EVALUATION OF A MOLYBDENUM DEPOSIT IN
GLACIER BAY, ALASKA

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STATEMENT BY AUTHOR

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ABSTRACT

Molybdenum-bearing rocks crop out on Nunatak Mountain, which is about 80 air miles northwest of Juneau, Alaska. The Mountain is located on Muir Inlet in Glacier Bay National Monument. Molybdenite occurs in deposits associated with fault zones and a quartz monzonite stock. The monzonite, which appears to be of Eocene age, has intruded into a sedimentary sequence of Devonian (?) age. Trench samples of the fault zones contain on the average 0.075 to 0.102 percent molybdenum. Quartz, garnet, diopside, epidote, and pyrrhotite are the contaminating constituents of the ore deposit. The brecciated zones show an aggregate of approximately 225,000 tons per 10 feet of depth of indicated molybdenum-bearing rock.
I. INTRODUCTION

A. Purpose

In order to assist in the compilation of Alaskan geology, this investigation takes into consideration a known molybdenum deposit. It is intended not only for those concerned with evaluating the deposit but also for those searching for new molybdenum deposits in the region. A desirable preliminary step in an exploration program is to acquire as much information as possible about the deposits that are already known. This report, hopefully, provides some of this information by describing the geologic setting of southeastern Alaska. By describing a known deposit—its structural control, mode of origin, host rocks, kinds of ore and gangue minerals present, grade and the extent to which it has been explored—this report should be helpful for future exploration throughout the region.

B. Location of Area

The area under study is located on Upper Muir Inlet in Glacier Bay National Monument. The Monument is situated at the northwest end of the Alexander Archipelago in southeastern Alaska, locally referred to as the "Panhandle". The absence of roads in the area limits travel to boats and aircraft (Figures 1 and 2).
Figure 1. Index map of Alaska, showing the location of southeastern Alaska and Muir Inlet.
Figure 2. Index map of southeastern Alaska, showing principal cities and features.
The Nunatak molybdenum area is approximately 80 air miles or 130 sea miles from the city of Juneau. The Nunatak promontory rises abruptly from Muir Inlet to a height of 1,165 feet. It is surrounded on two sides by water and the other sides by a morainal filled valley (Figures 3 and 4).

Due to glaciation in the area, involving the breaking up of valley glaciers and forming of icebergs, accessibility by boat is limited to the period from approximately early May to October. Seaplane operations are limited to late May to October.

C. Previous Investigations

John C. Reed, in 1941, of the United States Geological Survey, first reported the molybdenite occurrence at Nunatak Mountain. According to records at the Alaska State Division of Mines, John Johnson, of Hoonah and Tom Smith, of Juneau were the first discoverers and had staked the deposit prior to Reed's report.

In the following year, 1942, Dr. W. S. Twenhofel of the United States Geological Survey mapped the deposit in detail; his map and report have been the preliminary basis of most of the later investigations (Twenhofel, 1946).

R. S. Sandford, G. A. Appleland, and F. A. Rutledge, in 1943, did considerable channel sampling and a small amount of diamond drilling on the property for the United States Bureau of Mines (Twenhofel, 1946). Their results will be discussed in a later section of this report.
Figure 3. Looking eastward across Muir Inlet towards Nunatak Mountain.
Figure 4. Glacial filled valley on east side of Nunatak Mountain.
The area has been staked several times since 1943 and it was not until 1957 when Climax Molybdenum Company staked the deposit and P. O. Hachey directed the assessment work that any further publications were obtained (Roach, 1968). Mr. Hachey spent three days on the property at which time he checked the geologic setting as previously described by Dr. Twenhofel.

In 1966, Keevil Mining Group of Toronto, Canada, completed approximately 2,000 feet of drilling on the property. The claims at that time were owned by James Walper, a local prospector from Vancouver, British Columbia.

Mr. Walper leased the property to Superior Oil Company in 1967. George Moerlein, Consulting Exploration Geologist, was contracted by Superior Oil to examine the deposit. (The writer worked on the property with Mr. Moerlein and is grateful to Superior Oil for the opportunity to do the field work necessary for this paper.) At the end of the field season, approximately 7,000 feet of core had been obtained from drilling and assayed. Due to the confidential nature of the assay results, they have not been made available at this writing.
Geomorphology

Southeastern Alaska includes a part of the Pacific Mountain System. This system is made up of a number of distinct ranges forming a mountainous belt paralleling the seaboard. In southeastern Alaska the belt averages about 50 miles in width but broadens to the northwest so that at Prince William Sound it measures 200 miles across. Its mean altitude varies from 5,000 to 10,000 feet, with many peaks from 10,000 to over 15,000 feet high (Figure 5).

In this region of Alaska, the mountains are designated as the Coast Range and stretch north from the international boundary at Portland Canal for some 300 miles across the head of Lynn Canal and again crossing the boundary, pass inland behind the St. Elias Range (Figure 2). They have no distinctive crest line, but are made up of an irregular line of peaks with connecting ridges, forming an elevated tract from 40 to 80 miles in width. Their general summit altitude has a marked uniformity, for only here and there a peak rises above the general level. At Portland Canal, the relief is between 5,000 and 6,000 feet, but the altitude increases to the north with heights of 8,000 and 9,000 feet being reached at the head of Lynn Canal.

The boundaries of the Coast Range are ill-defined; on the south it is continued as the Coast Range of British Columbia; on the north and the east it merges with the higher parts of the British Columbia plateau; on the west it merges into the mountains of the Alexander...
Figure 5. Part of Pacific Mountain System of southeastern Alaska near Juneau.
Archipelago. Numerous fiords break the western face of the Coast Range and some penetrate far inland. Indeed, the Portland Canal on the south cuts through almost the entire range.

Viewed from the sea these mountains present, for the most part, steep scarps rising directly from the water's edge or from narrow rocky beaches. The lower slopes are clothed in a dense growth of evergreens giving the scene a sombre tone. At the present time relics of hanging glaciers are found along the coast giving rise to many high valley streams and waterfalls (Figure 6). Some of the water courses draining the western front of the Coast Range occupy narrow and steep valleys that were formed by glaciers which have retreated to the head of the valley many miles inland.

The international boundary between Alaska and Canada lies within and parallel to the Coast Range in southeastern Alaska, so that only a small part of this mountain mass lies within Alaska. The boundary is an irregular line connecting some of the more prominent peaks that lie not far from the sea front of the Range. Only at White and Chilkoot Passes near Skagway does the boundary follow the watersheds.

West of the Lynn Canal, the St. Elias Range forms a coastal barrier to the interior of Alaska and Canada. Beginning at Icy Strait, this range stretches over 250 miles to the northwest. The St. Elias Range has an average width of over 80 miles and a mean altitude of approximately 8,000 to 10,000 feet. It probably has greater mass than any other mountain range on the continent; and, rising as it does, to great altitudes almost directly from sea level, it presents a scene of
Figure 6. Typical Alpine glaciation of southeastern Alaska.
grandeur unexcelled in the world. A southerly extension of the St. Elias Range is to be found in the mountains which traverse the western part of the Chichagof and Baranof Islands. To the northwest it merges with the Chugach and Wrangell Mountains.

In southeastern Alaska most of the precipitation is in the form of snow. This occurrence in the higher parts of the mountains causes large ice and snow fields (Figures 5 and 6) which give rise to numerous glaciers that discharge on both sides of the ranges. The largest and most spectacular glaciers are located on the seaward side (Figure 7).

On the lower slopes, especially in mid-summer, streams emerge from steep-walled valleys that were formed by glaciers, but in general the drainage is through many smaller watercourses. Many of the major streams meander through broad valleys giving the impression of old age but in reality, are valleys of youth which have been filled with morainal debris.

One such valley is that of the Alsek River which cuts across the St. Elias Range, dividing it into two parts. Of these, the eastern, stretching parallel along the coast to Glacier Bay, is called the Fairweather Mountains, and the western constitutes the St. Elias Mountains. The Fairweather Mountains rise from the sea up to altitudes of 8,000 to 15,000 feet and include an enormous ice cap that discharges into Glacier and Lituya Bays, the Alsek River, and directly into the Gulf of Alaska.

The effect of glaciation is very pronounced upon the land features and inland fiords of southeastern Alaska. For the most part, the
Figure 7. Discharge of Muir Glacier into Muir Inlet. Ice front is approximately 100 feet high.
topography is due to glaciation. The size, number, and variety of the glaciers stand as vivid proof that this region is still in an active glacial period (Figures 5, 6, and 7).

Within the Glacier Bay National Monument, the glaciers are both in a state of recession and advancing. In 1794, Captain George Vancouver, the first recorded explorer of southeastern Alaska, found a solid front of ice at Icy Strait. Probably only a small indentation in the coast line at this location gave an indication of the present day entrance to Glacier Bay.

When John Muir, in 1892, first came into Glacier Bay the ice front terminated near Adam's Inlet. This ice front, later named Muir Glacier, has split into at least eight glaciers with the Muir Glacier being the largest and most active. The Muir Glacier, since 1892, has retreated to its present day configuration and location, leaving many scars upon the landscape.

When Muir traversed the glacier, the molybdenum deposit was covered to a height of approximately 1,000 feet with ice, leaving only a knob of rock. Muir therefore called it a nunatak and thus the present accepted name of the mountain is the Nunatak and will be referred to as the general area of the deposit throughout this report.
III. REGIONAL GEOLOGIC SETTING

A. Pre-mineralization Lithology and Structure

The regional geology of southeastern Alaska is incompletely known due mainly to the lack of detailed mapping. Most of the work that has been done was in specific localities in the late 1930's, giving rise to broad interpretations of the lithology and structure from one district to another without field verification. The most recent investigations have been reconnaissance geology by exploration companies and these have been limited to known mineralized areas. Until a detailed mapping program is undertaken the interpretations presented in the literature must be taken as a reconnaissance effort and subject to many changes.

Brew, Loney, and Muffler (1966) considered the pattern of southeastern Alaska from available material and has concluded that the oldest known outcropping strata are of Ordovician age. They stated that the many metamorphic exposures in southeastern Alaska may be of Cambrian age. Verification of this has not been attained and it is likely that once drilling data and more detailed mapping have been analyzed the metamorphic rocks will be located more precisely in time and space.

The known Ordovician and Lower Silurian strata are predominantly graywackes and volcanics. The sequence from Middle Silurian through Devonian (?) is classed as graywackes and volcanics with evidence of
shallow-water carbonates and conglomerates which locally interrupted the eugeosynclinal sedimentation of the region (Rossman, 1963b).

Middle and Upper Devonian strata consist primarily of carbonates, clastics, and volcanics, with layers of conglomerates lying unconformably over the Ordovician and Lower Silurian. Brew, Loney, and Muffler (1966) suggest that this represents local emergent areas to the southwest of the area. This may be verified once the ocean floors of the Gulf of Alaska have been studied in detail and the rock types compared.

Throughout southeastern Alaska, sporadic outcrops of Carboniferous perlites and carbonates are found unconformably on the older strata. Many volcanics of this age have been identified by Rossman (1963b). He believed that the volcanism during the Carboniferous period was greater than in other periods and most intense in the northern portions of southeastern Alaska. The eruption of these basic lavas was accompanied by epeirgenic movements which probably persisted into the Triassic.

Brew, Loney, and Muffler (1966) states that sedimentation was possibly interrupted throughout the Mesozoic giving rise to geologic highs and lows at a local level. The Triassic is represented by volcanics which are widespread and limestones which are very sporadic. In some localities a thick sequence of Jurassic and Cretaceous graywackes and perlites is believed to be derived from local source areas.

During the Late (?) Cretaceous (Brew, Loney, and Muffler, 1966), the region was undergoing widespread plutonic activity and metamorphism which obscured and obliterated earlier tectonic and sedimentary
events. This intrusive activity probably continued until Tertiary and is still evident along the coastal islands where many extinct volcanoes are found. Tertiary deposits are characteristic of continental clastics and found in local and/or restricted basins (Figure 8).

Quaternary deposits are composed mainly of morainal debris and lava flows which are found throughout the region and are restricted to basins that are superimposed upon the Tertiary strata (Figures 9 and 10).

The structure of southeastern Alaska was of eugeosynclinal nature throughout the Paleozoic. Unconformities, as previously stated, occur in the sequence of eugeosynclinal deposition at several levels, which probably represents times of orogeny, local metamorphism and plutonism.

According to King (1966), the eugeosynclinal rocks became widely deformed and metamorphosed in middle Mesozoic time; he has correlated this with either the Nevadan or Coast Range Orogeny.

B. Regional Ore Mineralization

The metallic mineralization of southeastern Alaska is so widespread and located over such a span of time that only the molybdenum-containing deposits will be discussed in this paper. Correlation of the data to define a metallogenetic province will be discussed on a wide basis. Molybdenum-bearing deposits of British Columbia, associated with the Coast Range, will be considered, and the Alaskan and the British Columbian deposits will be discussed as to their characteristics and relationships.
Figure 8. Generalized geologic map of southeastern Alaska. (After Berg and Cobb, 1967)
Figure 9. Glacial debris located 1-1/2 miles north of Nunatak Mountain. Valley is approximately 300 feet deep. Looking east toward Black Cap Mountain.
Figure 10. Looking westward from glacial debris valley across Muir Inlet.
According to McKechnie (1966), the molybdenum occurrences in northern British Columbia are rather restricted and are minor in comparison to the better known deposits in southern British Columbia. Although McKechnie's work is the most recent and thorough on British Columbia's molybdenum deposits, he lists only the productive deposits and his list is limited to a rather narrow range in time and space.

The Coast Range Region of British Columbia is similar to that previously described in Alaska. Only the southern part of British Columbia has been mapped in any detail. Many minor deposits of molybdenum in northern British Columbia have been mentioned but the geologic setting has not been described.

The age dating of the molybdenum deposits of British Columbia has been accomplished (Ney, 1966) only in the productive districts. The deposits appear to be restricted to the Paleogene Period.

It is significant to note that in the older rocks containing molybdenum, copper sulfides are predominant with molybdenum in a minor role. In the younger rocks molybdenite is the principal ore mineral and copper minerals are minor constituents.

The reported deposits in southernmost British Columbia in which molybdenum occurs as a minor element appear to be associated with a variety of porphyry dikes with a general north and northeast trend which in turn have been cross faulted. This faulting has caused strongly brecciated zones, thus forming areas for the hydrothermal deposition. The principal ore minerals appear to be bornite and chalcopyrite with the molybdenite in very small amounts. This is very
similar to the copper deposits in the southwestern United States (McKechnie, 1966).

Northward in British Columbia, the molybdenite becomes the more prominent ore mineral. The best example of this type of a deposit is that located at Alice Arm, British Columbia. There are three occurrences of molybdenite mineralization in this area. One occurrence is associated (Woodcock, 1966) with quartz and alaskite on the boundaries of argillite and limestone. Another occurrence is found along fractures in a granodiorite, and the third occurrence is found within the granitic rocks along with younger intrusions of monzonite.

According to Woodcock (1966) the intrusives in this region are found approximately 1/2 to two miles from larger intrusives that are part of the Coast Crystalline Belt and appear to be very similar in composition and age. All three stocks are composite bodies in which quartz diorite, quartz monzonite porphyry and alaskite are represented. According to Ney (1966), the quartz monzonite porphyry is of middle Eocene Epoch and appears to be the source of the molybdenite mineralization. Ney's dating will be used as a basis for age dating and correlation of some of the deposits in southeastern Alaska.

These three deposits in the Alice Arm Area, as they have been described, are very similar in most respects to the Nunatak molybdenum deposit. These similarities are; molybdenite occurring along fractures, shear planes, and brecciated fault zones; it principally occurs in fine-grained, tight quartz veinlets. All are associated with a quartz monzonite porphyry in contact with a limestone-argillite sequence.
No producing molybdenum deposits have been worked in southeastern Alaska. There are many reported findings; therefore, these will be mentioned as to host rock only since most of the claims have not been mapped in detail and little is known of their geologic setting.

The reported molybdenite deposits are scattered throughout the islands around Sitka. Every one of these deposits or showings have been associated with a quartz diorite (?). It is of interest that the larger assay values are those associated with hornfels in contact with marble and the diorite (?).

Robinson (1944), for a private company, investigated a molybdenite deposit on Kosciusko Island about 65 miles southwest of Petersburg. He reported the deposit as being in a brecciated fault zone near a hornblende diorite. The molybdenite appeared to be sparsely disseminated in the diorite but the significant mineralization was confined to the fault zones. Robinson reported molybdenite as the only mineral of economic value present in the area. Molybdenite occurred as disseminated fine grains, as crystals in cavities still partly open, as coatings on crystals of other minerals and more rarely, in veinlets.

These are the principal molybdenum bearing deposits that have been reported in southeastern Alaska, with the exception of the Nunatak, which will be discussed in greater detail in a later section.

C. Post-mineralization Lithology and Structure

Due to the limited age dating of the molybdenum deposits of the region the assumption is made that the deposition of the ore minerals
took place in Early Eocene (?). This is based primarily on the geologic similarities of the British Columbian deposits that have been dated.

Assuming that the quartz monzonite porphyry and molybdenum were formed in close association, the primary units of interest are the intrusives. These intrusives range in composition from granitic to ultrabasic dikes but appear to be limited to small bodies.

Faulting evidently occurred repeatedly during mineralization as reported by all investigators. This led to many brecciated areas that were favorable to mineralization. From the period of mineralization to the present, active tectonic forces have caused faulting of the geologic units and in many cases obliterating previous structures. Until relationships of age and time between the different rock units are established no definite regional correlations can be made.
IV. GEOLOGY OF THE NUNATAK AREA

A. Pre-mineralization Lithology and Structure

Twenhofel (1946), of the United States Geological Survey stated: "the bedrocks of the Nunatak area include a metamorphosed sedimentary sequence of tightly folded Paleozoic (possibly Devonian) hornfels with some shale and limestone." Certain deviations from Twenhofel's description are to be made by this writer. These deviations are of significant importance as guidelines to explanation.

A brief sequence of pre-mineralization geology is as follows:
1. The oldest rocks in the area are thin-bedded limestones and cherts that have locally been changed into tactite.
2. Massive limestone conformally overlies the thin beds.

The massive limestone is found on the northwest side of Nunatak Mountain, striking northeasterly and dipping vertically. No fossils were noted and dating is by correlation with other areas.

Changes due to metamorphism have caused discoloration of the thin bedded exposures. In part, the beds have been replaced by garnet and diopside to form a garnetized zone and tactite. The sequence as described by this writer is very similar to that described by Rossman (1963b). He described a sequence of limestone and hornstone in the Black Cap Mountains that was dated by fossils to be of Middle Devonian. These sedimentary rocks crop out approximately three miles to the east of Nunatak Mountain.
Three events probably took place which localized deposition of the molybdenite: faulting, intrusion, and mineralization. The deformation of the area probably started with the small stock of quartz monzonite that is found on the northeast end of Nunatak Mountain. This stock contains conspicuous molybdenite and pyrrhotite (Figure 11).

During the intrusion of the monzonite the sequence of events probably were, but not necessarily in this order:

1. Injection of hydrothermal fluids into the sedimentary rocks.
2. Formation of the tactite and garnetized zone.
3. Uplifting of the sedimentary sequence into a domal structure.
4. Faulting and fracturing of the sedimentary rocks.
5. Intrusion of the silica envelope, quartz veins and metallic minerals into the brecciated zones.

The monzonite is composed of K-feldspar, some of which occurs as large, zoned crystals. Quartz crystals are common in some parts of the body. A little biotite was noted in parts of the rock. In comparison to the surrounding sedimentary rock, the monzonite is relatively unshattered as the stock's center is approached.

Many fault sets occur in the area (Figures 13 and 14). The "Nunatak Fault", the major fault in the area, strikes north and dips about 65° east (Figure 12). One fault set strikes northeasterly and
Figure 12. Looking northward toward Nunatak Mountain, showing "Nunatak" fault scarp. Black line is drawn along trace of fault.
Figure 13. Looking westward toward Nunatak Mountain. Photograph shows major faults and joint patterns. Dashed lines are faults and solid lines are major joints.
Figure 14. Looking eastward toward Nunatak Mountain. Photograph shows major faults (dashed lines) and major joint patterns (solid lines) along their traces.
dips 20° to 60° southeast, and another set of faults strike north-westerly and dip 30° to 70° to the southwest. A major fault trending parallel to the shoreline and dipping 70° SE was noted on the west side of the area. This fault may have truncated the major zone of mineralization with the down thrown block under Muir Inlet (Figure 15). Epidote is the common alteration product in the fault zones and some carbonate gouge was noted.

The "Nunatak Fault" zone contains a brecciated network of quartz veins with conspicuous molybdenite (Figure 16). This is the only fault that displays fracturing of the wallrock which probably offered avenues for the entrance of mineralizing solutions. Secondary fracturing is present, indicating subsequent movement of the fault. The molybdenite was found in the primary fractures and in the quartz veins. Very small amounts, less than .1% of copper are found in the "Nunatak Fault" zone.

The two sets of faults intersect on the northwest side of Nunatak Mountain (Figure 17). This intersection produced another area favorable to mineralization. The lowest exposure of this zone is at sea level. This lower portion of the zone also contains the most conspicuous fracturing and mineralization (Figure 18) and becomes less fractured near the top of Nunatak Mountain.

The brecciated zones (Figures 16 and 17) show molybdenite as fine grains in the quartz stringers. Molybdenite is also present along the contact of the stringers and the gangue minerals. Some shears devoid of quartz, have coatings of molybdenite (Figures 18 and 19). Pyrrhotite and chalcopyrite are also found in the fractures and as
Figure 15. On northwest end of the Nunatak Area. Photograph shows a vertical fault along water line cutting massive limestone. Vertical displacement is approximately 30 feet at this location.
Figure 16. Looking down on north end of Nunatak Mountain. Area outlined shows trace of "Nunatak" fault molybdenite deposit. Approximate area is 215,000 square feet.
Figure 17. Looking down on shear zone on the northwest side of Nunatak Mountain. The dashed line outlines approximately 200,000 square feet as the surface expression of molybdenite mineralization.
Figure 18. Stockwork. Quartz veins are shown cutting diopside-rich rock.
Figure 19. Molybdenite along fracture. Vein is approximately 10 inches wide.
disseminated masses through the monzonite and tactite. Thin sections show a close association of time of deposition between the pyrrhotite and molybdenite. The writer estimated 80 percent of the quartz veins in the brecciated zones strike N70°W and dip 80° southwest, approximately parallel to one of the major fault sets.

The shearing that resulted from the doming and subsequent faulting is a principal control in localization of the mineralization. The events causing this shearing or brecciation seem to have been going on during the passage of the mineralized solutions. This is indicated by the three types of molybdenite occurrences:

1. Fine grains of molybdenite associated with the quartz stringers.
2. Platy flakes of molybdenite along the contacts of the gangue minerals and the quartz veins.
3. Platy flakes of molybdenite along shear faces.

C. Post-mineralization Structure

Emplacement of stocks and dikes is the major post-mineralization event. The first of the intrusions, after the quartz monzonite, was diorite. This diorite stock is located on the northern end of Nunatak Mountain. The trend of the long axis of the stock is northwest, and cuts across the trend of the sedimentary rocks (Figure 11). Xenoliths of monzonite, tactite, and silica have been noted in the diorite.

Three dacite dikes are found cutting across the bedding of the area (Figure 20). These dikes strike northeasterly and dip 70°
Figure 20. Looking eastward at Nunatak Mountain. Photographs show structural features and weathering effects. White areas are dacite dikes. Reddish brown shows limonite stain from pyrite weathering.
southwestward. Offsets along these dikes give good indications of recent fault movements.

The andesite dikes form the bulk of the intrusions in the Nunatak area. These dikes vary in width from six inches to five feet. The writer found that they had an affinity for old fault zones. This affinity enabled the writer to map the structures in detail and to follow the traces of the faults for great distances. No andesite dikes were found trending to the northwest but were restricted to the northeast fault set (Figure 21).

The major structures of the area consists of the "Nunatak Fault". It appears to be an active fault as evidenced by secondary fracturing. The large fault trending parallel to the coastline probably occurred after mineralization as evidenced by the mineralized veins being vertically displaced.

The most recent activity of the area has been glaciation. Glacial debris overlies the entire area. On the west side of Nunatak Mountain the debris is only five to 25 feet thick. On the north and the east sides, gullies show depths of 300 feet or more. This glaciation probably uncovered the present mineralized zones.
Figure 21. Dark vertical rock is typical andesite dike cutting bedding of the sedimentary sequence. Vertical displacement of fault is approximately five feet. The dikes have an affinity for the old fault zones. White areas are limestone and dark green areas are chert.
V. GUIDES TO MINERALIZATION

A. Geological

On a regional basis, the best guide to molybdenite mineralization is the contact zone near a monzonite intrusion and a limestone-argillite sequence. Many of the old molybdenite discoveries of southeastern Alaska were associated with diorite. Closer examination of these diorites may prove them to be monzonites and warrant a more detailed study of the areas.

The contact metamorphism produces a tactite which serves as a guide to igneous activity. If the intrusions are exposed these would serve as guides. The tactite is not necessarily an indicator of molybdenite but can be used as a guide for a more detailed study of the area. Using the Nunatak area as an example, the discoloration of the tactite leads to the more conspicuous molybdenite zones. On the outer periphery of the Nunatak area the tactite has a banding of white limestone and light green chert; closer to the mineralized shear zones the cherty bands become darker green and the white limestone starts to turn pink. This change is gradual and the change occurs within 1/2 mile of the shear zone.

As the shear zones are approached the sedimentary beds have been completely changed to a massive garnet, grossularite. Along the shear zone on the northwest end of the Nunatak area the grossularite is light
pink and highly fractured (Figure 22). The garnetized zone grades into the massive stockwork of dark green diopside rock and quartz veins. The quartz veins increase in size and frequency toward the stockwork.

In conjunction with the alteration products and stockwork a structural analysis of a region serves as a guide to similar molybdenite deposits. Any domal structure and fault intersection with monzonite and tectite would be an excellent guide to molybdenite mineralization in southeastern Alaska. This assumption is based on the writer's field observations of the Nunatak area.

B. Geochemistry

The results of the geochemical and geophysical surveys, except the magnetic, are confidential. The writer has Mr. Walper's consent to describe the data and procedures used.

The geochemical survey consisted of sampling on a 100 foot grid over the mapped area. The survey was conducted by Mr. George Moerlein and his sampling technique, chip or soil, is not known.

The results of the survey did not reveal any anomalous concentrations of molybdenum. In the type of topography such as that found in the Nunatak area, the writer believes geochemistry is of limited value. Glaciers have exposed most of the mountain tops and sides so that geological guides are better. The valleys are filled with glacial debris which would give values that have no relationship to the underlying rock.
Figure 22. On northwest side of Nunatak Mountain, Garnetized limestone and chert is shown as the light pink and brown.
Three geophysical techniques were used at the Nunatak area during the summer of 1968. First was an induced polarization survey conducted by McPhar Geophysical Company. Second, the writer ran a magnetic survey during the month of July, and the third type of survey was that of gravity.

Conversation with the party chief for the induced polarization crew indicated that this technique was not reliable in the Nunatak area. No anomalous zones were found along any of the lines. Since most of the lines were in the glacial filled valley the results were erratic, probably due to the buried ice.

The gravity survey was conducted after the writer left the project. Mr. Al Perry of Superior Oil Company stated that this survey only proved that the floor of the valley sloped to the northeast.

The magnetic survey was conducted by the writer during the month of July. The results of this survey are shown as Figure 23. The survey was conducted after it was found that the pyrrhotite and the molybdenite were in close proximity and appeared to have been deposited about the same time. This was the first reported occurrence of pyrrhotite in the area. The pyrrhotite was also found to be highly magnetic, thus enabling anomalous concentrations to be located by a magnetometer.

Analysis of the contours of the magnetic map indicate high values trending northeasterly. These trends indicate concentrations that seem
to follow the fault patterns in the area. A large magnetic high is located over the shear zone where conspicuous molybdenite is found. Large magnetic highs are also located north of Nunatak Mountain and may indicate the possibility of favorable mineralization.

The writer believes that a more precise magnetic survey should be conducted over the area, extending along a belt 10 miles wide and 20 miles long with the long axis running east-west. About 10 miles west of Nunatak Mountain molybdenite has been reported. A low level aerial survey would be recommended. This survey would also reveal any concentrations under Muir Inlet.
VI. ECONOMIC POTENTIAL

A. Sampling

There have been three types of sampling techniques applied to the Nunatak area. The first being random sampling, chip and grab, by various investigators. The second type was an extensive trenching program by the United States Bureau of Mines. A total of 10 channels were prepared and sampled by this organization and the area sampled covered approximately 2000 feet by 3000 feet. Two additional channels by the American Metal Climax Exploration, Incorporated have been reported (Figure 24). The third type of sampling involved diamond drilling.

The trench samples by the United States Bureau of Mines and American Metal Climax Exploration, Incorporated were taken from the same area. This location was restricted to the large shear zone located on the northwest side of Nunatak Mountain (Figure 24). These were rather shallow trenches and represented the surface mineralization along the shear zone.

The Keevil Mining Group drilled three holes on the west side of Nunatak Mountain (Figure 24) for a total depth of 2,000 feet. Two United States Bureau of Mines' drill holes are reported but these were less than 300 feet in total depth and the exact location is not known by the writer. The majority of drilling was conducted by Superior Oil Company in the summer of 1968 for a total depth of about 7,000 feet.
The drilling logs and assay results of the Kevill Mining Group were made available to this writer. After careful study of this data, it is felt by this writer that the assay results from this drilling could not be a true representation of the molybdenum content. This is due in part to the poor core recovery and also to the nature of the mineralization and structure.

The above conclusions are based on the following information and observations. First, due to the water-film flotation characteristics of molybdenite, any of the molybdenite that was broken free or deposited along fractures would be subject to washing action of the drilling fluids and would be "floated" out of the drillhole. This would cause a large percentage of the mineral to be lost with the drill water. Superior's drilling program consisted of diamond drilling with water as the coolant. During this writer's stay on the project, only one sludge sample was taken and assayed. The sample was in a five foot fault zone where there was no core obtained from the normal drilling. This sample was later assayed in Tucson, Arizona; it contained more than two percent Mo. This is an indication that molybdenite is concentrated in the gougy zones.

It is recommended that any future drilling in this area take the above features into consideration. This would probably result in a different type of drill and sampling technique; such as churn drilling or sampling of the coolant throughout the diamond drilling program.
B. Evaluation

Twenhofel (1946) reported that the United States Bureau of Mines sampling program contained 0.02 to 0.21 percent of molybdenum. These results are from the shear zone and are marked within the area of Figures II and 24 as conspicuous molybdenite-bearing rock. The numerical average of the results is 0.075 percent molybdenum. The samples taken by the Bureau of Mines from the Nunatak fault deposit contained from 0.04 to 0.34 percent of molybdenum with a numerical average of 0.102 percent.

The results of the American Metal Climax Company's two trenches in the same area were given to this writer by Mr. P. O. Hachey in a telephone conversation. For channel number 1 the average MoS$_2$ content was 0.14 and that of channel number 2 was 0.25 percent, giving an average of the channels of 0.19 percent MoS$_2$.

The assay results from Keevil Mining Group's drilling program are very sketchy. In hole number 1 there was less than 0.002 MoS$_2$ reported. In hole number 2 the results are from 0.004 percent to 0.983 percent. Hole number 3 had results ranging from 0.004 percent to a high of 0.163 percent MoS$_2$. These are not good representative values due to poor core recovery.

The results of Superior Oil Company's drilling are of a confidential nature and therefore cannot be evaluated in this report. Any depth calculations are based on many assumptions, the main one being that the mineralization is continuous with depth. The above assay
results, coupled with a detailed visual examination, indicates there is practically no significant body of material cropping out on the Nunatak that could be considered ore under present conditions.

The only reported calculations of tonnage has been that of Twenhofel (1946). His estimates are based on a density factor of 10 cubic feet per ton and the surface area of the shear zone of about 2,170,000 square feet. These calculations give a tonnage of 180,000 for each 10 feet of depth. This writer has extended the area as mapped by Twenhofel and calculated an average tonnage of 225,000 tons per 10 feet of depth. These figures, plus the assay results of any composited 10 foot section, would probably give a good value of the deposit.
VII. PROBLEMS IN EXPLORATION AND DEVELOPMENT

A. Climatic

The climatic data concerning the area are meager. The only recent weather observation available are the amateur records kept by the author during the summer of 1968. The comparison of these records with those of Juneau's weather bureau show that the Nunatak is approximately 10° colder. Assuming this to be carried over into the winter months then the average temperature from October to June is 29°F.

The obvious problem to be encountered in the area is that of precipitation. Juneau weather records indicate that precipitation averages 95 inches during a calendar year, with the month of September recording, on the average, 10 to 15 inches more than any other month. From conversations with various people in the Glacier Bay area, it has been reported that the Nunatak is subjected to heavy snowfalls with drifts of 10 to 20 feet. This precipitation would determine the most practical mining method for the area.

Wind records were not kept during 1968 and no reports of high winds were available.

Tides are rather drastic as compared to the continental United States. The low is minus six feet with a high of plus 20 feet as reported by the Coast and Geodetic Survey. These tides would create problems for shipping due to the venturi effect of the narrow inlets at Icy Strait.
Generally, the climate would not be a problem to the development of the area into a mine. It would, however, limit the exploration and movement of drills to approximately five months when the area is free of snow. The weather outlined is very similar to most parts of British Columbia where mining is presently being conducted.

B. Transportation

Transportation for the exploration and development of south-eastern Alaska and the Nunatak area is based on a successful sea operation. For approximately five months of the year the waterways are open and ships of ocean going capacity could be utilized. The inlets around the Nunatak area are ideal for deep seaports; the depth of Muir Inlet at Nunatak Mountain is 300 feet as shown on Coast and Geodetic charts. The Nunatak area is ideally located for a tide water operation and ocean shipping being the cheapest method of transportation would be well suited for the development of a mining venture.

Communications with any city, such as Juneau, could be conducted by airplane or radio-telephone. Assuming that government restrictions could be removed, an airstrip could be built adjacent to Nunatak Mountain that could accommodate large aircraft for supplying and maintaining an operation during the winter months.

The high cost of transportation, especially for exploration, is the greatest problem (Table I). Field crews are rather limited as to areas that can be covered by foot and the best solution found is the use of the helicopter. Many companies are finding the use of large
Table 1. Estimated cost of a four month period of diamond drilling in southeastern Alaska.

<table>
<thead>
<tr>
<th>Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling - 5,000 feet NX @ $15.00/foot includes moving, mobilization, cementing, etc.</td>
<td>$75,000.00</td>
</tr>
<tr>
<td>Road and site preparation</td>
<td>3,500.00</td>
</tr>
<tr>
<td>Transportation, boat and fixed wing aircraft</td>
<td>10,000.00</td>
</tr>
<tr>
<td>Geological supervision</td>
<td>8,000.00</td>
</tr>
<tr>
<td>Food, fuel and cook</td>
<td>10,000.00</td>
</tr>
<tr>
<td>Assays and freight</td>
<td>3,500.00</td>
</tr>
<tr>
<td>Contingencies @15%</td>
<td>15,000.00</td>
</tr>
<tr>
<td>Total</td>
<td>$125,000.00 U.S.</td>
</tr>
</tbody>
</table>
boats, that will accommodate their crews, plus a helicopter the ideal combination. This gives the geologist tidewater and airborne capabilities. The average cost for a 10 man boat plus all supplies is approximately $150 per day. A helicopter can be leased for approximately $10,000 per month with a minimum daily requirement of flying time, usually four hours.

The transportation of men and supplies is critical in a remote area. Therefore, any operation should be planned well in advance. Supplies should be obtained in such a manner as to have a minimum of seven days in case of any unforeseen difficulties. Recreational facilities should be provided for the men; such as movies or trips to town.

C. Government Control

A problem in exploration or development of a mineral deposit in the Glacier Bay National Monument is that of governmental restrictions. This region is one of the few national monuments that allow exploration and mining. The use of any form of transportation, other than boats, has to be cleared through the Ranger Headquarters at Bartlett Cove.

Floatplane operations are restricted to salt water. No wheel aircraft is allowed to land in the area except under emergency conditions. Therefore, any airstrips that have to be built or that were desired, would have to be well justified.

Land vehicles that are to be used in any mining operation would also have to be cleared at the Ranger Headquarters. Restrictions as to the type of work are very prohibitive.
Regulations governing the building of cabins are also restrictive. The property in question would need to have proven economic value before any type of permanent building would be permitted. For any mining operation in the area a townsite would have to be negotiated with the Park Service.

Any form of exploration or development within the Monument should be well planned. Representatives of the Park Service should be consulted as to what can or cannot be done at the specific location. The normal federal mining laws are in effect in this area.
VIII. CONCLUSION

The analysis of the geologic data from the Nunatak area leads to the following conclusions:

1. the siliceous zone is not more favorable for the occurrence of higher-grade molybdenite in depth than at the presently exposed surface;

2. that a particular sedimentary horizon, as it approaches the silicified zone, was not more extensively fractured and mineralized than the surrounding rocks;

3. there is evidence of contact metamorphism in the thin-bedded limestones and cherts;

4. the metamorphism has caused discoloration of the sedimentary rocks with the darker areas at or near the mineralized zones;

5. the mineralized zones are found predominantly along the faults and intersections of faults.

The field studies show that the best mineralized zone is not at the top of Nunatak Mountain but is located in a highly fractured zone near sea level. The fracture density is found to be greatest near sea level. The quartz veins also increase in size and number as sea level is approached. This probably means that topographically, the grade of the molybdenite could increase with depth or the more potent source of mineralization is deeper seated.
Throughout the drilling programs there has been reported conspicuous molybdenite in the quartz monzonite. From the mapping and field observation by the writer it is believed that the zone of alteration, the zone of silicification and the stockwork are all related to the quartz monzonite. Surface outcrops of the quartz monzonite, however, have very little, if any, molybdenite. From these observations, it seems probable that the intrusive increases in size and in values with depth.

For any future operations in the Nunatak area the following recommendations are suggested:

1. an aerial magnetometer survey be conducted;
2. aerial photo analysis be made to detail the structure of the area;
3. future drill holes be designed to:
   a. intersect and outline the quartz monzonite at depth;
   b. determine the shear zone's extent to depth;
4. close control of all drilling and sampling to insure recovery of the molybdenite.
REFERENCES


FIGURE 23
MAGNETIC MAP
NUNATAK AREA
GLACIER BAY NATIONAL MONUMENT, ALASKA
MAGNETOMETER-JALANDER
SURVEY CONDUCTED BY JACK C. REED
JULY 1968
FIGURE 24  TRENCH & DRILL SITE LOCATIONS, NORTHWEST SIDE NUNATAK MOUNTAIN