide minerals elsewhere in the Crillon-LaPerouse stock. Rossman (1963a, p. 43, 44) shows tables indicating the ilmenite contents of samples from the Crillon-LaPerouse stock and semiquantitative spectrographic analyses of heavy mineral concentrates from the stock.

Some layers of the Astrolabe-DeLangle stock contain concentrations of ilmenite, and others contain as much as 20 percent titanium-bearing magnetite (Rossman, 1963a, p. 44). Most of the layers that contain much ilmenite or magnetite crop out through a "stratigraphic" thickness of about 1,000 feet, high in the mountains that form Astrolabe Peninsula. The mineralized layers appear to be continuous throughout the mountains. Rossman (1963a, p. 45, table 8) shows the content of ilmenite- and titanium-bearing magnetite from rocks of the Astrolabe-DeLangle stock.

Kennedy and Walton (1946, p. 71) report that an intrusive layer about 5 feet thick that crops out for several thousand feet along the south wall of the valley of North Crillon Glacier contains as much as 60 percent ilmenite.

On the basis of present knowledge the layered gabbros of the Fairweather Range are a potentially important resource of titanium and possibly iron and other metals. More accurate evaluations of their economic potential require detailed exploration and sampling. Such investigations would be inhibited by the remote and rugged terrain of the Fairweather Range and would be costly and time consuming.

Placer Deposits near Lituya Bay

The beach placers north and south of Lituya Bay (fig. 3A) (87) (88) have been investigated by Mertie (1933, p. 117-135), Rossman (1957), and Thomas and Berryhill (1962, p. 37-39). The latter two investigations stressed the ilmenite content of the placers. Detailed descriptions of the placers are in the section of this report describing placer gold deposits. The placer deposits have yielded a small production of gold, and they and their probable offshore extensions are potential sources for gold, titanium, and possibly other metals. The largest known placer concentrations of heavy minerals in the Monument are along the beaches between 2 and 13 miles south of Lituya Bay. The upper parts of all of the bare beaches and most of the tree-covered beaches north and south of Lituya Bay contain between 5 and 40 percent heavy minerals. Some of the deposits are large, extending for more than 2 miles along the beaches with widths of several hundred feet.

Rossman's (1957, p. 6, table 1) samples from the beach deposits between Palma Bay and Dry Bay indicate that these deposits contain between 0.25 and 21.0 percent ilmenite and as much as 10 percent magnetite. The TiO_2 content of the ilmenite from these samples ranges from 46.80 percent to 52.38 percent (Rossman, 1957, p. 8, table 2).

The U. S. Bureau of Mines investigations of the placers north and south of Lituya Bay consisted of sampling 26 auger holes and collecting 11 shovel samples (Thomas and Berryhill, 1962, p. 37-39, table 21, fig. 12). The magnetic fractions of these samples contained between 0.1 and 16.5 pounds of iron per cubic yard, and the nonmagnetic fractions contained between 0.3 and 89.5 pounds of TiO_2 per cubic yard.

Tungsten

Deposits that contain tungsten in potentially minable quantities are not known in the Monument. The one previously reported tungsten occurrence consists of minor amounts of scheelite in a gold-quartz vein east of Reid Inlet (Rossman, 1959, p. 56). Tungsten was detected in samples from only two of the deposits that we examined. This is attributable in part to the low sensitivity for tungsten in the semiquantitative spectrographic analysis, but it is mainly because of the scarcity of tungsten.

A sample of pyrrhotite-rich massive sulfide float from the Margerie copper prospect contained 3,000 ppm tungsten, and a sample from a quartz vein at the prospect contained 150 ppm tungsten (fig.3A) (table 9) (19). A sample representative of a 1-foot thick sulfide-bearing tactite that has replaced marble in the northern part of Gilbert Island contained 150 ppm tungsten (fig. 3A) (table 9) (43).

Samples of sediments from streams entering the north part of Dundas Bay contained as much as 150 ppm tungsten and 30 ppm tin and indicate a geochemical anomaly (table 4). Tracing the anomalous metals to their source might lead to the discovery of a tungsten deposit of interest.

Tactite bodies and, to a lesser extent, gold-quartz veins are generally favorable hosts for scheelite deposits, and the fact that many deposits of these types were examined and sampled with negative results presages little support for successful tungsten exploration in the Monument. Wolframite and other tungsten minerals are elsewhere associated with leucocratic granitic rocks similar to some rocks that are fairly abundant in the Monument. With the possible exception of the geochemical anomaly north of Dundas Bay no evidence linking tungsten mineralization to these rocks was found during our investigations.

Vanadium

Vanadium was detected in minor amounts in samples from many deposits in the Monument. The highest concentration of vanadium found was 1,500 ppm in a sample of sulfides replacing metavolcanic rocks near Mount Young (fig. 3A) (table 9) (1). Vanadium was detected in quantities between 500 and 700 ppm in a few samples and in lesser amounts in many samples (tables 9, 11, and 15).

The ilmenite and the titanium-bearing magnetite in layered mafic intrusive rocks of the Fairweather Range contain subordinate amounts of vanadium, and vanadium would possibly be a byproduct from mining deposits of these minerals. Rossman (1963a, p. 44, table 7) indicates that the vanadium content of heavy mineral concentrates of 9 samples from the Crillon-LaPerouse stock was less than 1 percent.

By analogy with known deposits, the search for vanadium in the Monument should focus on prospecting for concentrations of vanadium-bearing ilmenite and magnetite in the layered intrusive complexes of the Fairweather Range. The Bushveld complex of Africa, which has some similarities with the layered intrusions of the Fairweather Range, contains the largest known reserves of vanadiferous iron ore in the world.

Geologic Influences on Localization of Metalliferous Deposits

Almost all of the known deposits in the Monument can be related, at least spatially, to magmatic sources. The relationships range from strictly magmatic deposits, such as the titanium and iron deposits in the layered gabbros of the Fairweather Range, through many deposits associated with granitic plutons and dikes that are inferred to be late-stage magmatic derivatives, to a few deposits with only tenuous magmatic affiliations far from exposures of igneous rocks.

Correlations and affinities of specific rocks and geologic settings with specific types of mineral deposits are well documented in the geologic literature. In the Monument such affinities are exemplified by the ilmenite and magnetite deposits in the layered gabbro, the probability of chromite and platinum deposits in ultramafic rocks of the layered intrusive complexes, nickel-copper deposits in the lower and peripheral parts of the layered intrusives, magnetite-rich skarn deposits and base metal deposits in marble near contacts with intrusive rocks, and molybdenite deposits in or near epizonal intrusive rocks. Many of the gold lodes may be inferentially related to felsic granitic rocks.

Structural and tectonic factors have been important in localizing some of the deposits. Disruptive intrusions shattered the wallrock at the Nunatak molybdenum deposit and probably at a few other molybdenum deposits, and created myriad fractures that were sites for subsequent mineralization. An east-trending structural zone in the east-central part of the Monument may have influenced the formation of the nearby molybdenum deposits. This zone contains many porphyritic plutons, and some of them are associated with molybdenum deposits.

Carbonate rocks near intrusive masses are favorable sites for a variety of ore deposits, and such associations are known from many places in the Monument. Besides the carbonate rocks, hornfelses and other rocks near intrusive bodies are potential hosts for metals derived from the magmas. The northwest-trending mixed rocks and hornfels that extend from west of Lamplugh Glacier to near the northern boundary of the Monument contain numerous altered zones.

NONMETALLIC COMMODITIES

Deposits of several nonmetallic commodities are known in the Monument, but their economic potential is minimal because of their low grade, small size, impurities, poor access, and cheaper availability from other sources. Limestone and marble are distributed widely throughout the central and eastern part of the Monument, particularly on islands in the southern part of Glacier Bay and on the nearby mainland. The most extensive limestone and marble deposits are on Willoughby, Drake, and Francis Islands, the Marble Islands, and on the mainland south of Sandy Cove and near Marble Mountain (fig. 3A). Although many of these deposits are large and are accessible to tidewater, our limited examinations indicate that most of them are contaminated with silicate or dolomitic phases or other impurities and they are also cut locally by numerous dikes and veins.

Most of the dolomite bodies appear to be too small to be of interest. A possible exception is the dolomite that is exposed at a rather remote location on the ridge west of Geikie and Hugh Miller Glaciers (fig. 3A) (Seitz, 1959, p. 115, 116), but little is known concerning the composition and relative purity of this mass.

Minor amounts of several other nonmetallic commodities are known from the Monument. Barium is associated with many of the lode deposits (table 9), but in amounts too small and grades too lean to be of significance. A small amount of celestite (strontium sulfate) has been found in the Monument (Seitz, 1959, p. 115), but the deposits are too small to be important. Sand and gravel are available at a few places in the Monument, but their utilization is negated by the lack of nearby markets and by the widespread occurrence of similar and better deposits closer to potential markets.

PETROLEUM AND COAL

By George Plafker

PETROLEUM

Within Glacier Bay National Monument potentially petroliferous rocks of Tertiary age underlie a coastal lowland-and-foothills belt less than 4 miles wide and about 40 miles long southwest of the Fairweather Fault (fig. 32). Tertiary rocks are also presumed to occur over much, if not all, of the adjacent offshore area within the Monument. The Tertiary rocks are underlain by regionally metamorphosed and complexly deformed Mesozoic(?) sedimentary and volcanic rocks that represent effective "basement" for petroleum potential in this area.

The portion of Glacier Bay National Monument described herein lies within the Lituya District of the Gulf of Alaska Tertiary Province. The Gulf of Alaska Tertiary Province has been studied by Don J. Miller, who published many reports on the area and summarized its geology (Miller and others, 1959). The descriptions of the structure and stratigraphy of the Tertiary sequence in the Lituya District are based mainly on detailed mapping by Miller and others (Miller, 1953, 1961) and on unpublished U. S. Geological Survey field data obtained by the writer during a stratigraphic reconnaissance of part of the area in 1963.

Stratigraphy

Bedded rocks of Tertiary age in the Lituya District include marine and nonmarine clastic and volcanic units with a composite thickness of at least 12,000 feet which unconformably overlie the Mesozoic basement. The sequence has been subdivided into three formations: the Cenotaph Volcanics of Oligocene(?) age, the Topsy Formation of probable Oligocene age, and the Yakataga Formation of Miocene and Pliocene age (Plafker, 1967). Relations between the Topsy Formation and Cenotaph Volcanics are obscure; the two units are believed to be at least partly equivalent in age, for the predominantly or wholly nonmarine beds of the Cenotaph Volcanics appear to grade into and interfinger with the marine Topsy Formation. Both formations are disconformably overlain by the marine Yakataga Formation. Generalized stratigraphic sections and tentative correlations of the Tertiary sequence are shown on figure 33.

The Topsy Formation ranges in thickness from about 1,200 feet at the type section along upper Topsy Creek to at least 4,400 feet at Icy Point. It consists of about 75 percent hard, calcareous or concretionary siltstone, and 25 percent fine- to medium-grained gray or greenish gray argillaceous and carbonaceous sandstone. Deposition in a marine environment in pre-middle Miocene, probably Oligocene, time is indicated by a sparse molluscan fauna.

At Lituya Bay the Cenotaph Volcanics of Oligocene(?) age consist of at least 850 feet of green, red, and purple volcanic breccia and tuff, overlain by 400 feet of interbedded green and red tuffaceous siltstone, green glauconitic sandstone, and glauconitic pebble-cobble conglomerate. Andesitic lava flows are present in the basal part of the formation south of Lituya Bay, and lenses and discontinuous beds of low-rank coal occur locally within the uppermost part of the formation. The Cenotaph Volcanics were probably deposited under predominantly nonmarine and near-shore conditions during a period of intermittent volcanic activity.

The Yakataga Formation of late Miocene and Pliocene age is as much as 8,400 feet thick, and is the youngest and most widely distributed Tertiary formation. It consists of a lower unit, ranging in thickness from 600 to at least 2,400 feet, consisting mainly of interbedded siltstone and sandstone containing calcareous lenses or concretions and sparse isolated pebbles. The overlying upper part of the sequence consists of at least 6,000 feet of sandy mudstone, siltstone, sandstone, and minor conglomerate interbedded with abundant conglomeratic sandy mudstone (marine tillite) which characteristically contains unsorted ice-transported clasts of diverse lithologies. Deposition in a cold water shallow marine environment is indicated by an abundant molluscan fauna.

Structure

The narrow belt of Tertiary rocks south of Lituya Bay is folded into a shallow syncline and a strongly asymmetric faulted anticline (section A-A', fig. 32). These folds pass to the southeast into a seaward facing homocline which is nearly vertical or slightly overturned. The south limb of the anticline is believed to be cut by an unexposed thrust or reverse fault that strikes parallel to the coast. Upper Tertiary rocks in the two small outliers near Fairweather Glacier form a broad northwest-trending syncline unconformably overlying the pre-Tertiary volcanic rocks.

Potential

The petroleum potential of the Tertiary sequence within Glacier Bay National Monument is poor within the area of outcrop on land. There are no oil or gas seeps such as those which occur abundantly throughout the coastal portion of the western part of the Gulf of Alaska Tertiary Province. Deformation of the older siltstones and a low organic content in the less deformed younger siltstones limits the source-rock potential. However, the reported occurrence of an oily film and petroliferous odor in sandstone at one locality near the top of the Cenotaph Volcanics (Miller and others, 1959, p. 44) suggests that at least some hydrocarbons have been generated in the lower part of the section.

A critical factor for petroleum accumulation is the availability of adequate reservoir beds. Sandstones in all units except the uppermost part of the Yakataga Formation are commonly argillaceous and probably have low permeability and porosity. Some of the stratigraphically highest sandstones in the Yakataga Formation are good potential reservoirs, but they are several thousand feet stratigraphically above the possible source rocks and are separated from them by one or more disconformities or unconformities.

An anticline (section A-A', fig. 32) is a marginal prospect as a structural trap because: (1) it probably does not have structural closure; (2) potential reservoir sands in the upper parts of the Cenotaph and Topsy Formations are breached by erosion; and (3) the structure is cut by an axial fault and is probably complicated by faulting at depth.

The offshore petroleum possibilities within the Monument cannot yet be adequately evaluated although there is no reason to believe they will differ significantly from those landward. Structures may be more favorable, and the source rock potential of the sequence may improve in a seaward direction away from the zone of intense deformation associated with the Fairweather Fault. On the other hand, potential reservoir rocks are likely to become scarcer with increasing distance from shore, and drilling depths to objective horizons in the Cenotaph Volcanics and Topsy Formations could rapidly become excessive.

COAL

Reported occurrences of coal in the Glacier Bay National Monument are limited to the sequence of bedded sedimentary and volcanic rocks of probable Oligocene age, which is exposed in the Lituya District, and to a single specimen of float material of unknown origin found near the terminus of the Casement Glacier (E. H. Lathram, oral communication, 1966).

In the Lituya District coal occurs as thin stringers and beds less than 8 inches thick in conglomerates of the Cenotaph Formation at both the type section on Cenotaph Island and in the valley of Coal Creek immediately south of Lituya Bay. Thin beds of carboniferous siltstone and silty coal up to 3 inches thick are also interbedded with sandstone and siltstone of the Topsy Formation at Clay Point.

The one available analysis of the coal, which was made on a grab sample collected by Don J. Miller from Coal Creek, indicates that it has a high ash content and is probably of sub-bituminous rank:

Proximate analysis of coal from the Cenotaph Formation, Coal Creek. (U.S. Bureau of Mines, lab. no. F-47643)

	As received	Moisture free
Moisture	2.4	
Volatile matter	34.6	35.5
Fixed carbon	34.0	34.8
Ash	29.0	29.7
	100.0	100.0
Sulfur	0.5	0.5

The coal in the Lituya District has little or no commercial potential because of its low rank, and its occurrence as thin discontinuous beds and stringers.

REFERENCES CITED

Berg, H. C., Eberlein, G. D., and MacKevett, E. M., Jr., 1964, Metallic mineral resources, in Mineral and water resources of Alaska: Prepared by the U.S. Geological Survey in cooperation with State of Alaska Department of Natural Resources, U.S. Gov't Printing Office, 179 p.

Buddington, A. F., and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U.S. Geol. Survey Bull. 800, 398 p.

Cornwall, H. R., 1966, Nickel deposits of North America: U.S. Geol. Survey Bull. 1223, 62 p.

Hawkes, H. E., 1963, Dithizone field tests: Econ. Geol., v. 58, p. 579-586.

Huff, L. C., 1951, A sensitive field test for detecting heavy metals in soil or sediment: Econ. Geology, v. 46, p. 524-540.

Kennedy, G. C., and Walton, M. S., Jr., 1946, Geology and associated mineral deposits of some ultrabasic rocks in southeastern Alaska: U.S. Geol. Survey Bull. 947-D, 19 p.

Lathram, E. H., Loney, R. A., Condon, W. H., and Berg, H. C., 1959, Progress map of the geology of the Juneau [1:250,000] quadrangle, Alaska: U.S. Geol. Survey Map I-303.

Mertie, J. B., Jr., 1933, Notes on the geography and geology of Lituya Bay: U.S. Geol. Survey Bull. 836-B, p. 117-135.

Miller, D. J., 1953, Preliminary geologic map and correlated columnar section of Tertiary rocks in the southeastern part of the Lituya District, Alaska: U.S. Geol. Survey open-file report.

Miller, D. J., 1961, Geology of the Lituya District, Gulf of Alaska Tertiary Province, Alaska: U.S. Geol. Survey open-file map, June 2, 1961, 2 sheets.

Miller, D. J., Payne, T. G., and Gryc, George, 1959, Geology of possible petroleum provinces in Alaska, with an annotated bibliography by E. H. Cobb: U.S. Geol. Survey Bull. 1094, 131 p.

Myers, A. T., Havens, R. G., and Dunton, P. J., 1961, A spectrochemical method for the semiquantitative analyses of rocks, minerals, and ores: U.S. Geol. Survey Bull. 1084-i, p. 207-229.

Plafker, George, 1967, Geologic map of the Gulf of Alaska Tertiary Province, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-484.

Reed, J. C., 1938, Some mineral deposits of Glacier Bay and vicinity, Alaska: Econ. Geology, v. 33, no. 1, p. 52-80.

Rossman, D. L., 1957, Ilmenite-bearing beach sands near Lituya Bay, Alaska: U.S. Geol. Survey open-file rept. 149, 10 p.

Rossman, D. L., 1959, Geology and ore deposits in the Reid Inlet area, Glacier Bay, Alaska: U.S. Geol. Survey Bull. 1058-B, 25 p.

Rossman, D. L., 1963a, Geology and petrology of two stocks of layered gabbro in the Fairweather Range, Alaska: U.S. Geol. Survey Bull. 1121-F, 48 p.

Rossman, D. L., 1963b, Geology of the eastern part of the Mount Fairweather quadrangle, Glacier Bay, Alaska: U.S. Geol. Survey Bull. 1121-K, 53 p.

Sanford, R. S., Apell, G. A., and Rutledge, F. A., 1949, Investigations of Muir Inlet or Nunatak molybdenum deposits, Glacier Bay, southeastern Alaska: U.S. Bur. Mines Rept. Inv. 4421, 6 p.

Seitz, J. F., 1959, Geology of the Geikie Inlet area, Glacier Bay, Alaska: U.S. Geol. Survey Bull. 1058-C, p. 61-120.

Smith, P. S., 1942, Occurrences of molybdenum minerals in Alaska: U.S. Geol. Survey Bull. 926-C, p. 161-207.

Thomas, B. I., and Berryhill, R. V., 1962, Reconnaissance studies of Alaskan beach sands, eastern Gulf of Alaska: U.S. Bur. Mines Rept. Inv. 5986, 40 p.

Twenhofel, W. S., 1946, Molybdenite deposits of the Nunatak area, Muir Inlet, Glacier Bay, in Twenhofel, W. S., Robinson, G. D., and Gault, H. R., Molybdenite investigations in southeastern Alaska: U.S. Geol. Survey Bull. 947-B, 38 p.

Twenhofel, W. S., Reed, J. C., and Gates, G. O., 1949, Some mineral investigations in southeastern Alaska: U.S. Geol. Survey Bull. 963-A, 43 p.

Turekian, K. K., and Wedepohl, K. H., 1961, Distribution of the elements in some major units of the Earth's crust: Geol. Soc. America Bull., v. 72, p. 175-192.

U.S. Coast and Geodetic Survey, Chart 8202.

U.S. Weather Bureau, 1937-1966, Climatological data: U.S. Dept. of Commerce, Environmental Sciences Service Administration, vols. 23 through 52.

Wright, F. E., and Wright, C. W., 1937, The Glacier Bay National Monument in southeastern Alaska, its glaciers and geology: U.S. Geol. Survey open-file rept., 224 p.

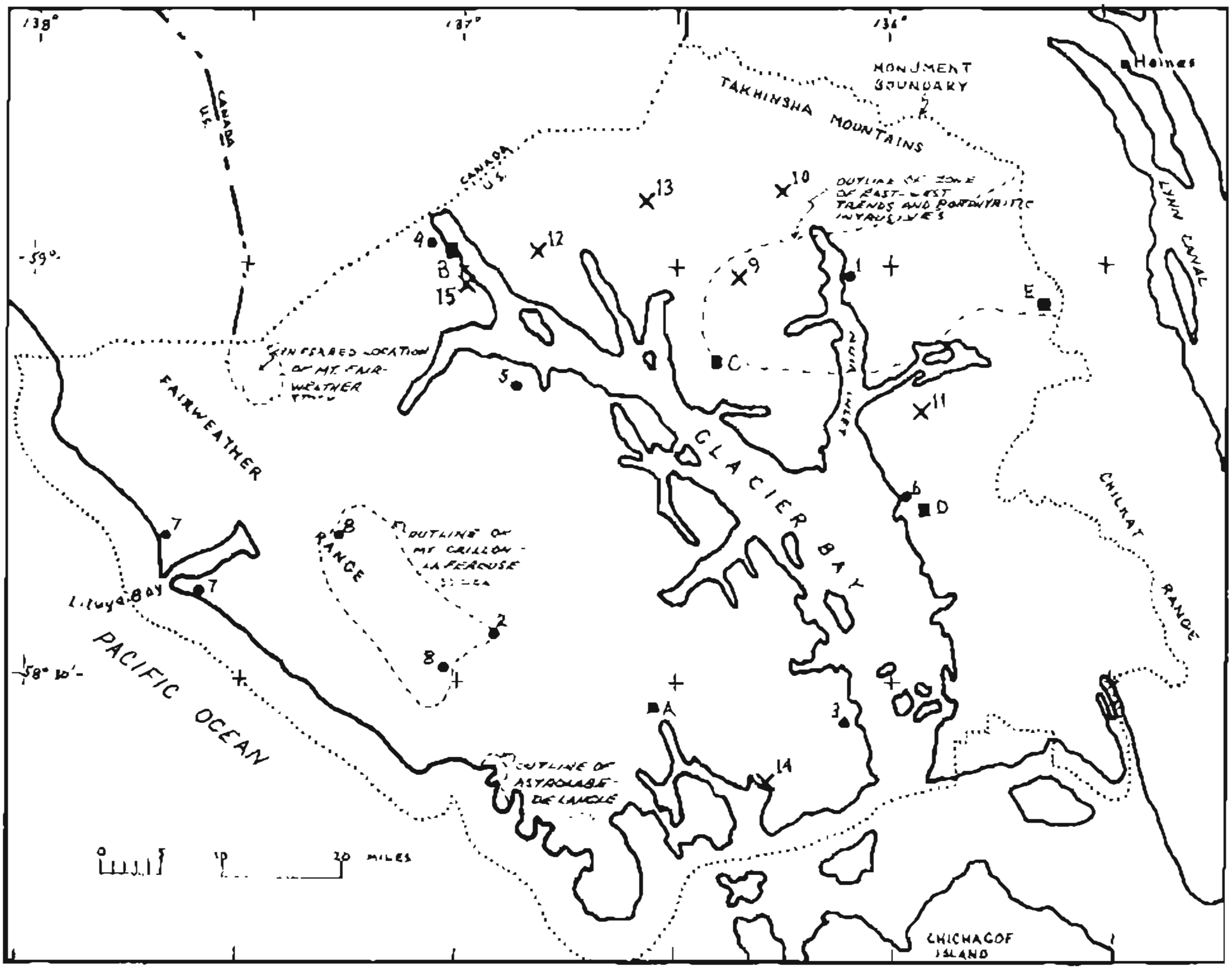

FIGURE 1. MAP OF GLACIER BAY NATIONAL MONUMENT, ALASKA, SHOWING SELECTED MINERAL DEPOSITS, GEOCHEMICAL ANOMALIES, AND OUTLINES OF SOME AREAS FAVORABLE FOR MINERAL DEPOSITS. DOTS INDICATE PREVIOUSLY KNOWN DEPOSITS WITH ECONOMIC POTENTIAL, X'S INDICATE DEPOSITS OF POSSIBLE ECONOMIC INTEREST FOUND BY U.S.G.S. INVESTIGATIONS; ■'S INDICATE GEOCHEMICAL ANOMALIES.

KEY TO LOCALITIES SHOWN ON MAP

1 THE NUNATAK, MUIR INLET
2 BRADY GLACIER
3. ALASKA CHIEF
4 MARGERIE GLACIER
5 REID INLET
6 SANDY COVE
7 LITUYA BAY PLACERS
8 MT CRILLON GABBRO
9 BRUCE HILLS
10 MT BRACK
11 WHITE GLACIER
12. SOUTH OF RENDU GLACIER
13 GABLE MOUNTAIN
14. ALTERED ZONE EAST OF DUNDAS BAY
15 WEST OF TARR INLET
A. MAIN ARM OF DUNDAS BAY
B. WEST SHORE OF TARR INLET
C. MT MERRIAM
D MILLER PEAK - SANDY COVE
E UPPER BERG CREEK

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.