Mineralization of the Driftwood Property, McConnell Creek District, British Columbia 94D/

by Andrejs Panteleyev

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MINERALIZATION OF THE DRIFTWOOD PROPERTY, McCONNELL CREEK DISTRICT, BRITISH COLUMBIA

by

ANDREJS PANTELEYEV

BSc., University of British Columbia, 1964

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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Geology

We accept this thesis as conforming

to the required standard

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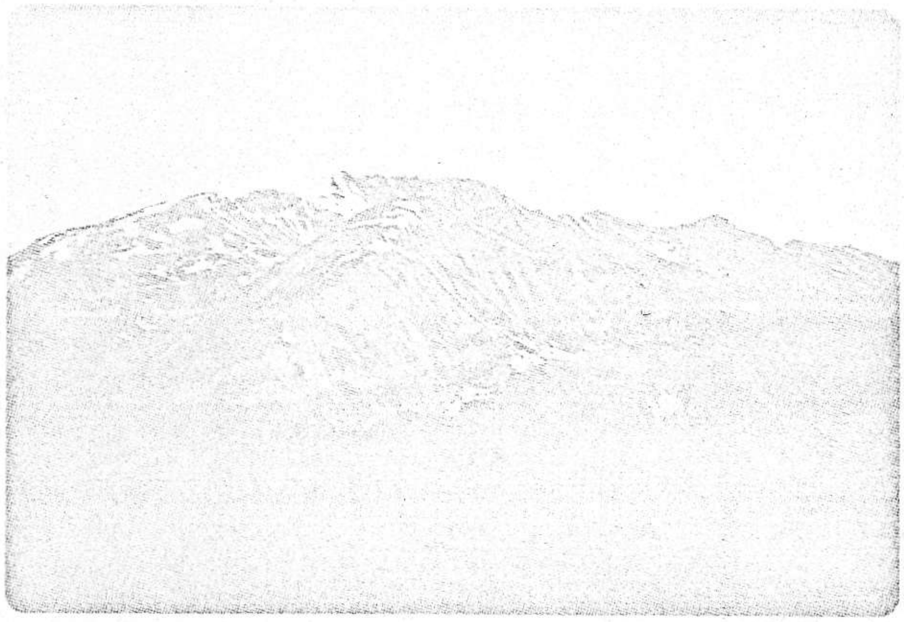

A northwesterly view of the ridge on which the Driftwood Property is located. The gossanous outcrops in the foreground are intrusive rocks of a Kastberg Porphyry and strata of the Takla-Hazelton Group.

ABSTRACT

The Driftwood Property is located in the southwest corner of the McConnell Creek map-area, about 87 miles north of Smithers, B. C. The property lies in a northwesterly trending belt of volcanic-sedimentary rocks that were mapped as Takla Group - Upper Division (Lord, 1948). The rocks are more correctly correlated with the Hazelton Group. They are bounded on the west and east by younger sedimentary formations. To the west is the Bowser Group and to the east, the Sustut Group.

A Kastberg porphyry of Tertiary age has intruded the Takla Group rocks. Intrusion was into the epizonal environment and produced an irregular dyke-like body having a roof zone with anastamosing dykes and small roof pendants. The composition of the stock varies from granodiorite to quartz monzonite and alaskite. Differences in the stock are observed in textural, mineralogical, and chemical variations.

Automorphism of the stock has resulted in propylitic alteration and contact metamorphism has resulted in an enveloping zone of hornfels. Temperatures at the intrusive contact as derived from heat flow calculations were probably a maximum of about 495 to 550°C and varied with respect to the type of rocks intruded. A biotite hornfels of the albite-epidote hornfels facies has formed an aureole over 100 feet wide. A hornfels of the hornblende hornfels facies has been

developed in narrow zones adjacent to parts of the intrusive contact.

The porphyry is a metal enriched intrusion in which some metallic grains formed in an accessory manner but most of the mineralization is epigenetic. The deposit has characteristics of both porphyry copper and quartz stockwork deposits with disseminated, fracture filling, vein, and replacement mineralization in the intrusive rock, hornfels, and skarn. The primary metallic minerals identified were: molybdenite, pyrite, pyrrhotite, chalcopyrite, arsenopyrite, sphalerite, galena, tetrahedrite, marcasite, aikinite, bournonite, and magnetite. Secondary or alteration minerals are rare and only minor goethite, maghemite, malachite, and ferrimolybdite were found. A five stage paragenesis is shown with at least three successive stages of veining. Sulphide deposition is believed to have started at temperatures in the order of 700°C and continued along with re-equilibriation of sulphides down to temperatures below 400°C and possibly 300°C for the sulphosalts.

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MINERALIZATION OF THE DRIFTWOOD PROPERTY,

McCONNELL CREEK DISTRICT,

BRITISH COLUMBIA

INTRODUCTION

Location

The McConnell Creek District is the area underlain by a north-west trending belt of Late Paleozoic to Cenozoic rocks that is contained in the McConnell Creek map-area and the areas immediately adjacent to the west and south. To the west and south no published maps of the region are available but the area has been mapped by the author and others. To the east, is the southwest corner of the Aiken Lake map-area and to the southeast, the Fort Saint James map-area.

The Driftwood Property is found in the extreme south-west corner of the McConnell Creek map-area at latitude 56° 2'15" and longitude 126° 5'13" approximately 87 miles north of Smithers. The property is contained within the MOTASE B Claim Group which lies along the east flank of an isolated ridge overlooking the Driftwood River. The ridge is near the north end of the Driftwood Range about three miles south of Drift Lake, five miles west of Bear Lake, and three and a half miles east of Motase Lake, as shown in Figures 1 and 2.

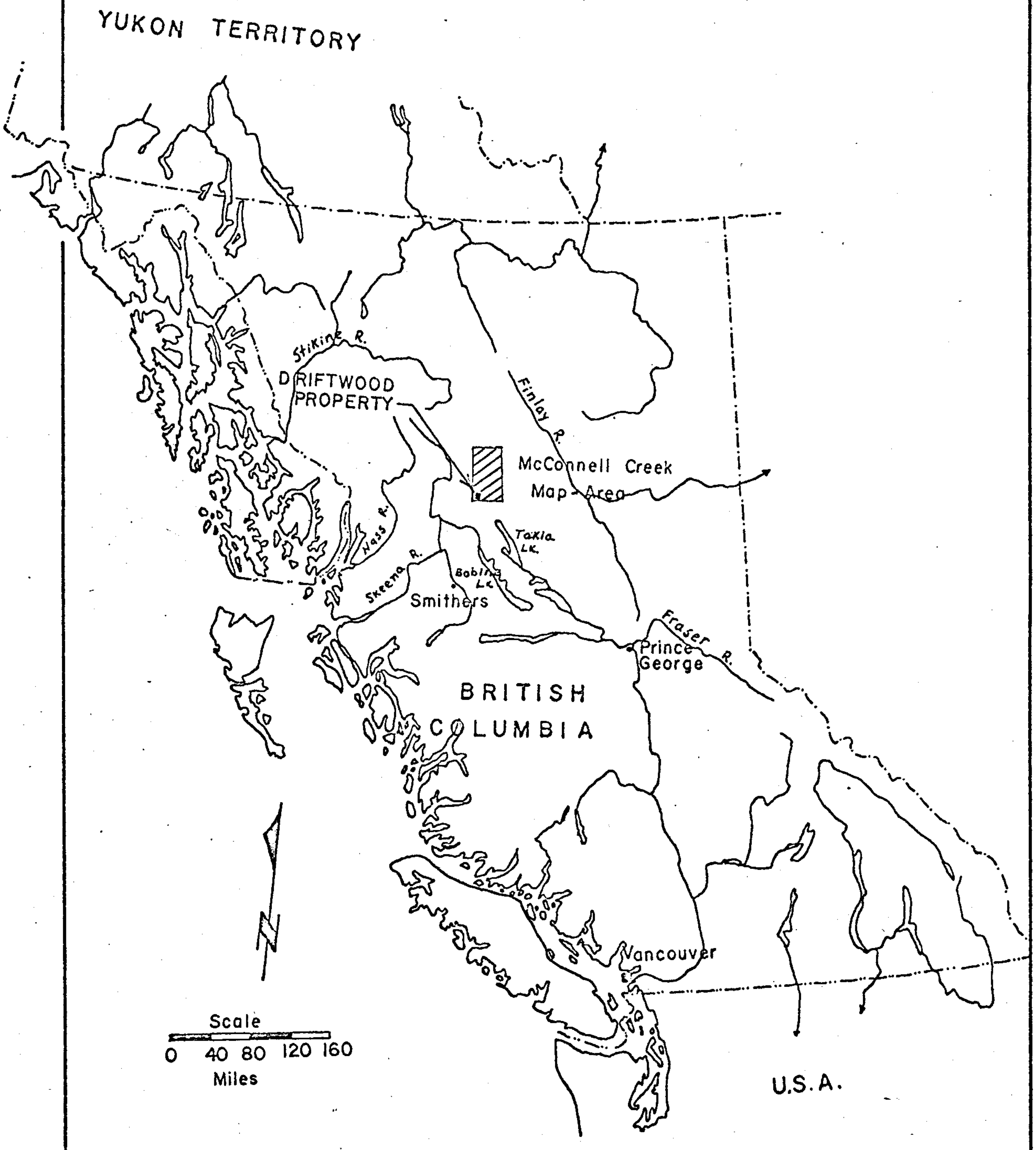


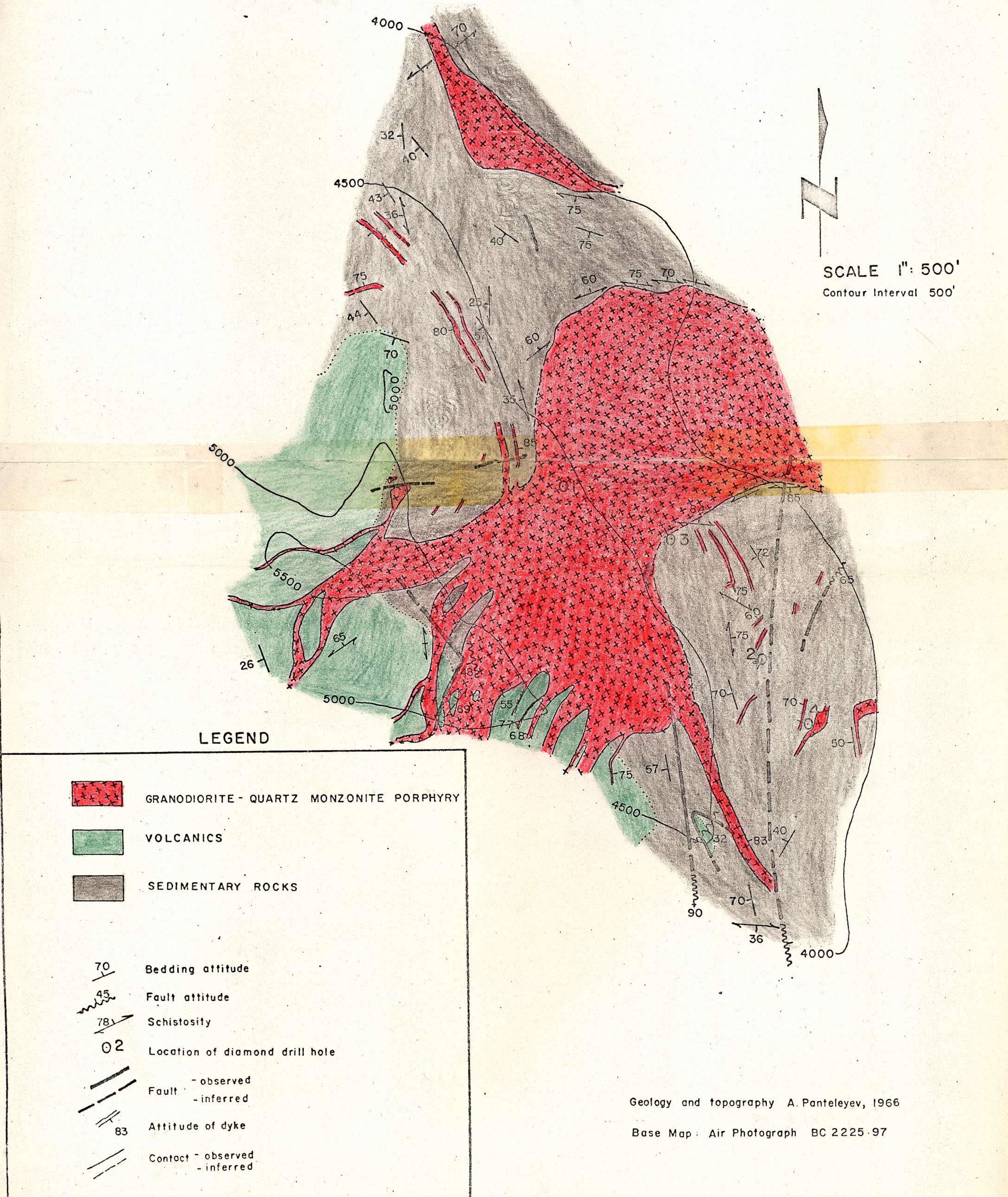
Figure I

Location of Driftwood Property,
McConnell Creek Map-Area

History

The earliest mining interest in the area was in 1899 when placer gold was discovered in McConnell Creek. However, the placers were not very productive and interest in the area lagged. Prospecting in the area was only casual and intermittent prior to mapping by the Geological Survey of Canada. Systematic mapping of the area by C. S. Lord during 1941, 1944, and 1945 resulted in the publication of Memoir 251: McConnell Creek Map-Area, Cassiar District, British Columbia, in 1948. Varied and widespread mineral potential was indicated during the mapping but despite recommendations by Lord as to the most favourable rock types, exploration was only slightly intensified and was largely restricted to the northeast and eastern portions of the map-area in the gold-bearing regions near the Omenica intrusions. Some discoveries of placer gold together with platinum, mercury, and vanadium and a large number of lode deposits of gold, copper, silver, lead, zinc, beryllium, molybdenum, and chromium were made. In the southwest part of the map-area the Atna group of claims and located by M. S. Lang in June, 1945, in the center of what is now the Driftwood Property. One mile to the northwest on the same ridge, thirty five claims were staked during the same summer on behalf of Yukon Northwest Explorations, Limited. All these discoveries and a number of occurrences on the Tsaytut Spur to the east were of copper usually accompanied by silver or

MAP 1: GEOLOGY - DRIFTWOOD PROPERTY



occasionally gold values in volcanics that were mapped as Takla Group.

Exploration activity decreased during the late 1940's and was carried on mainly by independent prospectors. In the 1950's some gold deposits were located on Motase Mountain and Northwest Exploration Company and other companies examined parts of the map-area but nothing warranting a continuing interest was discovered. In 1960 the younger sedimentary formations of the Sustut Group were examined by Pan American Oil Company but again no apparent interest in the area was generated.

Renewed interest in the entire region was shown in the early 1960's as a result of discoveries of economic ore-bodies and promising mineral deposits to the south. By 1965 there had been and were a number of companies and independent prospectors working in the McConnell Creek map-area and surrounding regions. Their work resulted to the discovery of more gold veins in the Motase Peak area, a number of disseminated copper - molybdenum deposits associated with intrusive stocks and some stratabound copper and associated copper-silver vein deposits in sedimentary and volcanic rocks. Active exploration and evaluation of many of these deposits has been in progress since 1966.

Physiography

The southwest corner of the McConnell Creek map-area and regions to the south and west are characterized by north-westerly-trending mountain ridges separated by broad valleys. The Driftwood River and drainages to the south of the Driftwood Property flow southeast into the rolling hill country of the Takla region which is part of the Fraser River system. To the west and east of the Driftwood Property the Motase and Bear Lake Valleys drain northwesterly into the Skeena River system.

Topography is strongly influenced by underlying rock types and structures and shows decreasing ruggedness and elevations from the west towards the east. In the central area to the west of Bear Lake and around the Driftwood Valley, Takla Group rocks are exposed as northwesterly-trending ridges such as the Driftwood Range and Tsaytut Spur. These ridges rarely exceed 7000 feet in elevation and are characterized by asymmetrical cross-sections due to inclined strata. They show ragged, knife-edged portions, spires, well developed cliff faces and loose crumbling slopes on one side and more gentle, uniform slopes on the other. To the west the topography is much more rugged. The mountains such as the Sicintine Range have granitic cores and are asymmetrical, extremely ragged in profile, many being over 8000 feet high. To the east of Bear Lake in the Sustut Group rocks the topography is distinctly different. In regions of flat-lying strata there are gently undulating or flat, plateau-like surfaces which are bounded by steep cliffs such as those found along the east margin of Bear Lake. Further to the east where the strata are more contorted and inclined, are hogback and cuesta structures such as those observed in the Connelly Range. There, the ridge crests are close to 6500 feet in elevation and many have spectacular cliffs and talus slopes on one side.

Glaciation

Most ridges and peaks are so rugged that little or no glacial record has been preserved on them. Glacially scoured outcrops were observed on the crest of a ridge near the Driftwood property at an elevation of about 6400 feet. To the north glacial erratics were found on a small plateau surface at an elevation of 5500 feet. No direction of ice movement could be determined.

The main northwest-trending valleys such as the Bear Lake and Driftwood River Valleys show the best evidence for widespread glaciation. They are U-shaped in profile with truncated spurs and hanging valleys. Some drumlin-like structures are visible in the Driftwood Valley but generally in most parts of the valley and other valleys only a thin glacial cover of till or outwash gravels can be seen. Alpine glaciers are common in the western part of the region such as the Sicintine Range and parts of the Tsaytut Spur.

REGIONAL GEOLOGY

Introduction

The regional geology of the Driftwood Area as shown in Figure 2 has been taken from the southwest corner of Lord's McConnell Creek map-area (1948) and reconaissance work to the south and west by the author and others during 1965 and 1966.

The oldest rocks in the area are to the west of Bear Lake and underlie the Driftwood Property. Lord dated the rocks as Lower Jurassic on the basis of fossil evidence and called them 'Takla Group - Upper Division'. To the west Bowser Group rocks of Upper Jurassic to Lower Cretaceous age unconformably overlie the Takla Group, and to the east are Upper Cretaceous to Tertiary rocks of the Sustut Group. Granitic plutons and smaller masses of at least two ages intrude the strata as well as minor dykes, sills, and necks of basalt.

Takla Group

The Mesozoic volcanic-sedimentary rocks to the west of Bear Lake contain late Lower Jurassic faunal remains and were called the Upper Divisions of the Takla Group by Lord. Further to the east in the central and eastern parts of McConnell Creek map-area Lord found lithologically different, non-fossiliferous volcanic-sedimentary assemblages which he called the Lower Division of the Takla Group. In the same regions the Upper Division was found to contain Middle and Upper Jurassic (Oxfordian) fossils. The division of the Takla Group into an upper and lower unit was accepted by Armstrong who had originally defined the Takla Group further to the south. However, as a result of work in other map-areas it became necessary to re-examine and re-define Mesozoic rocks that had been assigned to the Takla and Hazelton Groups.

The redefinition for the McConnell Creek area was included in the general revision of the Hazelton and Takla Groups by H. W. Tipper (1959).

According to Tipper:

> 'In McConnell Creek map-area, the Takla group is subdivided into upper and lower divisions, roughly corresponding to Hazelton and Takla groups in their type areas, and a lithologic change from fine to coarse clastic sedimentary strata occurs between the two divisions. This change, however, apparently started in Early Jurassic time...'

> 'The definition of the Hazelton and Takla groups is most difficult when the Lower Jurassic strata have to be assigned. Upper Triassic sedimentary strata are almost invariably shales or argillaceous limestones clearly assignable to the Takla, and Middle Jurassic or later beds are generally conglomerates or greywackes typical of the Hazelton, but Lower Jurassic sedimentary beds may be either coarse or fine grained ... In McConnell Creek area, Lower Jurassic strata are closely related to and inseparable from the upper division of the Takla group (equivalent to Hazelton group). In Fort St.James area, the type area of the Takla group, Armstrong recorded the occurrence of Lower Jurassic conglomerates, greywackes, and shales and postulated marine, near-shore, or nonmarine conditions. These beds are distinctly different from the Upper Triassic sedimentary strata. Thus in both McConnell Creek and Fort St.James areas the Lower Jurassic could rightly be considered to be part of the Hazelton group (although in the Fort St.James

Table 1: TABLE OF FORMATIONS (modified after Lord, 1948).

Era	Period or epoch	Formation and thickness in feet	Character
Cenozoic	Recent		Stream alluvium and delta deposits, talus, and soil.
	Pleistocene		Glaciofluvial and glacio-lacustrine deposits, other glacial drift.
	Tertiary to Recent		Basalt necks, dykes and lava.
	Intrusive contact		
	Tertiary	Kastberg Intrusions	Feldspar and feldspar-quartz porphyries with dense, chalky weathering groundmass; medium grained porphyritic granodiorite and quartz diorite. Dykes, sills and stocks.
	Intrusive contact		
Mesozoic and Cenozoic	Upper cretaceous and Paleocene	Sustut Group 3,000 + feet	Buff to grey impure sandstone, conglomerate, and shales; minor dacitic tuff and coal. Well bedded continental deposits characterized by cross-bedding and fossil plant remains.
	Unconformity		
Mesozoic	Cretaceous and later	Coast Intrusions	Biotite granodiorite, quartz diorite, in plutons and satellitic bodies to the Coast Range Batholith.
	Intrusive contact		
	Upper Jurassic Lower Cretaceous	Bowser Group 20,000 + feet?	Fossiliferous marine and terrestrial conglomerate, greywacke, and shale.
	Unconformity		
	Jurassic	Takla-Hazelton Group	Porphyritic andesite flows, breccia; minor dacite and rhyolite; tuffs with interbedded conglomerate, greywacke shale, and argillite.

area Armstrong considered it part of the Takla group)'...

'With which group should the Lower Jurassic strata be correlated? They never have been included in the Hazelton group, but in places there now seems to be some justification for so doing. Armstrong placed both Upper Triassic and Lower Jurassic in the same group but probably more for convenience than because there was no valid reason for separating them.

'Early Jurassic time was apparently a transitional period in which environmental conditions changed from moderately stable to chaotic... The effect of these conditions was not felt everywhere at the same time, so that difficulty persists in mapping and correlating Lower Jurassic strata. It seems probable that in time the Takla group will be restricted to Upper Triassic strata, like the Nicola group of southern British Columbia, and the Lower Jurassic strata will be mapped as a new group. Until that is feasible there is no alternative but to map Lower Jurassic rocks with the Takla group where possible, as in Nechako River area, but as Hazelton group where they are lithologically inseparable from Middle Jurassic strata, as may be the case in McConnell Creek area.'

In view of this statement, the Lower Jurassic volcanic-sedimentary rocks in the Driftwood area are referred to herein as 'Takla-Hazelton Group'.

The volcanic and sedimentary rocks of this unit occupy a north-westerly trending belt to the west and south of Bear Lake Valley. At the north end of Tsaytut Spur by the north end of Bear Lake the belt is only about four miles wide but broadens southward to form the Driftwood and Bait Ranges and northern part of the Babine Lowlands where it is at least 20 miles wide.

The principal rock types are lavas, brecciated flows, and pyroclastics, with conglomerates, greywackes, shales and argillites. They form dark green and grey strongly jointed but otherwise seemingly structureless outcrops.

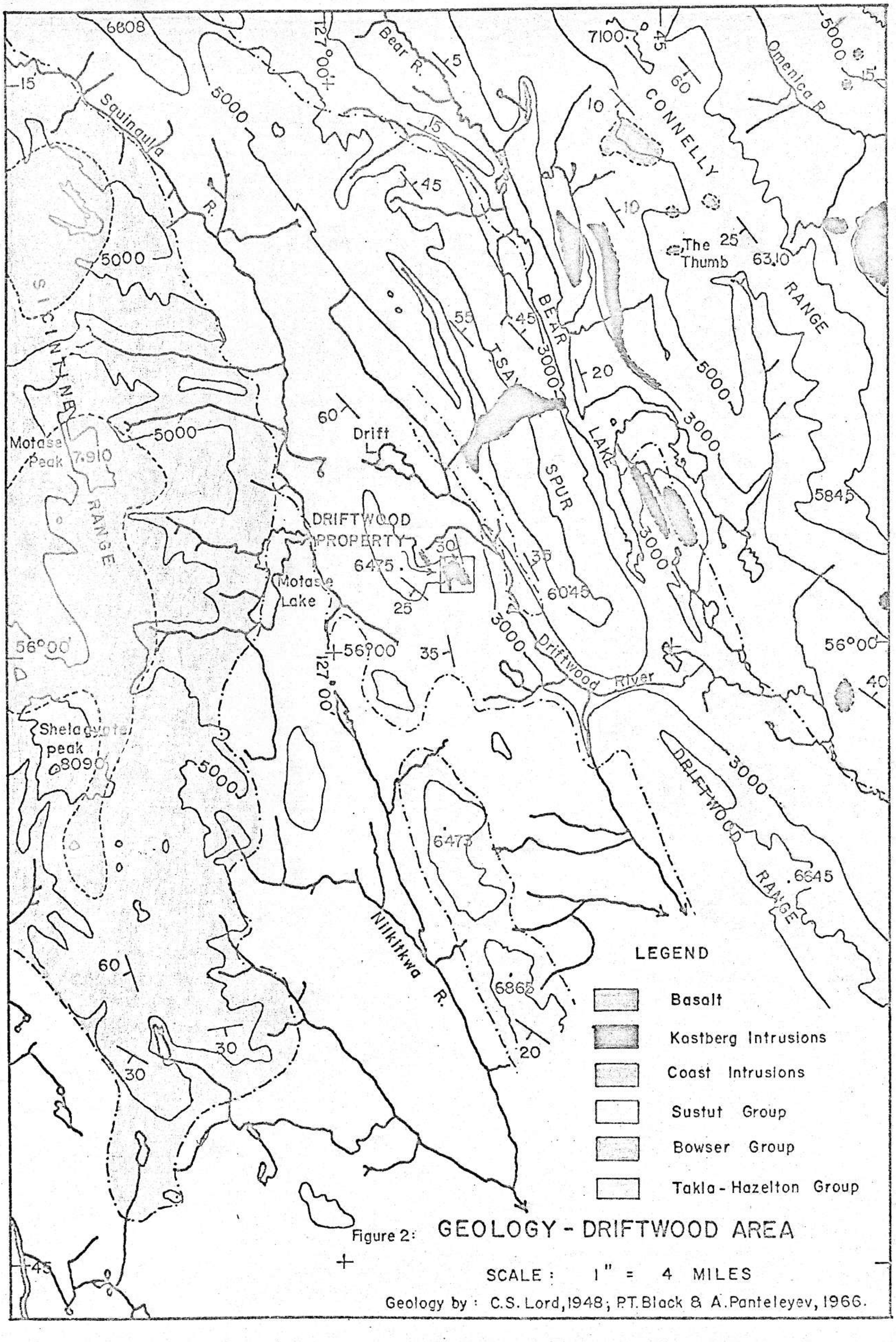


Figure 2: GEOLOGY - DRIFTWOOD AREA

SCALE: 1" = 4 MILES

Geology by: C.S. Lord, 1948; P.T. Black & A. Panteleyev, 1966.

Lithologic units are extremely difficult to recognize from a distance and even on close examination individual flows and volcanic members are inseparable. According to Lord (page 19):

....."The precise sequence is not known. Available evidence indicates that volcanic members greatly predominate among the lower strata and sedimentary members in the upper parts of the division, where, however, they are interlayered with volcanic rocks.

Approximately 18,000 feet of volcanic rocks outcrop between Bear Lake village and Driftwood River, where neither their upper nor their lower limits were recognized. Because of relatively complex structure few data are available on the aggregate thickness of the Jurassic sedimentary rocks. ...(Thus) the complete assemblage assigned to the upper division is probably considerably more than 23,000 feet thick.'

Lavas

These are mainly massive, dark green porphyritic rocks with lesser purplish red and grey varieties. Two types of porphyritic volcanics were observed. The more common type in the Driftwood region has small dark phenocrysts of chloritized pyroxene and amphibole. The phenocrysts appear as small, equant spots less than 1/16 inch across the face with diffuse boundaries and a shredded outline due to chlorite alteration. The other porphyyritic type has white or buff plagioclase laths which may be only slightly larger than the fine felted goundmass and almost indistinguishable from it but commonly grade to small phenocrysts up to 1/16 inch long that form at least 15% of the rock. Fragmental flows and portions of flows contain angular and rounded fragments of varying sizes. The composition of the fragments is almost identical to the matrix and they can usually be distinguished only on weathered surfaces. The matrix has a green chloritic appearance and fractures contain epidote, chlorite, calcite, and quartz which denote greenchist facies regional alteration.

Sedimentary rocks

The sedimentary rocks in the Driftwood area are mainly coarse clastic types. The description by Lord (page 21-22) is complete and little needs to be added to it.

'Greywackes. These are fine-to medium-grained, dark green to grey, sandy-textured rocks that weather green, grey-brown, or yellowish-brown. They are well bedded, and are interlayered with conglomerates, slates, and argillites. The beds range from a few inches to several feet in thickness; a few layers are indistinctly crossbedded. ... Occasional well-sorted beds grade from coarse at the bottom to fine at the top. The greywackes comprise mainly subangular to partly rounded grains of chert and microcrystalline volcanic rocks. ... Occasional grains of plagioclase feldspars and of quartz were also noted....'

Conglomerates. Most of the conglomerates have about the same composition as the greywackes and differ from them mainly in grain size. These are thoroughly consolidated grey, greenish grey, or limonite-stained rocks, and fresh fractures commonly pass through rather than around the pebbles. The conglomerates form layers ranging from a foot or so to many feet in thickness, but the thicker layers commonly contain lenses and beds of greywacke. The pebbles are subangular to rounded and are generally less than 2 inches in diameter. Most of them are black, grey, and green, cherty rocks...... Pebbles of white quartz and red and green volcanic rocks, with 1/16 - to 1/8 inch feldspar phenocrysts, are locally abundant. The matrix is apparently identical with the greywackes previously described. These conglomerates were probably derived from the same source as the greywackes, and are not known to mark significant breaks in deposition.'

Shales and argillites. These commonly occur as grey and black beds one to two feet thick interbedded as well defined beds and lenses with the finer-grained greywacke beds and occasionally as lenses in conglomerate-greywacke sections. Most beds are hard and silicious. A very few are calcareous and many probably contain fine tuffaceous material. According to Lord (page 22):

> ....'Argillites predominate, and are compact, banded rocks that break without particular reference to the banding into small, sharply angular blocks. Shaly beds, on the other hand, break along the bedding to form thin plates and slabs'.

Other rocks. Minor strata found in the Driftwood section intercalated with brecciated volcanic flows are thin beds of dense, purple tuff with a concoidal fracture and beds of fine-grained tuffaceous sandstone and quartzite.

Bowser Group

The Bowser Group is a marine and continental series of clastic sedimentary rocks containing Upper Jurassic and Lower Cretaceous fossils. The minimum total thickness is in the order of 20,000 feet but in the Driftwood area only 2,000 to 3,000 foot sections of the basal portions were observed where they unconformably overlie Takla-Hazelton rocks. Conspicuous bedding can be seen in all the Bowser Group outcrops and this, along with the grey colour, easily differentiates them from the Takla-Hazelton volcanic-sedimentary rocks.

Rocks of the Bowser Group form the Sicintine Range. Their eastern boundary is Takla-Hazelton rocks along the Squingula and Nilkitkwa Rivers and Motase Lake. Greywackes are the most common rock type. They vary in grain size and grade into grits, pebble conglomerates, and coarse boulder conglomerates on one hand and to argillites and slates on the other. All the rocks seem to have a similar composition and vary mainly in grain size. Bedding is well developed and distinct. Fine clastic beds are two to three feet thick; greywacke and conglomerate beds are commonly 5 to 10 feet in thickness but have been reported to be hundreds of feet thick in other areas. Bedding is emphasized by differences in darkness and resistance to weathering of the beds. Limestones and volcanic rocks are virtually absent. Coal forms thin seams in the basal sections of the group.

Sustut Group

The Sustut Group is a well bedded succession greater than 3,000 feet thick of Upper Cretaceous to Paleocene clastic rocks. They occur in a northwesterly trending belt 10 to 15 miles wide along the east shore and to the northwest and southeast of Bear Lake. The succession unconformably overlies Takla-Hazelton rocks.

The outcrops are bedded, grey to buff in colour, and composed mainly of pebble conglomerate, coarse sandstone and sandstone containing pebbles. The conglomerates most frequently have pebbles one to two inches in diameter but a few are up to eight inches. The fragments are rounded and composed of white vein quartz, chert, volcanic porphyries, green massive lavas and some equigranular granitic rocks, tuffs and shale fragments. The sandstones are finer grained equivalents of the conglomerates and crossbedding in them is not uncommon. The conglomerates form the thickest beds and may be as much as 100 feet in thickness. The sandstone beds rarely exceed 20 feet. Together, conglomerates and sandstones may be interbedded to form spectacular cliffs hundreds of feet high. The finer-grained sandstones are associated with dark grey, soft weathering, friable shale beds. In such sections small lenses of coal and many floral imprints and pieces of fossil wood are found. In sections examined by Lord, white-weathering dacitic tuff bands were noted. These showed thicknesses from 2 to 50 feet and were believed to occur only in the upper parts of the Sustut succession.

The overall appearance of the Sustut Group is quite similar to parts of the Bowser Group but can be distinguished in the Driftwood region by the virtually flat-lying or gently rolling structures; smaller average thicknesses of beds; greater abundance and composition of the conglomerates; lesser abundance of shales and argillites; and the presence of tuff beds. Examination of fossil remains, of course, clearly indicates their age difference despite some general lithologic similarities. The Sustut rocks are fresh looking and virtually unaltered. Where they are intruded by dykes and sills of granitic porphyries and basalt, negligable contact metamorphic affects are visable.

Pleistocene and Recent deposits

Glacial and alluvial deposits cover the valley floors in all the main valleys but unlike the regions to the south where such deposits reach great thicknesses, bedrock in the Driftwood region is usually within 10 feet of the surface and is exposed in most areas that have been incised by streams.

Intrusive Rocks

Coast Intrusions. These form small satellitic plutons along the eastern margin of the Bowser Basin in the Sicintine Range and the north end of the Bait Range in Takla-Hazelton rocks. The intrusions are so named to indicate a similar age with the Coast Range Batholith. The intrusions lie along an east-west 'arch' between the Omenica and Coast Ranges and should not be genetically associated with either except in a time sense. Intrusion occurred over an extended time period from possibly as early as Upper Jurassic to as late as Tertiary time.

The intrusions form irregular, light grey, well jointed stocks having very little thermal affect on the surrounding rocks. The compositions are most commonly of medium to coarse grained, equigranular, quartz diorite and granodiorite. An exception is a small highly irregular dyke-like mass overlooking the Squingula River in the northwest corner of the Driftwood area. The rock there is a porphyritic grey to pink granodiorite and quartz monzonite. Alteration of this stock is strong and has produced a large goassanous zone in and around the stock.

Kastberg Porphyries. The Kastberg intrusions occur in Takla-Hazelton and Sustut Strata and are believed to be early Tertiary in age (Lord, 1948). They are localized in the southwest corner of the McConnell Creek map-area in the Driftwood region and further to the south in the vicinity of Babine Lake (N. C. Carter, personal communication). The intrusions occur as sills and dykes and highly irregular plugs of porphyritic granodiorite, quartz diorite, and feldspar and quartz porphyry. They are grey and buff in colour and weather deeply with a soft, chalky surface.

The grain size of the porphyries varies widely. The finest-grained facies may show only small quartz eyes as phenocrysts. Most commonly visible are phenocrysts of plagioclase and needles of amphibole and biotite. The coarsest-grained rocks such as those found at the Driftwood Property contain plagioclase phenocrysts with hornblende and biotite and characteristic poikilitic orthoclase phenocrysts up to one inch in length. Most small intrusive bodies show a thin marginal chill zone but otherwise very little contact alteration affects.

Basalts. Minor dykes, sills and one prominent basaltic neck intrude Sustut Group rocks to the east of Bear Lake. The circular neck remains as a resistant mass, with well developed columnar joints and stands above the flat-lying Sustut strata as a prominant landmark called 'The Thumb'.

Structure

Most major faults and fold axes in the McConnell Creek map-area and regions to the west and south reflect the northwest Cordilleran trend. A few major and many minor faults strike north, northeast, and east. The Driftwood area lies to the west of a major fault zone which is bounded on the east by the Omenica River. This fault zone contains the Omenica, Carruthers, and Ominicelta faults and is ten to twelve miles wide. It is the northern extension of the Pinchi fault zone (Roots, 1954) mapped by Armstrong in the Ft. St.James area to the southeast. Faults are 25 to 1000 feet or more wide and are marked by fractured, sheared and otherwise altered rocks. Lord postulated that dips are steep and displacements along the major faults may be as much as ten thousand feet. He suggested that the southwest side of the Omenica fault moved upward but in the other northwest trending faults the northeast side moved upward relative to the southwest. Major displacements are believed to have taken place in post-Paleocene time.

In the Driftwood Valley Lord suggests that there may be an unmapped fault as suggested by the abrupt variations in altitudes and steep incinations displayed there by the Sustut strata. The author concurs and noted that mapping along the Driftwood Valley linear trend across the drainage divide into the Squingula Valley indicated that this valley system marked the abrupt eastern limit of Bowser Group Rocks. Further, the very presence of inclined strata of the Sustut Group on the floor of the Driftwood Valley would suggest that the valley may be a small graben structure relative to the Takla-Hazelton rocks on the Driftwood Property and Tsaytut Spur.

Folding has taken place about northwesterly trending axes and according to Lord has occurred during two periods. The first was during intrusion of the Omenica (and Coast Intrusions) following the deposition of the Takla-Hazelton rocks. The second interval was post-Paleocene, after deposition of the Sustut Group. During this time the region was subjected to some compression and thrusting from the southwest.

The various age-rock units in the area reflect the intensity and manner of deformation. The Takla-Hazelton rocks are relatively tightly folded. Dips from 10 to 65 degrees were reported with dips of 30 to 50 degrees most common but no overturned structures were noted. The Bowser Group rocks are moderately folded into well-defined, large open folds with dips rarely exceeding 30 to 35 degrees. In some areas around intrusive masses the beds are contorted and show complicated structures and beds with highly variable dips. Most of the Sustut Group strata are warped into large open folds with dips of 10 to 20 degrees or less. However, along the east flank of the Sustut belt in such regions as the Sustut and Omenica River Valleys the beds are crumpled into series of small, tight folds with some overturning in places towards the northeast. It appears that the beds have been pushed against a rigid barrier formed by the older Takla-Hazelton rocks to the east.

The intrusive rocks display very little internal structure. The Coast Intrusions are massive rocks which have sharp, chilled contacts with the Bowser Group sediments. Most of the plugs are irregular in outline but the contacts are steep and easily traceable with the exception of the one altered gossanous intrusion overlooking the Squingula River. There the plug is highly irregular, has many interfingering dykes and irregular apophyses adjoining the central intrusive core.

The small plugs and projections from the large plugs in the Bait and Sicintine Ranges seem to cut the Bowser and Takla-Hazelton rocks without disturbing them. However, in the Motase Peak region of the Sicintine Range and the Atna Range to the west, the strata around the larger intrusive stocks are contorted with irregular overturned folds. Such deformation could be caused both by the forceful injection of the intrusions and gravity collapse of the beds from domed areas.

The Kastberg intrusions form thin sills and dykes or highly irregular stocks and plugs. Some sills show columnar jointing which serves to distinguish them at a distance from the enclosing Sustut strata. The intrusions may show a thin chill margin composed of microcrystalline matrix in which there is visible some plagioclase phenocrysts and sometimes fine sulphides and magnetite. Their emplacement appears to have been largely influenced by pre-existing structures and zones of weakness such as bedding planes and faults. In most cases intrusion of the porphyries seems to have caused very little deformation and metamorphism of the intruded strata. An exception is at the Driftwood Property where some parts of the intrusive rock are enveloped in a thin zone of schist and the entire intrusive body is surrounded by an aureole of hornfels.

GEOLOGY OF THE DRIFTWOOD PROPERTY

Introduction

The Driftwood Property is underlain by a section of westerly-dipping sedimentary and volcanic rocks of the Takla-Hazelton Group which has been intruded by a small, irregular stock of granodiorite-quartz monzonite porphyry. The intrusion has been mapped by Lord (1948) as belonging to the Kastberg Intrusions of Tertiary age. Chalcopyrite, pyrite, pyrrhotite, and some molybdenite are contained in the intrusive rock as disseminated grains. Most molybdenite and pyrrhotite and some chalcopyrite and pyrite are found in a quartz stockwork and fractures in the hornfelsic periphery along the southern intrusive contact.

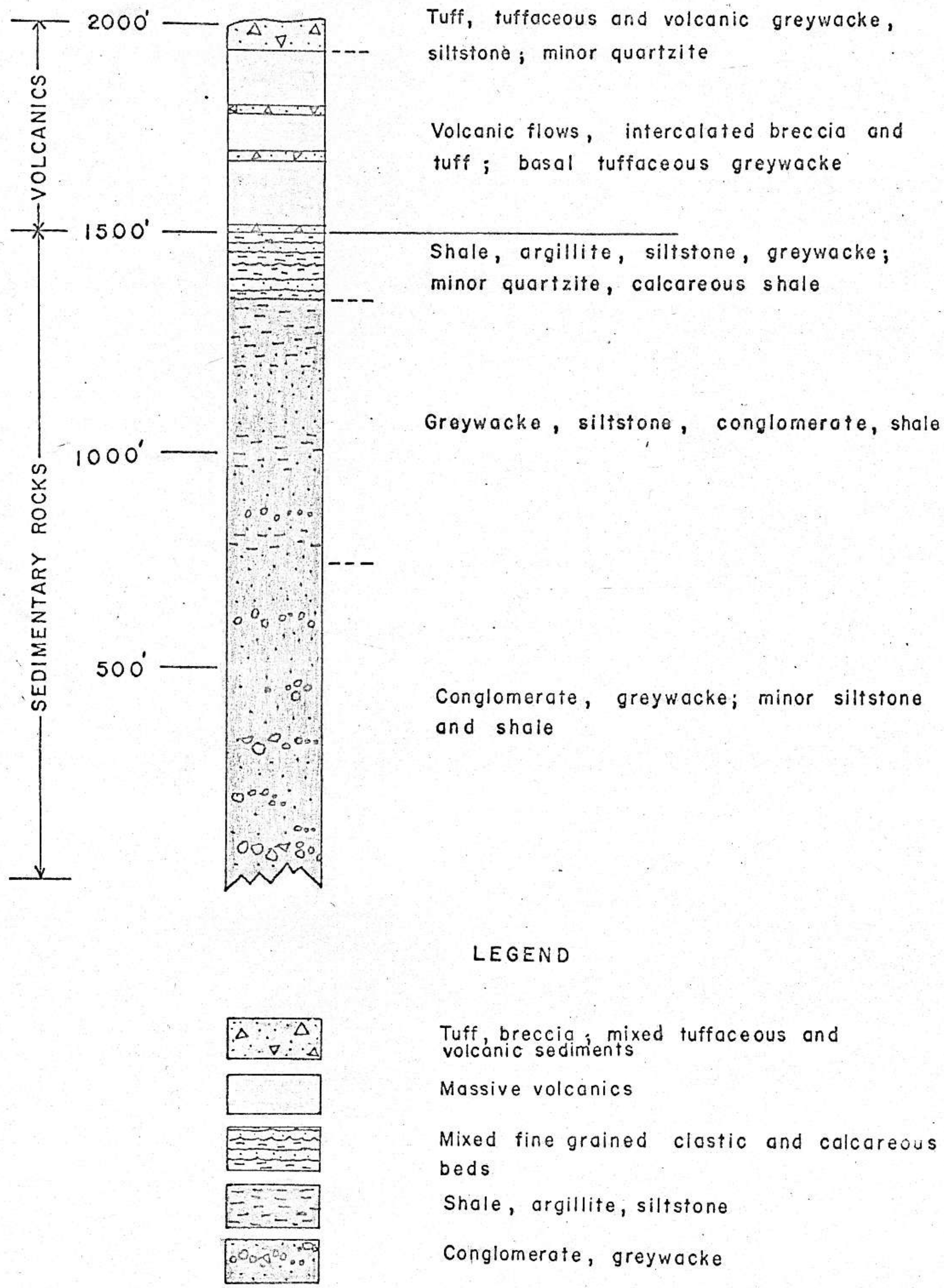
Takla-Hazelton Rocks

Stratigraphic Section. Iron stained and dark grey-green outcrops of inclined strata representing a stratigraphic thickness of over 2000 feet are exposed along the ridge forming the Driftwood Property. The base of the formation was not seen. The lowermost 1500 feet of the section is composed of sedimentary rocks and the upper 500 feet is a volcanic assemblage. The basal portion of the sedimentary section is composed of coarse clastic beds. These grade upwards into beds of fine-grained sediments and are overlain by massive volcanic flows with some intercalated breccia and tuff beds and an uppermost thin capping of tuff and tuffaceous sedimentary beds. A generalized stratigraphic column based on visual estimates of bed thicknesses and a few points of known elevation is shown in Figure 3.

The basal portion of the sections is composed of greywacke and conglomerate beds and lenses a few inches to tens of feet in thickness. Commonly the beds are graded and bedding planes or sharp distinctions between individual beds are not apparent. Thus, the beds represent a continuous depositional sequence without any major change in environment of deposition or supply. The middle portion of the section shows a transition from coarse to fine clastic sedimentation. The lower boundary was arbitrarily placed where greywacke became the dominant rock type relative to conglomerate. Conglomerate is present in minor quantities probably as lenses and greywacke, siltstone, shale, and argillite become the dominant rock types. The top of the sedimentary unit is marked by the presence of silicious and calcereous beds. The silicious beds are not cherty chemical precipitates but rather fine-grained clastic debris. They indicate a decrease in rate of sedimentation and an influx of a more mature sediment.

The volcanic section forms the top of the stratigraphic column. The bottom is marked by a basal bed of tuffaceous sediments that marks the advent of volcanism. Volcanic flows and brecciated flows are interrupted by the intercalation of at least two thin units of pyroclastic

Figure 3 : GENERALIZED STRATIGRAPHIC COLUMN, DRIFTWOOD PROPERTY



material. The lower one is composed of tuff and tuffaceous sediments and the upper one of glassy welded tuffs or flow breccia. The uppermost part of the section is a complex succession of tuffaceous and sedimentary beds. The sedimentary beds are composed of tuffaceous greywacke, greywacke derived from volcanics and minor quartz-rich clastic detritus and may indicate the return to a predominately sedimentary environment.

Conglomerate and Greywacke

The two rock types can be described together because they have the same composition and differ only in grain size. The rocks are dark grey in colour with a faint deep blue or brown cast and weather medium grey or brown with a thin chalky or limonitic surface layer. The conglomerates have a matrix of greywacke containing rounded and subangular pebbles. Angular fragments are not common but were observed to form a few lenses or beds of 'sharpstone' conglomerate. The pebbles are both lighter and darker than the matrix but frequently blend in and are discernable only due to subtle differences on the weathered surfaces. In all cases fresh fractures pass through and not around the pebbles. Pebbles form up to 60% of the conglomerate beds. In many of the greywacke beds pebbles and gravel form lenses or are unevenly dispersed throughout them so that it is an arbitrary distinction between pebbly greywacke and conglomerate. Thin sections of greywacke showed 80% of the rock to be composed of coarse sand-sized grains with the remainder a ferruginous matrix of salt sized particles and opaque 'dusty' sulphides or carbonaceous material. In zones near igneous contacts fine-grained brown biotite may be recrystallized from the matrix. Seventyfive percent of the fragments are derived from volcanic rocks. Most are from porphyritic volcanic composed of a felted matte of plagioclase microlites and finely disseminated opaque material and a small number of fragments are from a microporphyry in which irregular radiating groups of feldspar microlites in the indistinct grey groundmass form a cumulophyric texture. The remaining 25% of the fragments is comprised of chert, a few grains of crystalline quartz and a very small amount of feldspar, shale chips, and very finely divided white micas and clays.

Shale, Argillite, and Siltstone

The three rock types were distinguished from each other in the field on the basis of their fracturing. The shales split along bedding planes and parallel to them into thin platy fragments while argillite and siltstone broke into fragments without reference to bedding planes. Beds were called siltstone when the first trace of a clastic texture could be detected with an unaided eye. Silicious beds were distinguished by their hardness, toughness, and light grey colour. The rock made a ringing sound when struck and broke into spoon shaped fragments with concoidal fracture planes. Calcareous beds were indistinguishable in outcrop from ordinary shale and argillite beds. However, near the igneous contacts they contained calc-silicate alteration minerals and during geological mapping could be easily traced with hydrochloric acid bottle. Microscopically about 15% of the siltstone-argillite is composed of identifiable grains of quartz, feldspar, and fragments of volcanic rock and shale while the rest is an indeterminable matrix of silt and clay sized particles. A weak banded texture is emphasized by alignment of some of the mineral grains and fine grains of pyrite and carbonaceous material.

Quartzite and Silicious Siltstone

The beds form thin units in the stratigraphic column. The rocks are formed from fine grained clastic sediments whose maximum grain size is in the very-fine sand to fine sand size range. On the basis of the size classification the beds range from siltstone to very fine sandstone. The largest grains observed were 0.2 mm. Most grains are quartz or perhaps very fine grained chert fragments and minor amounts of plagioclase feldspar. The matrix appears to be an iron-rich clay and contains a small percentage of fine sericite and opaque minerals. It varies in volume from interstitial amounts in quartzite beds to dominant quantities in silicious siltstone. No mafic minerals were seen and only minor amounts of mica and opaque minerals could be identified in the matrix. The grains are surrounded and tightly packed and held together with the matrix to produce a dense, tough rock with an indurated appearance.

Tuffaceous Sediments

The outcrops are dark brown in colour with a weak to distinct purple cast. They are strongly jointed but there is no suggestion of bedding or parting planes or other foliation. Hand specimens show clastic texture with grains from silt to medium-sand size in a dark, glassy matrix. Some specimens show weakly developed bands of coarser grains or preferred orientation of the grains. Under the microscope the composition is seen to be largely grains of volcanic rocks and microlites or small laths of plagioclase with some opaque minerals and fine, rounded quartz grains. A number of grains of apatite were observed. These and the feldspar laths are somewhat corroded but still maintain roughly euhedral outlines. The matrix is light brown to grey and looks to be composed of glassy material. It contains fine, recrystallized chlorite and in a number of specimens, a little calcite. The abundance of volcanic fragments and plagioclase grains over quartz and chert and the general appearance of the matrix can be used to differentiate tuffaceous rocks from those in the sedimentary section.

Volcanic Breccia

This unit forms a thin bed or group of beds not more than 20 feet thick, and lies between two volcanic flow units. The outcrops are distinctly purple or red-brown in colour. Hand specimens show a fragmental texture with purple and green fragments up to $\frac{1}{2}$ inch across in a dense, glassy, purple groundmass. Under a microscope the rock appears to be almost entirely composed of glass fragments in a glass matrix of very similar composition. The boundaries of fragments are almost indistinguishable from the matrix. In polarized light the fragments are slightly cloudy or grey in appearance compared to the matrix but under crossed nicols the matrix shows many minute polarization tints. Fragments are present but form less than 10% of the breccia by volume. Some fragments are greywacke composed of fine volcanic rock grains and others are volcanic rock fragments with abundant fine opaque minerals. Crystal fragments are almost all plagioclase but one grain of what appeared to be microcline was seen.

Volcanics

The volcanics probably formed flows and flow breccias which now occur as jointed outcrops in which individual beds cannot be recognized. Two types of volcanics were differentiated on the basis of colour. The more common type is dark green and shows small spots of dark mafic minerals.

The other type is a darker green to black variety which may show a few amygdules filled with calcite. All the volcanic rocks are strongly altered and contain much chlorite and have crosscutting fractures containing calcite, epidote, and sometimes hematite. In the field the volcanics were simply classified as 'greenstone'. Microscopic examination showed the rocks to be completely and thoroughly altered. Whether the alteration is representative of the regional alteration intensity or whether it is partly due to the affects of the intrusive mass is uncertain. In some thin sections from specimens near igneous contacts higher grade alteration affects are obvious and thus the lowest grade alteration was assumed to be representative of the regional intensity.

The volcanics were probably andesitic and basaltic in composition. They now show only a relict texture with altered plagioclase laths in a matrix of chlorite and actinolite-tremolite. No trace of the original mafic constituents remains. The plagioclase laths are saussuritized and have corroded outlines. There is a size variation shown in almost all the specimens between large plagioclase laths in the order of 0.2 to 0.3 mm. and fine plagioclase microlites in intersitial positions. In the coarsest grained specimens, plagioclase phenocrysts up to 1.0 mm. long were seen. The laths commonly show no twinning or at best have poorly defined, broad twin lamellae from which a maximum anothite content of An 40 could be determined. Chlorite and tremolite-actinolite are intimately associated and enclose the plagioclase to produce an ophitic to subophitic texture. The chlorite is pleochroic green, has almost parallel extinction and is probably of the penninite type. The tremolite-actinolite is weakly pleochroic green to blue-green and may be a tremolitic hornblende in some cases. All specimens contain varying amounts of calcite and opaque minerals. Most of the opaques are magnetite and the grains were observed to form from less than one percent to as much as 10% of the rock. The grains most frequently occur as fine-grained, rounded to euhedral crystals but in one specimen, large skeletal grains were observed in which only parts of the original cube remained. Epidote forms up to 5% of some specimens but in most it is minor and forms only a few individual or aggregated grains. Some specimens contain minor amounts of clinozoisite and very fine-grained, micaceous, aggregated masses of what appear to be biotite or stilpnomelane. The individual plates are very fine grained, have strong pleochroism from yellow to brown to reddish brown, and show moderate anisotropism. Chlorite and the stilpnomelane or biotite forms the spots in the 'spotted volcanics' and represent a total replacement of the original mafic grains.

Intrusive Rocks

The intrusive body is a small stock along the east flank of a low ridge with irregular splaying dykes across the crest of the ridge. The outcrops forming the main part of the ridge are gossanous reddish-brown in colour and form steep to moderately steep slopes. The gossanous appearance is due to a thin surface stain of iron oxides and does not constitute an extensive gossanous capping. Fresh to weakly altered rock lies immediately beneath the stain.

Near the bottom of the gossanous outcrops is a broad bench-like area that forms a break in the slope profile. Below this the intrusive rocks form a grey precipitous cliff with a relief of over 300 feet. The intrusion has an irregular plan due to the anastamosing dyke pattern near the top of the intrusive mass along the ridge crest. Despite the irregular appearance and abundance of dykes, the intrusive rocks constitute a single intrusive body with a massive core from which the dykes have issued. No cross-cutting relations between igneous rocks were seen nor was there any evidence for more than one period or species of magmatic intrusion. In the field the rock was mapped as a granodiorite porphyry but zones of differentation reflecting variable cooling histories were obvious. The majority of hand specimens were coarse, grey-coloured porphyries containing tightly-packed plagioclase phenocrysts to 0.3 inches in length with intermingled smaller needles of hornblende, small plates of biotite, and in some cases sulphide minerals. Scattered in-frequently throughout are large poikilitic potash feldspar phenocrysts up to 1.6 inches in length and 0.5 inches in width. The interstitial material is extremely fine-grained and was judged to be an assemblage of quartz, feldspar, and mafic and accessory minerals. Weak foliation is developed in many hand specimens by preferred orientation of the poikilitic feldspar phenocrysts and mafic minerals. There is no apparent relation between the various parts of the intrusive body and in each outcrop or part of an outcrop the foliation seems to have a local orientation. Textural and compositional variations are most obvious in border and contact zones where the intrusion is finer-grained and lacks the large potash feldspar phenocrysts. In other zones potash feldspar is abundant as large phenocrysts and smaller grains throughout the matrix and the rock was mapped as a quartz monzonite porphyry.

Igneous contacts with bedded rocks are readily discernable. All the dykes show sharp, district boundaries with a thin chilled zone. The width of the chill zone is governed by the thickness of the dyke and the stratigraphic position or level of emplacement of the dyke in the stratigraphio column. The thin dykes and those intruding the upper units of the stratigraphic column into the volcanic rocks along the top of the ridge, have a thin chilled selvage and a border zone up to 1 inch thick in which the grain size is finer than the rest of the rock and more uniform. In the thicker dykes in the lower portion of the stratigraphic column the chilled margin was observed to be 2 inches in width and the border effect with diminished grain size and uniformly-sized grains extended to a width of 6 to 8 inches. The chill zone is a dark, glassy band which contains a few scattered phenocrysts of plagioclase and fine plates of biotite which show a foliation parallel to the contact. The contact along the main portions of the intrusive mass is not as sharply defined as in the dykes. As the intrusive contact is approached, the porphyry becomes less coarse and the phenocrysts diminish in size so that the size difference between the phenocrysts and the rest of the grains diminishes. The effect is visible over tens of feet and finally resolves in a border zone that is equigranular. Along the border zone the intrusion is composed of plagioclase and oriented needles of hornblende, fine mica and a extremely fine grained matrix. The actual contact is a zone from 2 inches to a foot wide that is sheared, brecciated and silicified. Quartz forms irregular patches, and fracture filings of coarse, crystalline, white, vein-type quartz in a granular rock with an aplitic texture that is composed of fine quartz and some feldspar and sulphide grains. To country rock adjoining the contact zone is foliated but does not appear to be silicified or otherwise strongly metasomatised.

The intrusion appears to be only weakly altered.

Only in the vicinity of diamond drill hole Number 1 does the feldspar show any suggestion of alteration and elsewhere the only obvious alteration is chloritization of the mafic minerals. The composition of the intrusive mass also appears to be relatively homogeneous. Only a few small xenoliths were seen and the largest of these was not more than one inch in diameter.

Structure

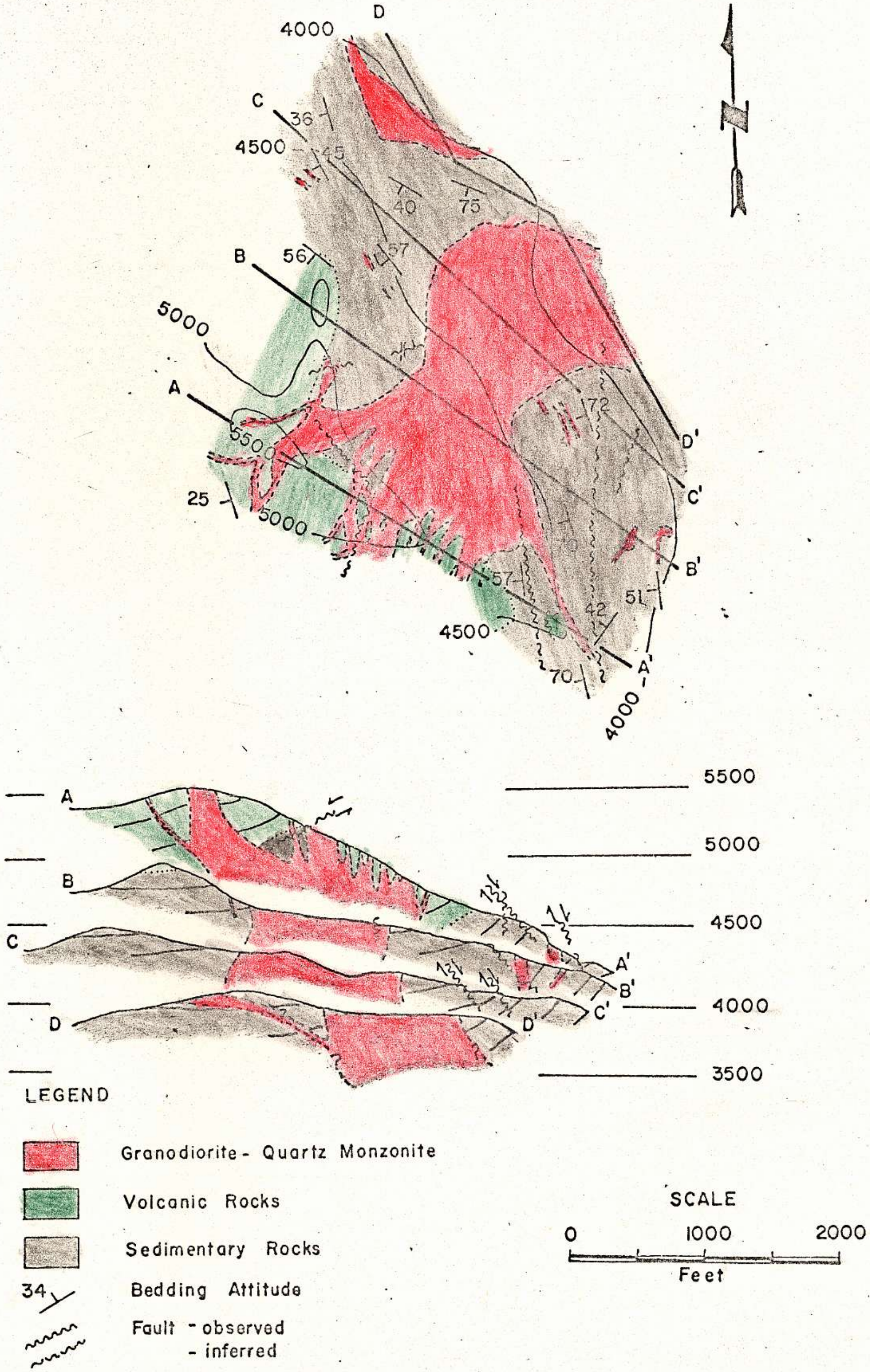
The Driftwood Property is underlain by west-dipping beds that have been intruded by an irregularly-shaped mass and numerous dykes of granodiorite-quartz monzonite porphyry. The beds strike in a northwesterly direction and have variable dips from twenty five to seventy five degrees towards the southwest. The beds lie along a ridge that forms on the western limb of a major anticline, the eastern limb of which forms the Tsaytut Spur. Dips that are steeper than the average of forty degrees are seen only in the proximity of the intrusive body.

The structure of the intrusion is highly irregular with many anastamosing dykes and may be described as a chonolith. However, the structure is easy to visualize if the effects of topography are considered and a number of cross-sections are drawn at various elevations as shown in Figure 4.

The sections cut the cupola and core of a thick,

FIGURE 4 : GEOLOGY and CROSS SECTIONS,

DRIFTWOOD PROPERTY



northwesterly trending dyke. The western and southwestern region of the map is the area of highest elevation. There the intrusion is exposed as the roof zone of the cupola. The underlying intrusive body has given rise to many steep, interfingering dykes that contain between slices of the country rock that are, in effect, roof pendants. Towards the northeast the intrusion as exposed at lower elevations and forms a single body at least 800 feet thick that has vertical or steeply northwest-dipping walls. The most northeastern outcrops of the dyke are exposed below 4000 feet elevation. At such low elevations both the north and south dyke walls are vertical or dip steeply toward the southeast. Thus, it appears that at depth the dip of the dyke changes from a steep northwest or vertical dip to a southeasterly dip.

Numerous small dykes are found along the border of the main dyke. Most can be followed for only short distances. A few, such as the dyke in the southern part of the map-area and two parallel dykes in the north-central part of the map are continuous for several hundred feet. The most prominent trend of the dykes is northeasterly roughly parallel to the trend of the main intrusion. A north to northwest trend is also common. The dykes in most cases have steep dips. In two cases, sill-like bodies have formed. One is at the extreme northern limit of mapping where a body of medium-grained, porphyritic granodiorite has a lopolithic structure.

The other is in the southeast corner of the map where a thin granodiorite body is conformable with the west-dipping beds for a distance of about 200 feet and then at the northern end swells into a wide, steeply dipping dyke with a northeasterly strike.

The intruded beds have been deformed by the intrusion. The north to northwest strike is preserved but the dips are generally steeper than the average for the region. The main mass of the intrusion appears to have forcefully intruded the beds and folded them about north to northwest-trending axes. At higher elevations in the roof zone of the cupola, the beds have been uplifted and domed. At the crest of the ridge the beds are not deformed but have been uplifted in blocks that retain their moderate westerly dips and form volcanic dip slopes along the west flank of the ridge.

A fault is believed to be marked by a prominent north-striking gulley in the southeast of the mapped area. Outcrops on both sides of the gulley are sheared and coarse breccia specimens with vuggy quartz-lined cavities and a chalcedonic matrix are found in the gulley. From the linear trend of the gulley, the fault attitude is inferred to be north with a dip about 65 degrees east. Three vertical or steeply dipping faults were observed. A north-south fault cuts the ridge near the southern limit of mapping. No sense of movement could be determined. Two other faults are in the north-central portion of the map close to the intrusive contact. Both trend easterly and in the case of at least the more western fault have the south side upthrown. Three normal faults were mapped. One lies to the east of the gulley, has a northeasterly strike and a dip towards the southeast of 65 degrees. The other two faults cut the ridge crest. The most southern of these strikes northeast and has a relatively flat dip or 32 degrees to the southeast. The trace is exposed on the cliff face and shows a downthrown thin wedge of volcanic rocks. The stratigraphic throw is in the order of two hundred feet. The northern fault is also relatively flat-lying and cuts sedimentary portions of two roof pendants.

Shearing adjacent to the main intrusive contact has formed a biotite schist or phyllonite from the hornfels in certain areas. It is best developed around the northernmost part of the main intrusion and to the east of diamond drill hole Number 3. In these localities the width of the schistose zone is about ten feet. The schistosity is gradational from a well developed biotite schist at the contact to a nonfoliated hornfels that is characteristic of the thermal aureole.

PETROLOGY OF THE STOCK

Introduction

Twenty three thin sections from outcrops representing the contact, border, core, and dyke environments were examined. Eighteen sections were selectively stained with sodium cobaltinitrate to distinguish plagioclase, orthoclase and quartz grains. The thin sections were then projected with a 35 millimeter slide projector equipped with a wide angle lens from a distance of 15 to 25 feet onto a large grid with 6 inch squares. Areas were determined and volume-percent modal compositions determined. The results are equivalent to 750 to 1150 counts using standard microscopic point counting techniques. The method was found to be good for rapid analyses of the coarser-grained rocks. The use of stained sections is essential and a projector with a long focal plane resulting in high magnification is advisable. The modes of the coarsest grained rocks were consistently reproducable by this method but the porphyritic rocks with a fine-grained matrix yielded results which varied by about 25 percent. In a number of cases where the matrix was extremely fine-grained, only the phenocrysts were counted from the projections and standard microscopic point counting had to be used to determine the matrix compositions. The modes derived from the volume-percent determinations were converted to weight-percent and the ideal chemical composition of the rock was calculated in terms of oxides using a fortran programme according to the method of Dietrich and Sheehan, (1964).

Textures

Textures in all the rocks are porphyritic. The phenocrysts are of various sizes but do not develop a seriate texture. Rather, there are a number of size groups such as the large, poikilitic orthoclases, somewhat smaller plagioclase phenocrysts, and the much smaller needles of hornblende and plates of biotite. The matrix in all cases is a relatively uniformly-sized granular to extremely-fine granular mosaic of quartz, orthoclase, plagioclase, accessory minerals, alteration minerals, and sulphides. Differences in fabric and texture within the stock enable four environments to be distinguished: border zone, dyke, core zone, and contact zone. These have three corresponding textural types.

The main textural type is a poikilitic porphyry. It forms the cores of the larger dykes and the core zone of the main intrusive body and represents almost ninety-eight percent of the volume of the intrusive mass. The rock may be described more fully as a 'crowded porphyry' with an interstitial, granular texture. The term 'crowded porphyry' is used because from 45 to 85 percent of the rock is composed of phenocrysts. The crowded appearance and large, poikilitic orthoclase phenocrysts are the diagnostic characteristics.

The border zone comprises about two percent of the total volume of the intrusion and forms the chilled margins of the stock and dykes. Two varieties of porphyry are developed in the border zone. The more striking is a glassy, chilled margin that is developed along some of the dyke walls. It varies in thickness from a thin selvage to about two inches wide and is a porphyry in which plagioclase and a few mafic phenocrysts are contained in a dark, glassy matrix. The other variety is by far the more abundant and widespread. It is a porphyry in which there is only slight difference in size between the phenocrysts and matrix. It grades from an almost equigranular fine-grained rock at the intrusive contact to a well developed porphyry over a distance of six to eight inches in the smaller dykes and up to twenty feet in the main intrusion.

The least common textural type represents a fraction of a percent of the total volume of the intrusion. It is a leucocratic rock with an aplitic appearance that is found in a small restricted zone near the southern contact of the stock called the contact zone. The rock has a relatively small proportion of plagioclase phenocrysts set in an aplitic groundmass. It appears to grade into a regular poikilitic porphyry to the north and no trace of it could be seen on the cliff face some two hundred feet to the west. A somewhat similar aplitic rock can be found along parts of the eastern intrusive contact wall adjacent to the intruded sedimentary rocks. In these locations a contact zone a few inches thick can be seen between the hornfels and border zone.

The rock has an aplitic matrix that contains abundant, irregular white quartz segregations.

Mineral Composition of the Intrusion

Feldspars are the most abundant minerals in the stock and form the largest grains. The large plagioclase phenocrysts are strongly twinned and zoned in an oscillatory-normal manner. Individual growth zones are of differing thicknesses but are usually thin so that a large number of zones or groups of zones are observed in each crystal. The maximum anorthite content is found in the cores of the crystals and ranges from An 44 to An 39 with An 40 most common. From the centre outward complex oscillatory-normal zoning is observed and there is a decrease to a minimum anorthite content of An 28. The most frequently observed anorthite content in the outermost zones is from An 30 to An 32. Small plagioclase laths and microlites form up to 25 percent of the matrix. Twinning is difficult to distinguish but where it could be resolved and the anorthite content measured, it was found to vary from An 27 to An 32. Thus, it appears that the anorthite content of the plagioclase in the matrix is the same or slightly less than the outermost zones of the large plagioclase phenocrysts. The plagioclase varies from basic to acidic andesine and the average anorthite content is about An 34.

Potash feldspar is orthoclase and forms large, poikilitic phenocrysts and fine-grained anhedral granules in the matrix. The grains in the matrix are intergrown with quartz and plagioclase. The phenocrysts are euhedral and usually show carlsbad twinning. Abundant inclusions are small, oriented crystals and grains of hornblende, plagioclase, and occasionally biotite and quartz. In a number of instances an unusual mantling effect or corona of orthoclase around a large grain of plagioclase are observed. The result is a combined phenocryst which contains a large grain of plagioclase rimmed by orthoclase. The plagioclase core shows weakly developed twinning and zoning and has a ragged, strongly corroded or resorbed outline.

Quartz is found in specimens of the intrusive rock as very small interstitial grains in the matrix along with potash feldspar and sometimes plagioclase. The quartz grains are intergrown with each other and with the feldspars in an anhedral interlocking mosaic.

The mafic minerals are hornblende and biotite. Hornblende is the more abundant of the two. It forms prismatic crystals and is green in colour with yellow-green to dark green pleochroism. Two varieties of biotite are found. One type forms large, scattered plates and thin hexagonal "books" and appears to be a relatively early mafic constituent in the porphyry. The other type forms fine, shredded-looking intergrowths in the quartz-feldspar matrix and can be regarded as a younger or 'secondary' biotite. This fine grained, or secondary, biotite appears to be commonly associated with the sulphides and was observed in some cases to weakly replace or at least rim the hornblende. Both the coarse biotite and hornblende are at least partly replaced by chlorite.

Accessory minerals are contained in the matrix of the rock and also sometimes in the outer zones of poikilitic feldspar phenocrysts. They consist of magnetite, sulphides, sphene, and apatite. Magnetite is the most abundant and forms small, equant crystals that are distributed throughout all parts of the matrix. Apatite occurs as small prismatic crystals that are randomly scattered. Sphene shows a size variation from fine grained to relatively large grains and is very irregularly distributed. Most sphene grains have the characteristic rhombic cross sections and some show twinning.

Minerals formed as alteration products are chlorite, calcite, epidote, sericite, clay minerals (montmorillonite?), and hydrous iron oxides. The feldspars are not strongly altered but differences in alteration intensity can be seen in them throughout the various parts of the intrusion. Most frequently the feldspars have a clouded or corroded appearance, especially in zones near the edges of zoned plagioclases. Saussuritization has resulted in the breakdown and reconstitution of the feldspars into very fine-grained intergrowths of zoisite or epidote, albite, sericite, calcite, and other constituents. In the more altered zones sericite can be recognized along cleavage planes and fractures. In the most highly altered zones associated with mineralization, alteration has produced sericite, clay minerals and calcite. The clay and sericite form crystallites that are pervasive throughout the feldspars but are more strongly developed along grain boundaries. Because of the extremely small grain size and erratic distribution of clay concentrations, microscopic examination cannot confirm the type of clay minerals present. It is most likely that the clay is a mixture of montmorillonite and hydromica.

Chlorite has formed as an alteration product of hornblende and biotite. It is developed in scaly masses and fine-grained aggregates. The species is probably prochlorite and possibly penninite. Calcite is found as interstitial grains in the mineralized parts of the intrusion especially in zones where there is clay, sericite, or strong saussuritic alteration. Epidote is a rare constituent that occurs as small grains throughout all parts of the intrusion. Hydrous iron oxides form minor encrustations along fractures. The substance appears to be a late alteration product formed by oxidation and percolation of groundwaters.

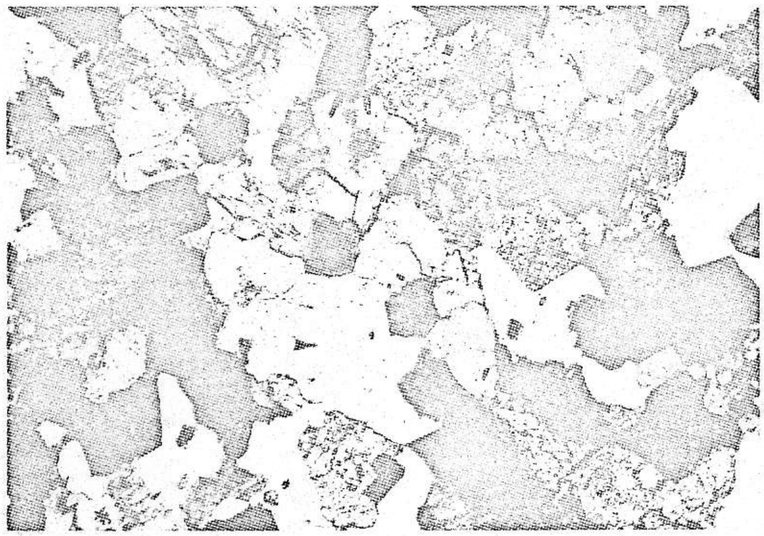


Plate 1: Quartz-feldspar mosaic with relatively uniform grain size in alaskite. Crossed nicols. Magnification X 58.

Plate 2: Coarse grained granodiorite ('crowded porphyry'). Plagioclase, orthoclase, and biotite phenocrysts with intergranular quartz-feldspar. Crossed nicols. Magnification X 58.

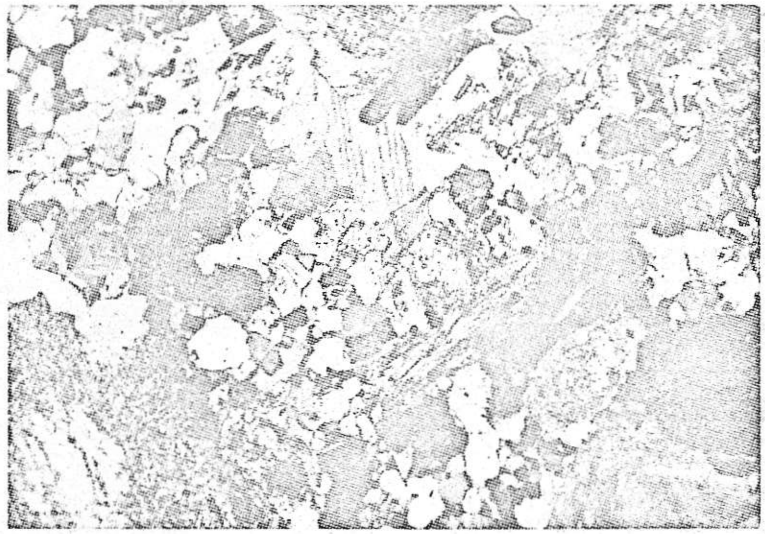


Plate 3: Matrix in quartz monzonite porphyry showing interlocking quartz-feldspar, shredded biotite, calcite, and minor sphene. Crossed nicols. Magnification X 58.

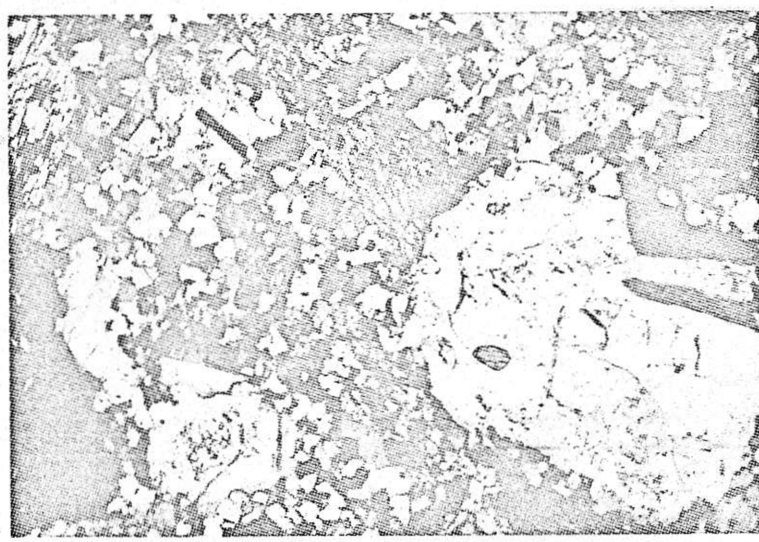


Plate 4: Granodiorite with fine-grained quartz-feldspar matrix, hornblende, and anhedral phenocrysts of orthoclase. Crossed nicols. Magnification X 58.

Plate 5: Phenocrysts of plagioclase and hornblende in a fine-grained matrix. Crossed nicols. Magnification X 58.

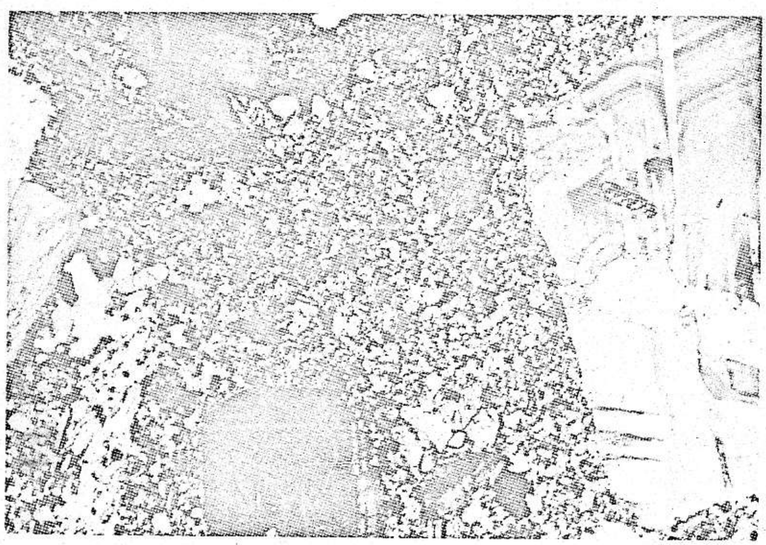


Plate 6: Zoned phenocrysts of plagioclase and grains of hornblende in fine grained matrix of quartz-feldspars, biotite, and minor apatite. Crossed nicols. Magnification X 58.

Plate 7: Zoned and twinned phenocryst of plagioclase. Crossed nicols. Magnification X 58.

Plate 8: Portion of composite plagioclase-orthoclase phenocryst. Plagioclase in core shows zoning, twinning, a partly corroded outline with poilili-tic border and is mantled by poikili-tic rim of orthoclase. Crossed nicols. Magnification X 58.

Classification of Rock Type

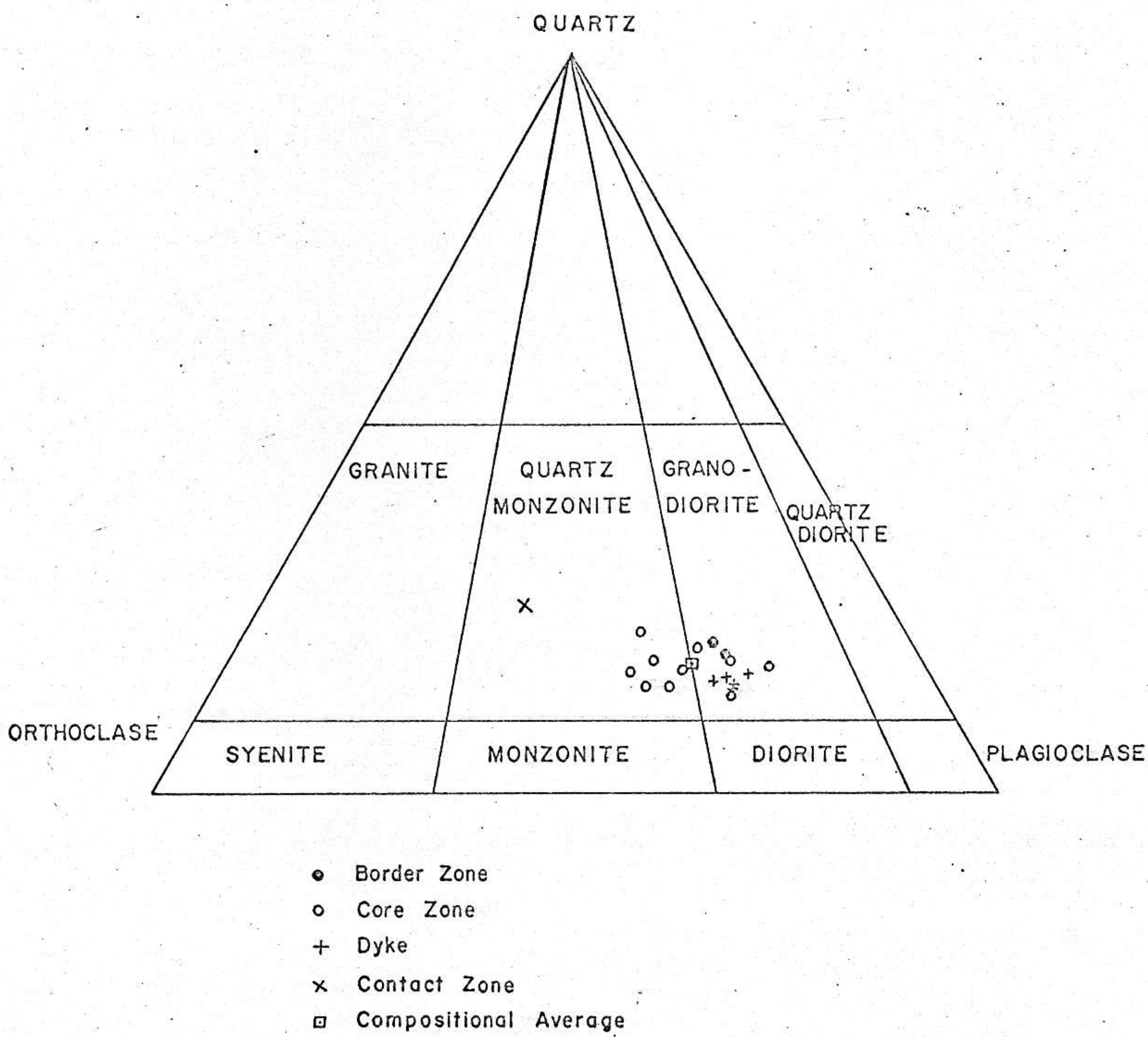
The stock seems to have been intruded as a single mass of magma. No internal crosscutting relations, internal contacts, nor breccia zones were observed. The modal average and mineralogical variation for the eighteen thin sections examined is given in Table 11. The modal average is probably a close approximation of the bulk composition of the stock.

Table 11: Weight-Percent Compositional Average and Compositional Range for 18 Specimens.

	Average (%)	Standard Deviation	Compositional Range (%)
potash feldspar	23.0	5.7	14.3 - 39.8
plagioclase	47.0	6.8	29.4 - 54.5
quartz	14.8	2.9	11.9 - 23.5
hornblende	12.0	5.6	1.2 - 22.5
biotite	1.9	1.9	0 - 7.0
chlorite	0.8		0 - 3.5

The ternary diagram (Figure 5) based on the essential minerals quartz-orthoclase-plagioclase represents at least seventy-eight percent by weight of the rock. The remainder is composed of mainly mafic minerals and these are relatively consistent in abundance throughout the intrusion. Using the nomenclature of Peterson (1960) for granitic rocks, it can be seen from Figure 5 that the composition of the Driftwood stock varies from granodiorite to quartz monzonite and the average composition of the eighteen specimens lies directly on the granodiorite-quartz monzonite boundary line.

Figure 5: Classification of the Driftwood intrusion based on modal Quartz-Orthoclase-Plagioclase. 18 specimens used. (After Peterson, 1960)



The average colour index for both the granodiorite and quartz monzonite is identical at 15.6. The solitary specimen in the quartz monzonite field nearest the granite boundary has a colour index of 7.6 and is therefore, more correctly classed a leucocratic quartz monzonite or alaskite.

Variations Within the Stock

Variation in the stock is evident in textural, mineralogic, and chemical differences. The mineralogical and modal data suggest that three rock types with three corresponding textural types can be recognized in the intrusive mass. The porphyry with fine grained matrix found along some of the dyke walls and the porphyritic rock of the border zone as well as the porphyry forming the dykes is, in all cases examined, granodiorite. The poikilitic porphyry in the core of the intrusive mass and the largest dykes is granodiorite or quartz monzonite. The aplitic, leucocratic, most highly differentiated rock in what is termed the contact zone, is alaskite.

Chemical variation within the intrusion was deduced from modal compositions. A Fortran programme was used to calculate the chemical compositions of the specimens from the volume-percent modal analysis using ideal chemical compositions for the minerals. Representations of the results are shown in a Larsen variation diagram (Larsen, 1938) and a ternary CaO-Na_2O-K_2O plot of Nockolds and Allen (1953). The Larsen variation diagram (Figure 6) shows the amounts of individual oxides and the sum of FeO plus Fe_2O_3 plus MgO relative to a base of $1/3\ SiO_2 + K_2O - (MgO + FeO + CaO)$. This representation was used rather than the more common representations using SiO_2 or some other oxide as a base value because it provides a much larger range along the absissca.

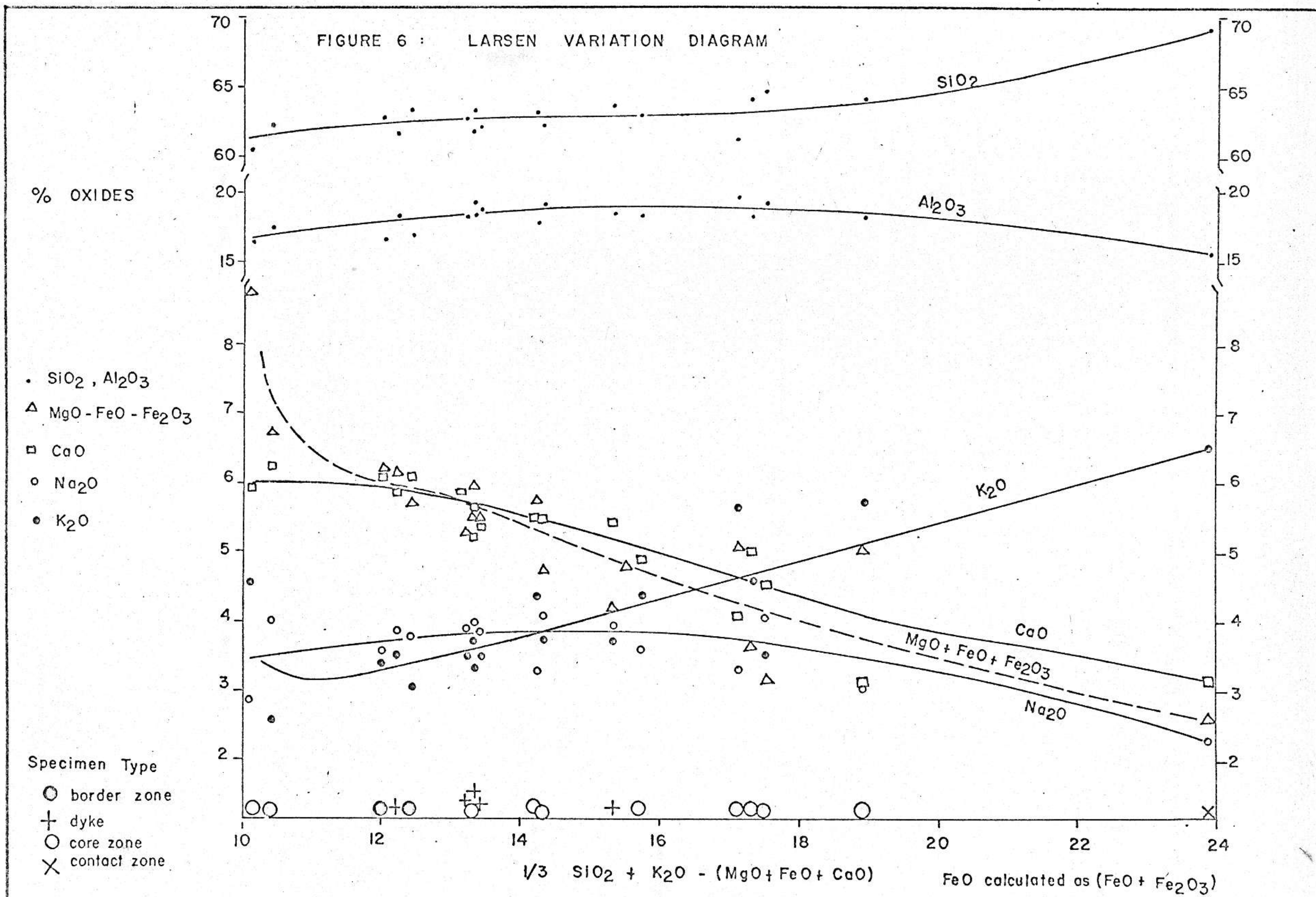
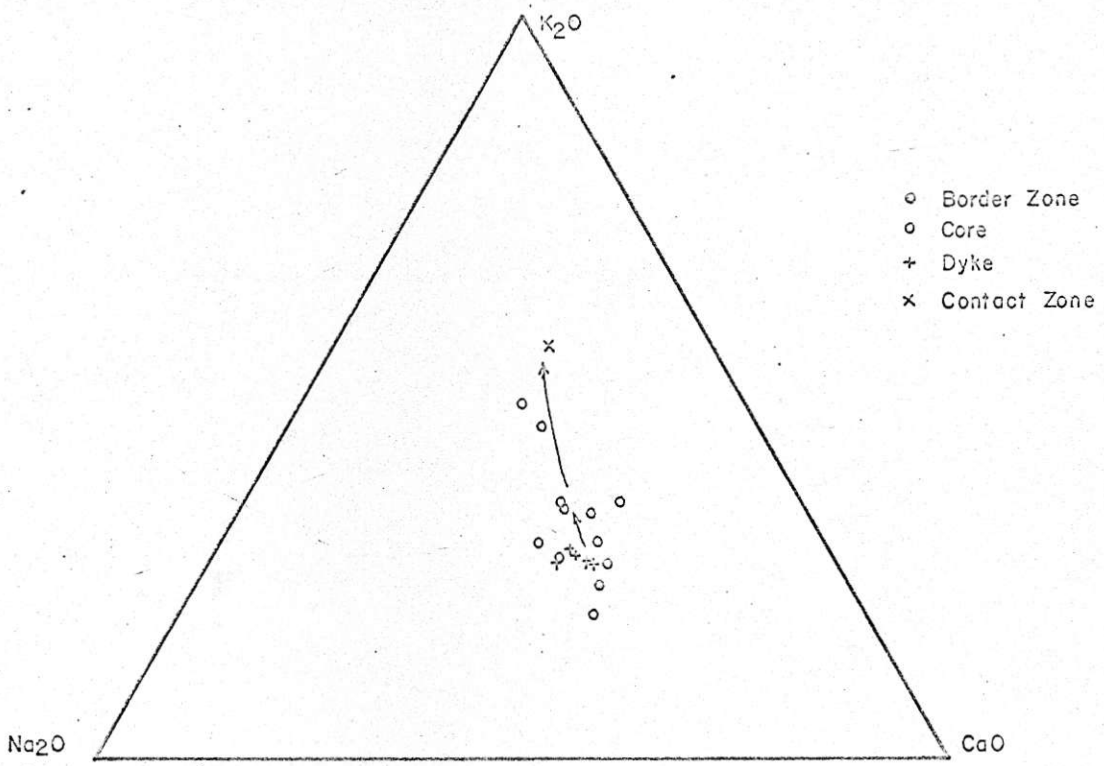


FIGURE 6 : LARSEN VARIATION DIAGRAM
% OXIDES
70
65
60
20
15
8
7
6
5
4
3
2
SiO_2
Al_2O_3
K_2O
CaO
$MgO + FeO + Fe_2O_3$
Na_2O
$\cdot$ SiO_2 , Al_2O_3
$\triangle$ $MgO - FeO - Fe_2O_3$
$\square$ CaO
$\circ$ Na_2O
$\bullet$ K_2O
Specimen Type
border zone
dyke
core zone
contact zone
10
12
14
16
18
20
22
24
$1/3$ SiO_2 + K_2O - ($MgO + FeO + CaO$)
FeO calculated as ($FeO + Fe_2O_3$)

The variation diagrams show the transition from granodiorite to quartz monzonite and alaskite. SiO_2 and K_2O show similar behaviour by increasing in the quartz monzonite and alaskite. K_2O has by far the greater relative variation. SiO_2 in 15 out of 18 samples ranges from 62 to 66 percent and the maximum variation is only about 13%. The maximum variation for the K_2O is almost 250 percent between the alaskite and the least potash-rich granodiorite. The CaO and sum of MgO and iron oxides behave in a similar manner and have an overall decrease towards the quartz monzonite-alaskite field. The CaO has a relative variation up to 100 percent and the mafic oxides up to 360 percent. However, there is a greater scatter of points along the curve for the total mafic oxides than for any other oxide. Al_2O_3 and Na_2O are similar and both remain at relatively constant amounts and show very little variation.

The Nockolds and Allen ternary representation, Figure 7, shows the differentiation trend from a parent granodiorite magma to quartz monzonite and alaskite. The K_2O is seen to increase relative to CaO while the Na_2O remains relatively constant.

Figure 7: Differentiation trend of a granodiorite magma using the system Na_2O-K_2O-CaO after Nockolds and Allen, 1953.



Intrusive History

The stock is believed to be a high-level intrusion of probable Tertiary age. A single magma has been intruded as an irregular stock and related dykes. Differences in cooling rate have resulted in textural variation throughout the stock. Dykes and the border zone have chilled margins and locally weak foliation parallel to the contact. This suggests intrusion into relatively cold country rocks. Cooling was rapid and conditions of nonequilibrium crystallization are shown by the porphyritic texture, aplitic or fine grained quartz-orthoclase-plagioclase matrix, strongly zoned plagioclase, poikilitic orthoclase phenocrysts, and mantles of orthoclase about plagioclase.

Emplacement of the intrusion may have been by forceful injection. The stock has a discordant relationship with the intruded rocks. All contacts are sharp and there is no evidence of any significant assimilation. The roof zone appears to be domed and bodily uplifted. The shell of schist about some parts of the intrusion may have been formed by the intrusion of a viscous magma. The outward pressure and possibly the drag of a viscous magma resulted in plastic flowage of the country rock next to the igneous contact (Buddington, 1959).

ROCK ALTERATION AND METAMORPHISM

Introduction

Metamorphic affects are evident in parts of the intrusive body and in a zone surrounding it. Within the intrusion, automorphism is believed to have caused the changes. Outside the stock contact metamorphism has caused an aureole of hornfels to develop. Dynamic metamorphism probably due to the intrusion of the magma has formed a thin layer of schist next to parts of the intrusive wall-rock. The schist grades outward through a transition zone of phyllite into the hornfels. The overall intensity of alteration is low to lower-middle grade.

Alteration of Granodiorite-Quartz Monzonite

Alteration of the intrusion is regarded to be automorphic mainly because the alteration intensity differs throughout the various parts of the stock. Also, no younger igneous rocks are apparent in the vicinity. The main mass of the stock is virtually unaltered or contains only minor chlorite. The most significant alteration observed is in a relatively small zone along the north-central part of the stock in the vicinity of drill hole Number 1. Most of the sulphide-bearing fractures and quartz veins have thin alteration envelopes. In all cases observed, the strongest alteration is coincident with zones of sulphide mineralization. The alteration is therefore, probably genetically associated with hydrothermal processes that resulted in sulphide deposition.

The type of alteration can be classed as propylitic, although the term is not rigidly defined and is used with different implications by a number of authors. According to Meyer and Hemley (1967), the propylitic assemblage includes epidote (zoisite, clinozoisite), albite, chlorite, carbonate, commonly with sericite, pyrite, or iron exides and less commonly with zeolites or montmorillonites. Creasey (1966) lists a similar assemblage but also includes talc and kaolinite as possible members. Sphene or leucoxene (rutile), and apatite accompany the alteration and quartz and muscovite are almost always present.

In the sections examined chlorite, calcite, epidote, sericite, and saussuritized feldspars were identified and the presence of montmorillonite is suspected. Both sphene and apatite are present throughout the sections along with magnetite and iron sulphides. The fine grained or secondary biotite commonly found in sulphide rich portions of the stock may possibly be part of the alteration assemblage. However, almost all parts of the stock contain some fine grained biotite as component of the matrix. It, thus, appears that the biotite is a late mafic mineral that formed with quartz and feldspar in a fine grained intergrowth during the last stages of magmatic crystallization. The magma remaining at such a late stage of crystallization may well have been enriched sufficiently in volatiles in some parts of the stock to effect hydrothermal alteration and sulphide deposition following the formation of biotite. The observed alteration assemblage is compatible with ACF-AKF diagrams of the propylitic alteration type, as used by Meyer and Hemley and Creasey. The alteration species observed would be classed as the chlorite-epidote-calcite variety using Creasey's nomenclature.

From Meyer and Hemley's ACF-AKF diagrams, the mineral constituents and relations observed in the specimens studied can be shown to be compatible with the propylitic alteration type. The granodiorite-quartz monzonite contains feldspar phenocrysts and coarse-grained hornblende and biotite in a matrix of fine-grained quartz, feldspars, and shredded-looking biotite that was termed 'secondary' biotite. Of these minerals, potash feldspar and quartz are unaltered, the plagioclase is saussuritized, and perhaps even weakly altered to clay minerals while amongst the mafics, hornblende is the most severely chloritized. The coarse biotite is only weakly chloritized and the secondary biotite is virtually unaltered. According to Meyer and Hemley, potash feldspar and biotite can remain as stable phases in the propylitic assemblage while plagioclase and hornblende are unstable in the presence of chlorite, sericite and clay minerals.

The only observed occurrences where the mafics including the secondary biotite were unstable are in a few specimens that contain silicified fractures or quartz veins with sulphide mineralization. One such fracture containing pyrite, pyrrhotite, and chalcopyrite had quartz-potash feldspar replacement and was bounded on both walls by a $\frac{1}{2}$ inch wide, bleached alteration envelope. Nearest the fracture all the mafics were destroyed and the rock was a mass of very fine-grained sericite, clouded plagioclase and possibly clay. Because of the extremely fine-grained alteration products the exact composition could not be determined. The stability of the potash feldspar and instability of plagioclase and biotite allows the possibility that the alteration envelopes represent incipient or weakly developed argillic alteration.

Contact Metamorphism

Contact metamorphism has resulted in the formation of a hornfels zone that envelopes the intrusive body. A number of species of hornfels have developed with a variety of compositions and textures. This variation reflects the compositional differences of the parent rocks from which the hornfelses were derived and also indicates a decreasing thermal gradient away from the intrusive contacts.

Small zones of tactite have formed from calcareous beds next to both the north and south intrusive contacts. The rock formed is a calc-silicate hornfels that contains small amounts of sulphides and iron oxides. The actual contact relations could not be observed in situ due to the precipitous nature of the region. However, a number of hand specimens were collected at increasing distances from the contact. Two similar specimens were taken about 70 feet from the contact. Both are only partly recrystallized and retain a relict thin bedding or lamination. Recrystallized bands lie parallel to the lamination and also crosscut the beds. About 65 percent of the rock is a fine-grained hornfels which acts as a matrix for the granoblastic bands. The matrix is composed of small grains of quartz, plagioclase, calcite, biotite, chlorite, silt or clay-sized particles, and relict clastic grains. The recrystallized bands have granoblastic texture and are composed of mainly andradite garnet, hornblende, diopside, calcite, quartz, and lesser plagioclase, epidote, and opaque minerals. Chlorite is a minor alteration product of hornblende in one specimen. A third sample taken from very near the contact is totally granoblastic to porphyroblastic in texture and is probably representative of the most intense thermal and metasomatic alteration affects. It is composed entirely of orthoclase, andradite, quartz, diopside, calcite, and a few opaque grains.

The grade of contact metamorphism is in the transition zone from albite-epidote hornfels to hornblende hornfels facies for the two partially recrystallized specimens. Winkler (1965) states that the appearance of diopside, hornblende, and grossularite-andradite and the disappearance of tremolite, chlorite, and epidote mark the beginning of the hornblende-hornfels facies. The two specimens contain the prescribed minerals and lack tremolite but they both also contain epidote and one contains some chlorite. Thus, unless the epidote and chlorite are retrogressive alteration minerals, the two samples represent an unstable assemblage approaching conditions of the hornblende hornfels facies. The granoblastic specimen from near the contact is a well-developed specimen in the hornblende hornfels facies. The abundance of orthoclase and the presence of diopside without hornblende suggest that the rock may have approached the upper limits of the facies but has not reached conditions of the pyroxene hornfels facies because wollastonite has not formed and calcite persists in the mineral assemblage.

Volcanic rocks have an intensity of alteration of the greenschist facies. Thus, contact metamorphism of the albite-epidote hornfels facies that resulted from the intrusion is indistinguishable from the regional affects. The only places where alteration or metamorphism can be definitely ascribed to the intrusion are at the bases of small roof pendants and in narrow zones along the intrusive contacts. A specimen from very near the contact contained altered, relict plagioclase laths in a recrystallized matrix of plagioclase, quartz, biotite, and hornblende. A recrystallized rock with a granoblastic texture collected from the base of a roof pendant was composed of coarse-grained hornblende, biotite, and garnet with finer intergrown quartz, plagioclase and minor diopside. These were the most intensely altered volcanic rocks observed and indicate that metamorphism has produced a mafic hornfels of the hornblende hornfels facies but that metamorphic affects of this grade are very limited in extent and restricted in environment.

Metamorphism of the intruded non-calcareous sedimentary rocks is shown by the formation of a biotite hornfels and a thin zone of schist next to the contact. The schist presumably formed as a result of plastic flowage of the rocks due to the drag of the intruding, viscous magma. It grades outward into a phyllite and finally a hornfels over a distance of about 10 to 15 feet. The biotite hornfels is developed for a distance of at least one hundred feet along the northern contact and over a greater width in the southeast corner of the map-area. This relation plus the abundance of dykes along the south contact is in keeping with the suggestion that the area is underlain by the intrusion which has a relatively flat dip towards the southeast.

The enveloping schist and hornfels have similar compositions and vary only in fabric. The schist is a foliated, granular intergrowth of quartz, feldspar, biotite, minor muscovite, and opaques. The grains are approximately uniform in size, and the quartz grains show considerable strain. The hornfels maintains a relict clastic texture in which porphyritic volcanic fragments, sedimentary rock fragments, chert, and crystalline quartz can be recognized. The matrix consists largely of fine-grained brown biotite but may contain minor chlorite, epidote, tremolite, and calcite.

Clastic quartz grains appear to be unaffected and show no strain affects, but most chert fragments display finely granular recrystallized rims. The intensity of alteration is, thus, low grade. The schist can be relegated to the quartz-albite-epidote-biotite subfacies of the greenschist facies of regional metamorphism and is equivalent to a biotite hornfels of the albite-epidote facies of contact metamorphism that represents the alteration intensity of most of the contact zone.

Sedimentary rocks outside the zone of biotite hornfels maintain their clastic fabrics and show very little evidence of recrystallization. Metamorphic minerals are minor chlorite, epidote, sericite, and calcite.

ECONOMIC GEOLOGY

Introduction

Mineralization at the Driftwood Property is similar to that in both 'porphyry copper' and quartz-molybdenite stockwork deposits. Sulphides occur within the intrusive rock and its contact aureole as disseminations, fracture fillings, and in quartz veins. At least 11 sulphide minerals have been deposited.

'Disseminated' Mineralization

Pyrrhotite and pyrite are by far the most abundant and widespread sulphides. Along with small amounts of chalcopyrite and molybdenite they are disseminated in the manner of accessory minerals in the groundmass of the porphyry or occur as small grains along fractures. In the adjoining hornfels, pyrrhotite and a little chalcopyrite, pyrite, and molybdenite form in fractures, small replacement zones and as disseminations.

Sulphides are found in small amounts through the entire stock and in many of the dykes. There is some concentration in the north-central portion of the intrusive body near the main contact in the most highly altered zones. In the hornfels, pyrrhotite is by far the most abundant sulphide. Sulphide concentration is observed in the sheared rock next to the contact and in the southeast part of the map-area in the extensive hornfels zone with the many dykes.

The sulphides appear to replace the rocks along bedding planes and where they are sheared or fractured. In a number of beds, clastic fragments could be discerned in a recrystallized and mineralized matrix. A number of sections of core showed sulphide in bands or veins up to one inch in thickness but most commonly the sulphides form as irregular, scattered grains.

Other minerals that are disseminated or dispersed throughout the stock and hornfels are magnetite and marcasite. Magnetite forms as accessory grains in the groundmass of the porphyry and as small grains in fractures, veins, and replaced beds in the hornfels. Marcasite is associated with pyrrhotite and pyrite in a sulphide-rich bed of coarse, hornfelsic greywacke in the southeastern hornfels zone.

Quartz Veining and Stockwork

Quartz veins and stringers containing molybdenite and other sulphides are found in both the intrusive rocks and hornfels. The main interest was in the hornfels zone where the intensity of veining was much greater than in the main body of the stock. Veins greater than one inch in thickness were not seen. Most are from 1/8 to 1/4 inch wide and nowhere are they numerous or well developed. Detailed examination showed the veins to have crosscutting relationships with a complex paragenesis based on sequential fracturing and sulphide deposition. Minerals found in the veins in order of decreasing abundance are: pyrite, chalcopyrite, pyrrhotite, sphalerite, molybdenite, arsenopyrite, galena, tetrahedrite, bournonite ($PbCuSbS_3$), aikinite ($PbCuBiS_3$), and marcasite.

Other Mineralization

The garnet-bearing skarn developed at the contact of the intrusive body and the calcareous beds contain pods and thin veins of magnetite. In a number of magnetite-bearing samples some pyrite and chalcopyrite grains are intergrown with magnetite.

A number of breccia fragments from the assumed fault zone in the prominent gulley in the southeast corner of the map-area were mineralized. The breccia is composed of fragments of porphyry and sedimentary or hornfelsic rock up to 2 inches across in a matrix of chalcedonic and vuggy quartz, in which were found small crystals of pyrite and irregular grains of bournonite. The bournonite was identified by its optical properties and X-ray powder pattern.

Weathering of the deposit has been superficial and very few alteration products have formed from the sulphide minerals. A thin goethitic coating covers most of the outcrops. Malachite and ferrimolybdite were seen in only one location. The magnetite in the skarn shows weak veining by maghemite (γFe_2O_3).

Textural Relations

Most of the metallic minerals in the deposit are epigenetic. The only minerals that may be syngenetic are fine-grained pyrite and magnetite which are disseminated in the sedimentary beds. Pyrrhotite, pyrite, chalcopyrite, and molybdenite occur interstitially in the porphyry matrix as individual grains or clusters, in the manner of accessory minerals. Indeed, some of the sulphides that form as interstitial granules in the silicate matrix are linked to each other by intergranular selvages that create a net or mesh texture. These grains, perhaps, represent small, re-equilibriated sulphide segregations in the silicate melt that solidified early in the crystallization history without much competition for space with the crystallizing silicates.

Replacement of hornblende, biotite, and magnetite by sulphides is apparent although it is generally only weakly developed. Replacement is seen along grain boundaries and cleavage planes where pyrrhotite, pyrite, and chalcopyrite replace the mafic silicates and magnetite. Hornblende is the most commonly and thoroughly replaced mineral. Biotite is only rarely replaced and when it does show replacement it is usually in the large 'books' of biotite rather than in the fine-grained, shredded biotite of the matrix.

The strongest sulphide replacement takes place in the most altered rocks where chlorite, calcite, sericite, and possibly clay minerals have formed. The grains of hornblende that had the most replacement by sulphides were also the most strongly altered to chlorite. It is, however, difficult to ascertain whether the sulphides preferentially replaced the rock because it was the most altered, or whether sulphide replacement and rock alteration are related processes and are interdependent.

From the sulphide-silicate relations it appears that most mafic grains crystallized before the sulphides and were partly replaced by them. On the other hand, the plagioclase and poikilitic orthoclase phenocrysts as well as the quartz-feldspar groundmass probably formed simultaneously or, perhaps, in part later, than some of the sulphides to form sulphide-silicate intergrowths with mesh textures. The disseminated sulphides are, therefore, classed as epigenetic and in part possibly paramagmatic (White et al, 1968) rather than accessory because they appear to be in part contemporaneous with, and in part younger than the various silicate minerals.

In the hornfels very little replacement of the clastic constituents can be seen. Most commonly it appears that the sulphides and recrystallized constituents of the hornfels (mainly biotite, quartz, and feldspar) all coexist in equilibrium.

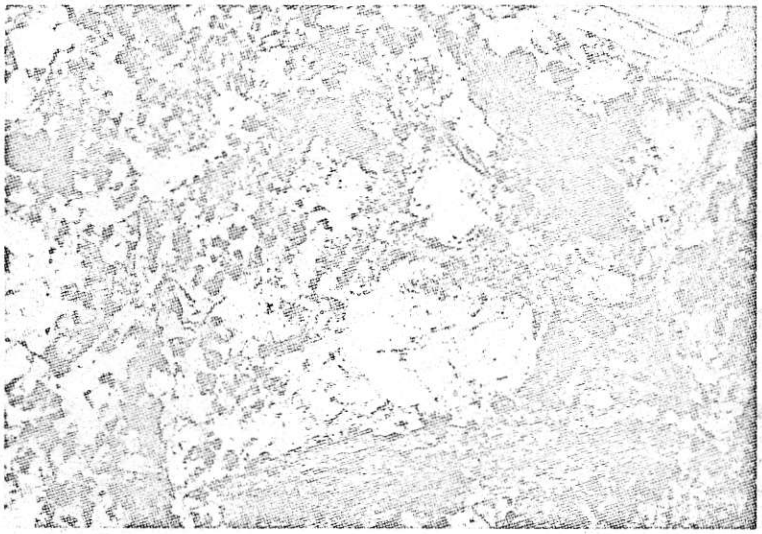


Plate 9 : Disseminated magnetite and a few sulphide grains with an accessory or interstitial distribution. Note association of opaque grains and mafic minerals. Plain light. Magnification X 58.

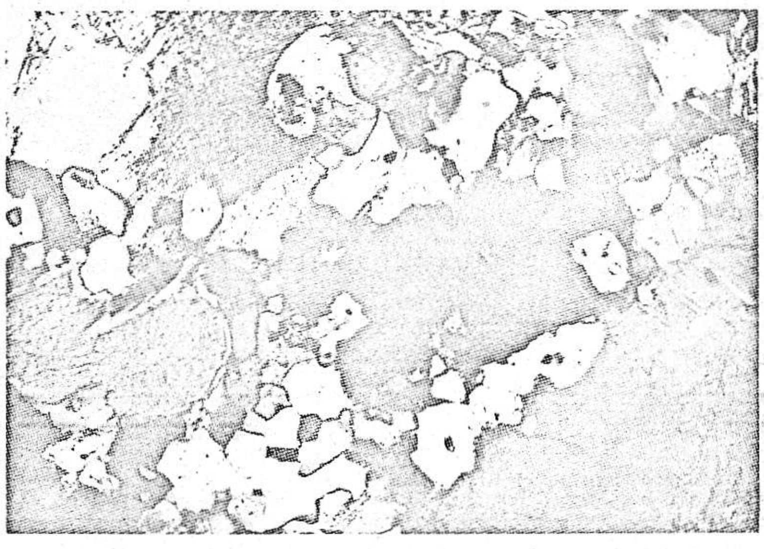


Plate 10 : Subhedral accessory grains of magnetite in quartz-feldspar matrix. Crossed nicols. Magnification X 150.

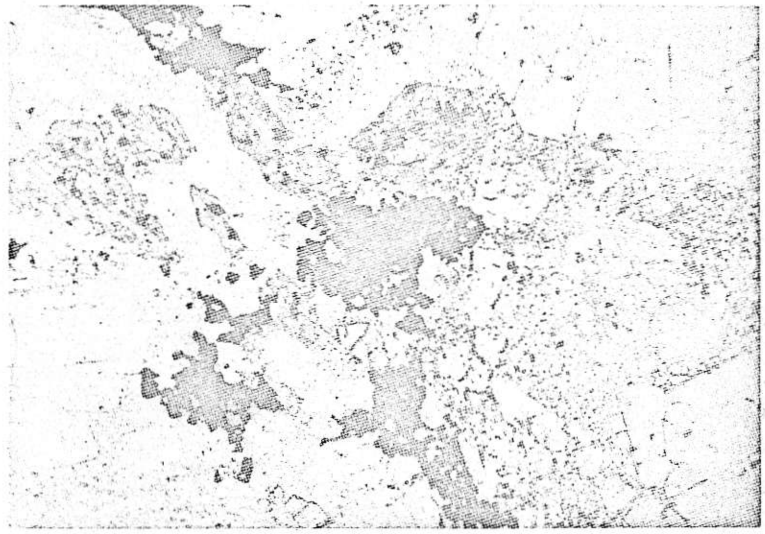


Plate 11 : Fine grained accessory magnetite and intergranular, replacement sulphides. Plain light. Magnification X 58.

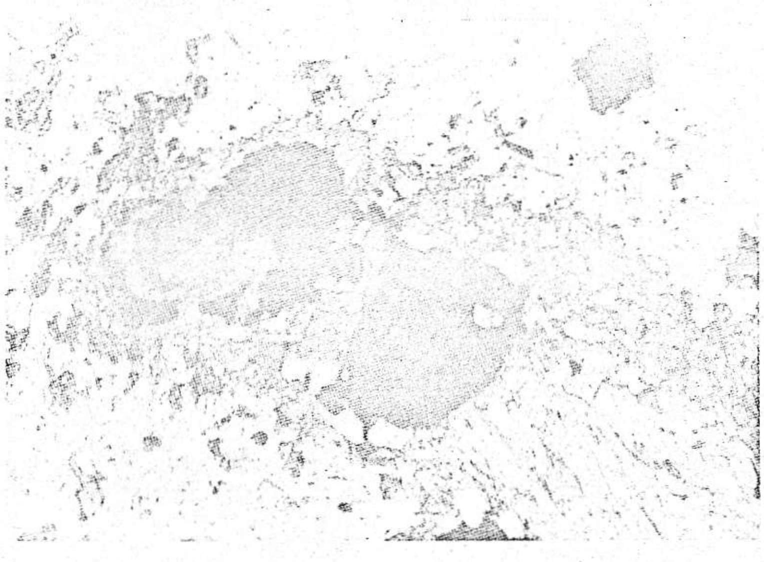
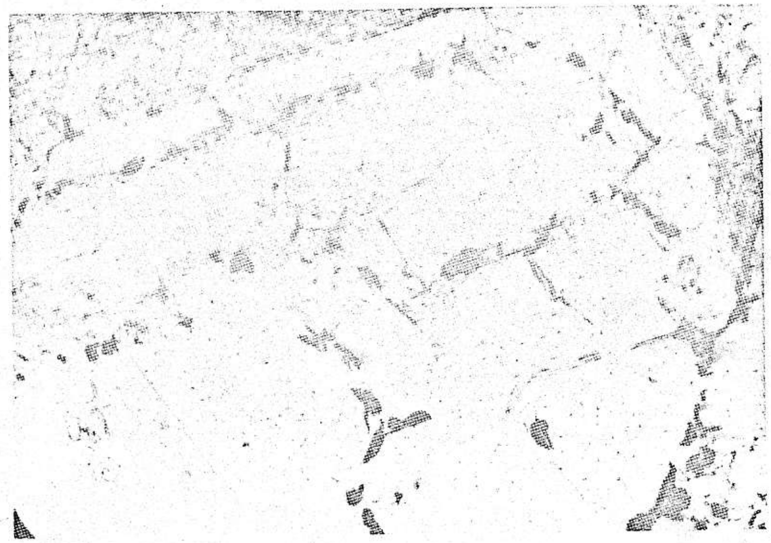
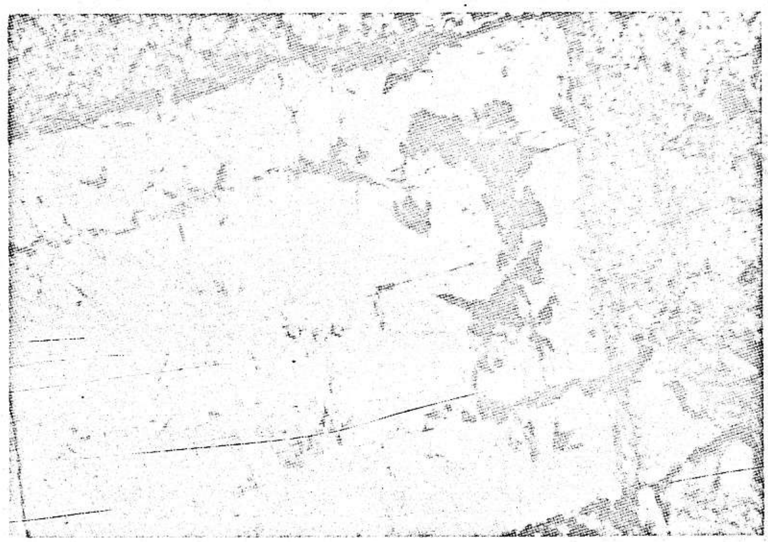


Plate 12 : Association of sulphide grains with fine grained, shredded (secondary) biotite and corroded hornblende and coarse grained biotite. Plain light. Magnification X 150.





Plates 13 and 14 : Poikilitic plagioclase phenocrysts with opaque grains concentrated in zones indicating early metallic mineralization during silicate crystallization. Plain light. Magnification X 150.

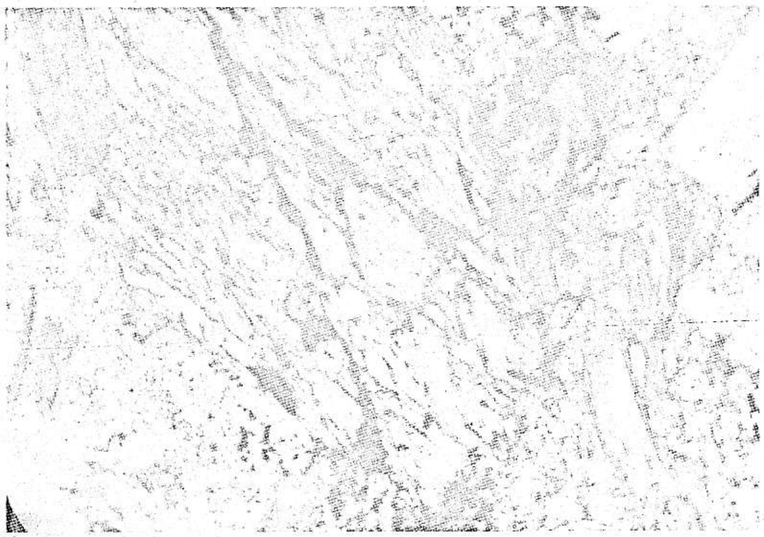


Plate 15 : Sulphide replacement of hornblende along grain boundaries and cleavage planes. Plain light. Magnification X 150.

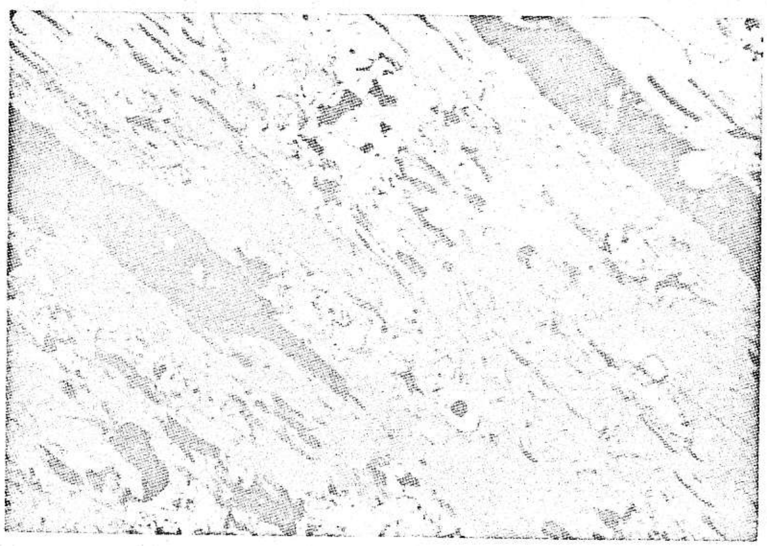
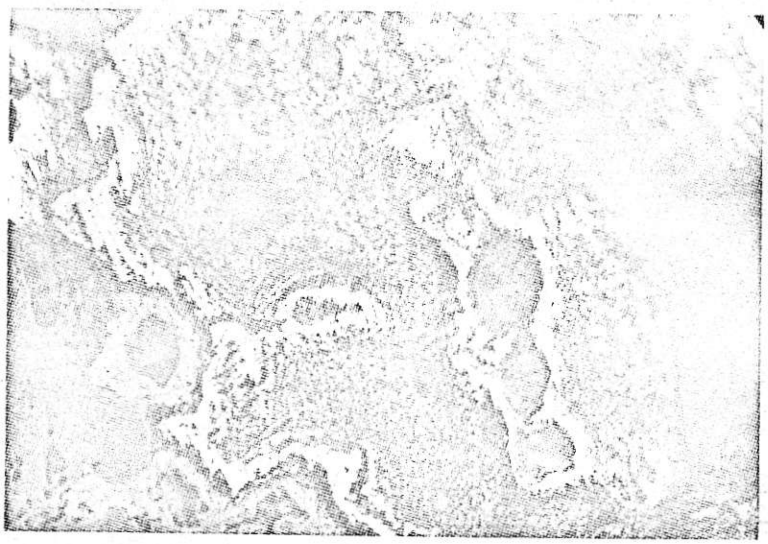


Plate 16 : Oriented sulphide grains replacing a large plate of biotite. Plain light. Magnification X 150.

In the veins, quartz is the most abundant vein material with calcite, sulphides, and magnetite. The sulphides in the veins, with the exception of molybdenite, form grains that are intergrown with the quartz or quartz-calcite vein matrix. The molybdenite most frequently forms along vein walls as granular selvages or as flakes and dusting parallel to vein walls in weakly developed 'ribbon vein' structures.

The sulphide minerals form individual grains, granular aggregates, and composite grains in which mutual boundary, replacement, and exsolution textures can be seen. Arseno-pyrite and some of the pyrite form the only euhedral species. Euhedral grains form mainly in the quartz veins although a few of the disseminated pyrite grains are also euhedral. Most commonly the disseminated pyrite grains have corroded outlines, especially if associated with pyrrhotite and chalcopyrite. Thus, it seems that the early generations of pyrite formed relatively large, euhedral grains that were later corroded or resorbed and later generations of pyrite formed fine-granular intergrowths that surround and replace the older grains.

Replacement textures are almost entirely of the caries type. No preferential zonal nor core replacement is obvious in the sulphides although core replacement of magnetite by sulphides was observed. Vein replacement is only weakly developed and is most commonly seen as chalcopyrite replacing fractured pyrite grains. Marcasite forms rims about pyrrhotite and pyrite and less commonly sphalerite rims chalcopyrite. The marcasite forms curved, lamellar, somewhat concentric rims about altered or totally replaced pyrite or pyrrhotite cores. The replacement is more correctly considered an alteration or conversion of the pyrite or pyrrhotite to marcasite possibly due to changes in acidity and temperature (Edwards, 1960). Marcasite was observed in only two specimens. In one pyrrhotite was abundant with pyrite and chalcopyrite in biotite hornfels near the southern contact of the intrusion. The other occurrence was a quartz-calcite vein from the main body of the intrusion in which marcasite replaced pyrite.



Plates 17 and 18: Zonation or concentric banding in marcasite grains. Grains are highly corroded due to polishing. Reflected light. Magnification X 550.

Mutual boundary textures are developed in many of the mineral pairs. Simultaneous deposition may have occurred in the pairs: chalcopyrite-sphalerite, sphalerite-tetrahedrite, bournonite-aikinite, galena-sphalerite, and galena-chalcopyrite. Exsolution textures are developed in the mineral pairs: sphalerite-chalcopyrite, tetrahedrite-chalcopyrite, chalcopyrite-pyrrhotite, and perhaps bournonite-aikinite. Exsolution is most frequently observed between sphalerite and chalcopyrite. This mineral pair as well as tetrahedrite-chalcopyrite and bournonite-aikinite is found in the quartz-calcite veins. Pyrrhotite-chalcopyrite exsolution is found in only a very few specimens from the hornfels zone immediately adjoining the intrusive contact. No exsolution textures were seen in the sulphides in the porphyry.

The size and distribution of exsolved grains depends on the degree to which unmixing has occurred. Commonly exsolution has produced the characteristic dispersion of many fine-grained globules of one sulphide within the other. In some samples where, presumably, cooling was slower or other conditions existed that were more favourable for diffusion and unmixing, exsolution has been more advanced and formed fewer but larger exsolved grains. The most highly developed stages of unmixing have an associated phenomenon of expulsion. In such cases separation and migration of the two substances can be seen to occur and the exsolved sulphide is expelled towards the grain boundary. The ultimate state of expulsion is to have both sulphides separated with the expelled substance at the grain boundary of the host as bordering grains or an enclosing rim.

. Both exsolution and expulsion textures are developed in the vein sulphides and have all manner of intermediate stages between them. Expulsion is best observed in sphalerite-chalcopyrite and tetrahedrite-chalcopyrite. Exsolution grains of chalcopyrite or sphalerite can be seen as dispersions in the cores of many of the sphalerite or chalcopyrite grains. The exsolved sulphide grains decrease in number but increase in size near the grain boundary of the host, especially if rims or adjoining grains of the same composition as the exsolved sulphide are present. From these relations, it seems most probably that at least some of the rims of sphalerite about chalcopyrite and boundary grains or rims of chalcopyrite about sphalerite have not formed by replacement but rather by grain boundary concentration through expulsion. The same relations are probably true for tetrahedrite-chalcopyrite pairs.

Aikinite in bournonite forms a number of small, irregular, rounded grains that are clustered together in groups that usually contain three to five grains. The exsolved granules vary in size as well as shape and show no tendency to segregate along grain boundaries. For this sulphide pair where fine granules appear to be expelled from the host sulphide and yet remain intimately associated in a cluster within the host, the term exsolution is probably applicable. If the exsolved sulphide appeared to have been ejected from the host and concentrated around the host grains' border, the term expulsion would seem more fitting.

Paragenesis

The paragenesis of the mineral suite is complex but has been deciphered from the fabric and textures of the mineral grains and crosscutting relationships of veins and fractures. The mineral suite was subdivided into four parts based on the four environments of formation of metallic mineralization. The divisions are: 1. disseminated sulphides in Takla-Hazelton beds (largely or totally composed of pyrite); 2. granular magnetite, pyrite, chalcopyrite in the skarn zone; 3. disseminated and fracture filling sulphides and magnetite in the quartz monzonite and hornfels: and 4. vein sulphides with quartz and quartz-calcite gangue.

The disseminated sulphides in the hydrothermally unaltered sedimentary beds are presumably syngenetic. The skarn, disseminated, fracture filling, replacement, and vein mineralization are related both spatially and in time to the intrusion of the grandiorite-quartz monzonite porphyry. Only a very small portion of the total volume of sulphides at the Driftwood Property is found in the unaltered sedimentary rocks and skarn zone, and therefore, these types of mineralization are of only minor importance. By far the greatest volume of sulphides and magnetite has formed as disseminations and fracture fillings in the intrusion and as fracture filling or replacements in the hornfels. The veins are neither large nor abundant and generally contain small amounts of sulphides. The veins do, however, contain the greatest number of sulphide species. The stages of mineralization related to intrusion of the porphyry are listed in Table III.

Table III. Sequence of Mineralization.

Stage 1.		Rock forming silicates, accessory minerals, magnetite
	1a.	Aplite dykes
Stage 11.		Quartz veining ("blue quartz") - containing molybdenite, pyrite
Stage 111.		Disseminated, fracture filling, and replacement sulphides and magnetite in porphyry, hornfels, (and skarn?)
	111a.	Quartz veining ("white quartz") - barren or containing pyrite, pyrrhotite, chalcopyrite, and sphalerite
Stage 1V.		Quartz-calcite veining - polymetallic
Stage V.		Surficial weathering and alteration

The relations between individual silicates and silicates with sulphides and magnetite have been discussed in the section dealing with textural relationships.

The conclusions drawn are that mafic minerals, magnetite, and other accessory grains crystallized early with zoned plagioclase phenocrysts and these were followed by quartz, potash feldspar, and more plagioclase in a fine, granular matrix. This assemblage is called Stage 1 and, in effect, describes the formation of the granodiorite-quartz monzonite porphyry. During the late stages of differentiation potash feldspar and quartz segregations formed small aplitic dykes and projections which represent the last stage of intrusion and are called Stage 1a.

Pyrrhotite probably started crystallizing from the magma or between the silicates at high temperatures and formed accessory grains. However, the main deposition of sulphides began after crystallization of the host rock. The earliest metallic minerals to form were magnetite, molybdenite, pyrrhotite, and pyrite. The molybdenite appears to have first been deposited along walls of fractures. Presumably as temperature decreased, pyrite and more molybdenite was deposited with quartz to form veins. Finally the veins were filled with clear quartz to end Stage 11 deposition. Formation of the Stage 11 veins coincided with re-equilibriation of the accessory pyrrhotite in the porphyry. The main deposition of pyrrhotite, pyrite, and chalcopyrite in the porphyry and pyrrhotite, pyrite, chalcopyrite, and magnetite in the hornfels marks the advent of

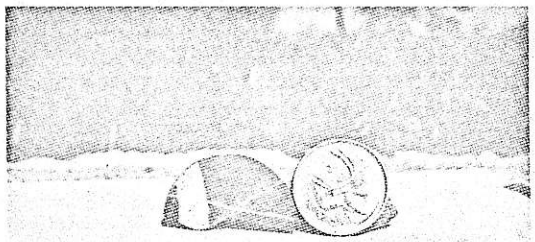
Stage lll and the transition from Stage ll.

The maximum age of the "blue quartz" veins of Stage ll is well defined as they can be shown to crosscut aplite dykes of Stage la. The younger age of the main sulphide mineralization of Stage lll is documented by the presence of abundant pyrrhotite, pyrite, and chalcopyrite as rims and bordering grains along "blue quartz" veins.

The magnetite-pyrite-chalcopyrite mineralization in the skarn zone is believed to have formed during Stage lll, although this age relation is difficult to substantiate. The assumption is based on the mineralogy and the conclusion that the skarn reflects a contact phenomenon similar to that which formed the hornfels and differs only in that it occurred in chemically more reactive rocks.

The second age of quartz veining (Stage llla) has formed white quartz veins which are the most abundant type of vein observed, especially in the hornfels. These veins are easily recognized by their milky white colour, simple mineralogy, greater than average widths, and varied shapes that result in highly irregular, lenticular and pod-like cross sections. The veins have been called Stage llla because they can be shown to crosscut stage ll "blue quartz" veins and Stage la aplite dykes. The term Stage llla is used rather than Stage lV to emphasize their close time association to the main period of pyrite, pyrrhotite, and chalcopyrite deposition in Stage lll. It is assumed that sulphides forming disseminated or replaced grains and lenses during Stage 111 were introduced at the same time with quartz into open spaces and resulted in the irregular white quartz veins of Stage 111a. The veins are not all mineralized. More than one half of the white quartz veins observed were barren and those that are mineralized contain only sparsely distributed grains of pyrite, pyrrhotite, chalcopyrite, minor sphalerite, and rare traces of galena.

The youngest veins are polymetallic quartz-calcite veins that have been observed to crosscut Stage 11 "blue quartz" veins, Stage 111 sulphides, and Stage 111a "white quartz" veins. They are termed Stage 1V and are easily recognized both by their sulphide and gangue mineralogy. The diagnostic minerals are arsenopyrite, tetrahedrite, bournonite, and aikinite as well as clear, crystalline quartz set in white to cream-coloured calcite and white quartz. The veins also contain pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, and marcasite. The first gangue to have formed appears to have been crystalline quartz that left much vuggy space that was later filled with sulphides, milky-white quartz, and calcite. The deposition in the veins began with euhedral pyrite, arsenopyrite, and quartz crystals and was followed by a second generation of granular, anhedral pyrite, white quartz, pyrrhotite, chalcopyrite, and some sphalerite and galena. Calcite with sphalerite, galena, tetrahedrite, sulphosalts, and marcasite were the final



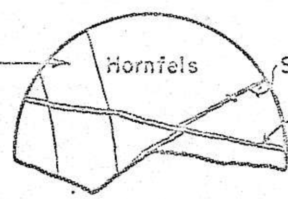


Plate 19: Polished section of diamond drill core with Stage la aplite dyke and Stage 11 "blue quartz" vein cut by Stage 1V quartz-calcite vein.

minerals deposited.

Two polymetallic calcite-bearing veins in the porphyry and one in the hornfels were observed that contained molybdenite. The molybdenite was found in its common habit as finely disseminated plates along the vein walls. These relations suggest at least two hypotheses regarding the age of the molybdenite. The first is that molybdenite was deposited continuously over a long period of time spanning Stage 11 through to at least the start of Stage 1V. A slight variation of this hypothesis is that molybdenite was deposited at the beginning of Stage 1V as a second period or generation of molybdenum mineralization. The second and alternative hypothesis is that the veins are composite and contain Stage 1V mineralization that has been superimposed on Stage 11 veins. The latter proposal is considered to be the more likely. Molybdenite probably formed first during Stage 11 mineralization and the same fractures were refractured and mineralized at a later time during Stage 1V (and probably Stage 111a, although composite veins of this age have not been recognized).

The final events in the history of mineralization are termed Stage V and represent the weathering and alteration products of the sulphides, magnetite, and rock-forming minerals.

Diagramatic Representation of the Paragenesis

Both the line diagram and the Vandeveer diagrams used in this study have been slightly modified to suit the particular requirements of the Driftwood mineralization. The representations have to be interpreted with the following restrictions and conditions in mind.

The line diagram shows the stages of mineralization as derived from crosscutting relations and textural evidence. The boundaries between the stages have purposely been left vague as there probably has been some overlap of certain minerals and continuity of deposition from one Stage to another. The sole exception is Stage lV which has arbitrarily had the presence of calcite in the veins placed as its diagnostic criterion. The use of the term 'pyrite l and ll' and 'magnetite l and ll' refers primarily to the fabric and carries only a secondary genetic implication. In the case of pyrite, the significance is that at least two types of pyrite were recognized. Pyrite l is the first-formed, euhedral coarse-grained variety that forms in a stage of mineralization, and pyrite ll is the finer-grained, granular type that surrounds pyrite l. The different appearance of pyrites in any stage of mineralization may be the result of being formed during at least two discrete periods, or may just represent two or more steps in a single depositional process. In the case of magnetite, the terms magnetite l and ll can be used.

to distinguish the mineral on a textural and time basis. Magnetite 1 refers to the fine-grained accessory magnetite in the porphyry, and magnetite 11 is formed as replacements and fracture fillings in the hornfels, porphyry, and skarn during Stage 111.

The Vandeveer representation has been broken down into two components in order to present the data in a more easily understandable manner and to emphasize the dual nature of the mineral assemblage. The simple mineralogy of the dissemination, replacement, and fracture filling type of Stages 1 and 111 has been shown as one component and the complex mineralogy of the veins in Stages 11, 111a, and 1V has been used in the other. For a full understanding of the paragenesis, both components must be regarded as occurring concurrently but under different physical conditions. The Vanderveer and line diagrams are shown in Figures 8 and 9.

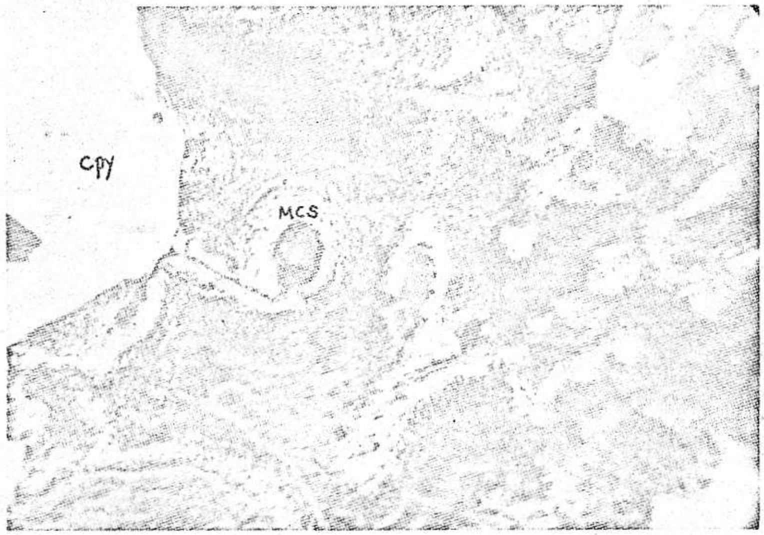


Plate 20: Chalcopyrite (cpy) truncating marcasite (mcs) bands. Reflected light. Magnification X 550.

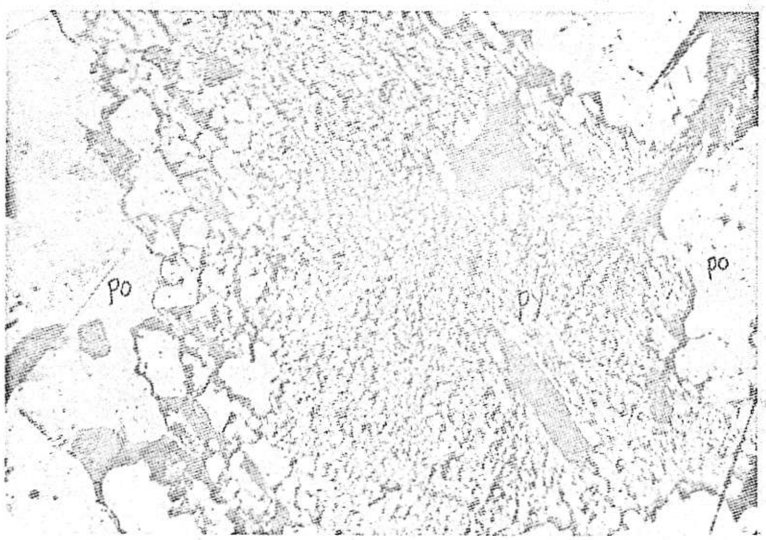
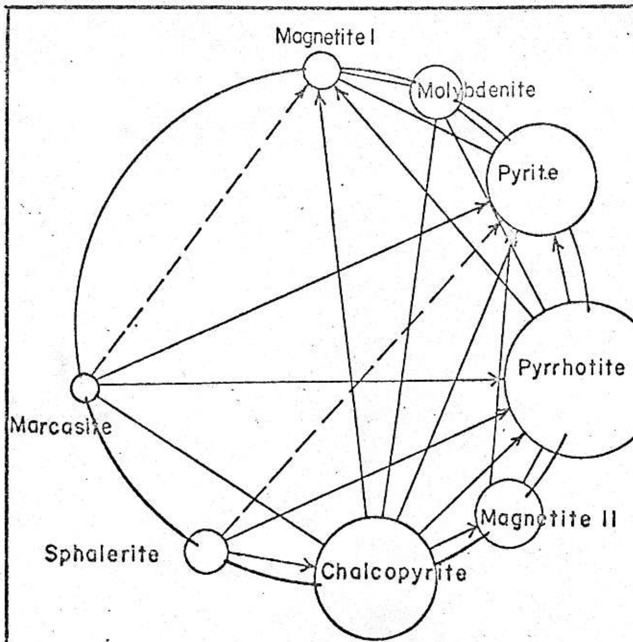
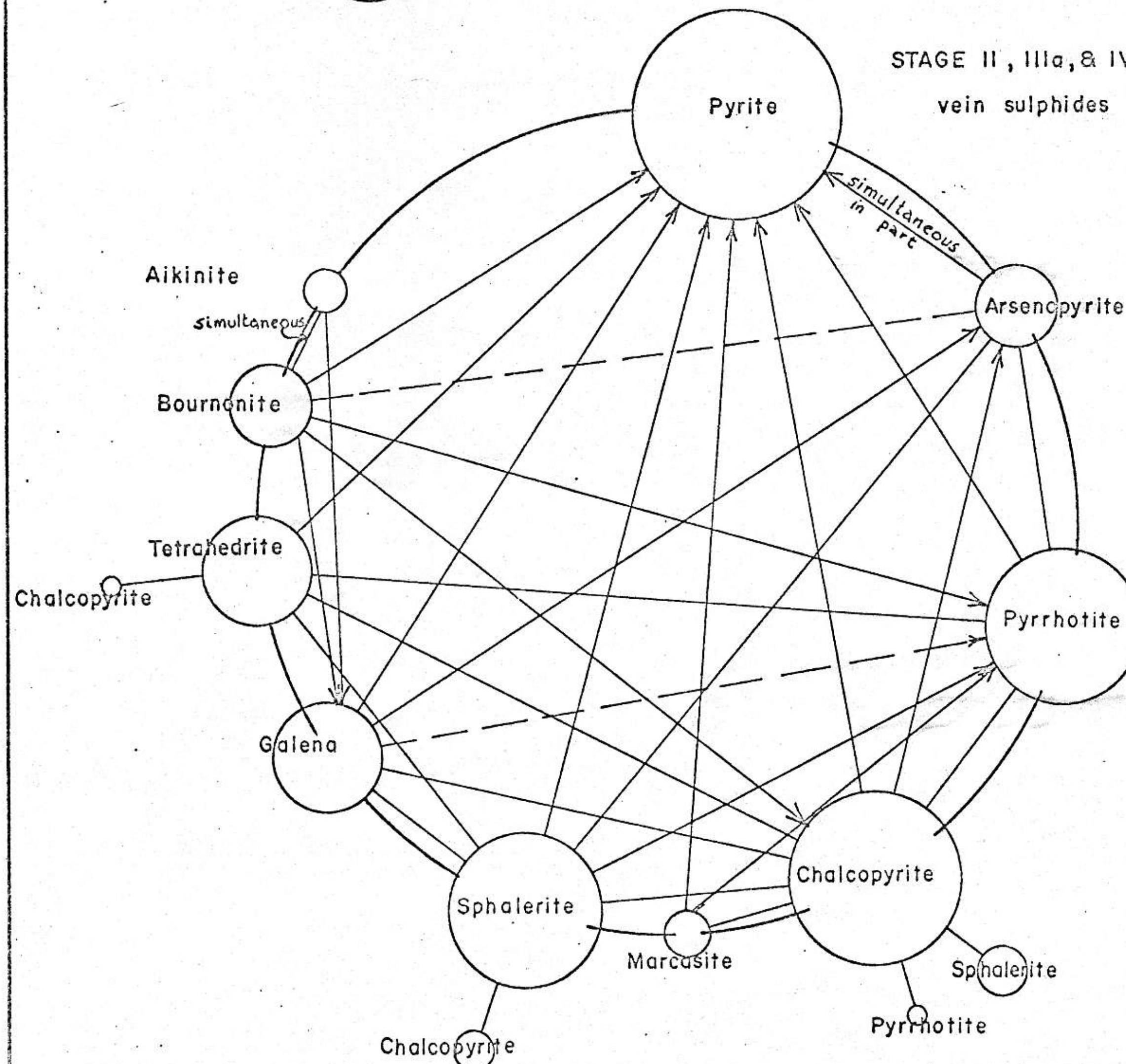


Plate 21: Shattered pyrite (py) with younger rims of pyrrhotite (po). Reflected light. Magnification X 184.

FIGURE 8 : VANDEVEER REPRESENTATIONS OF PARAGENESIS

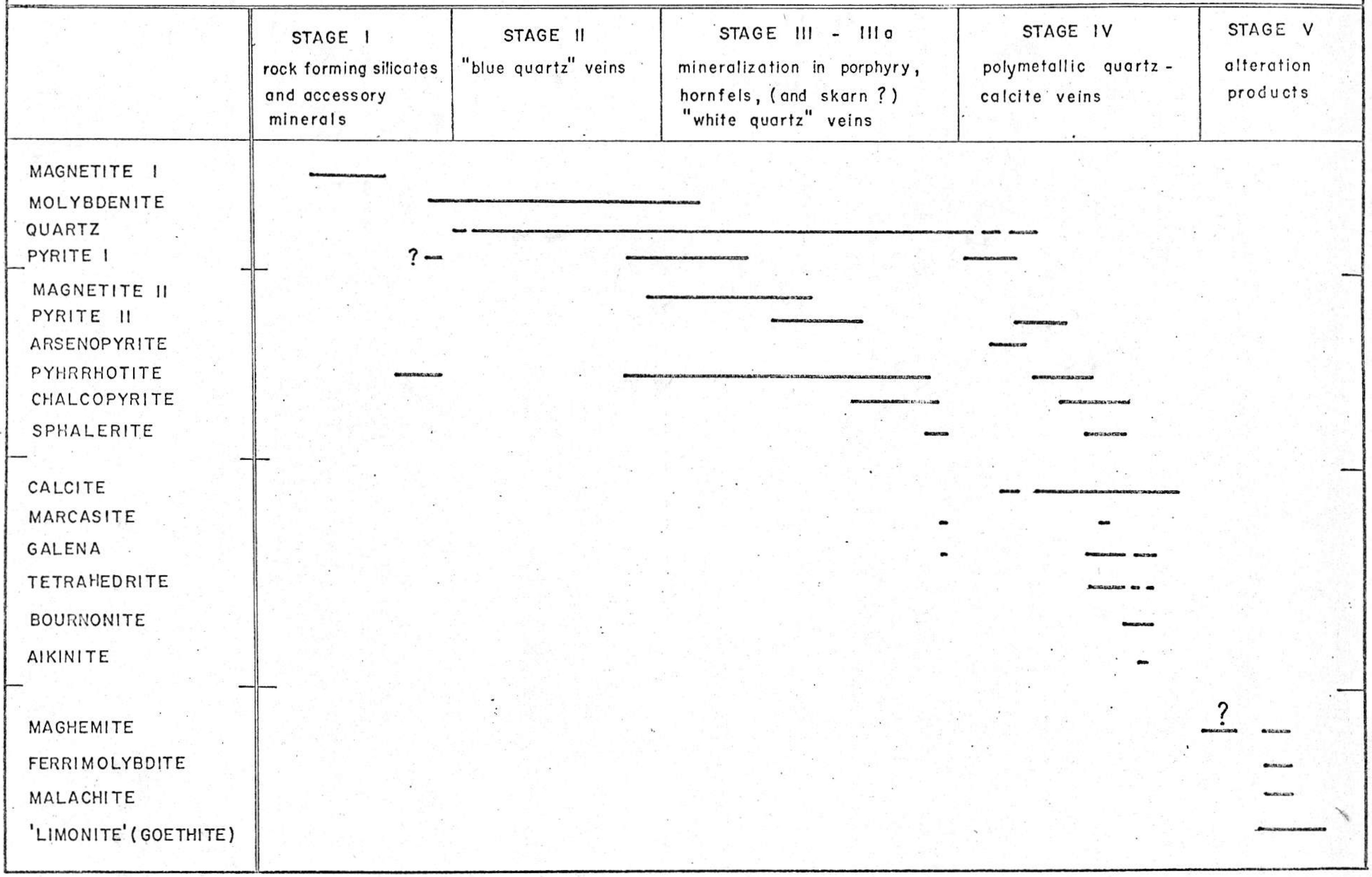


STAGE I & III : disseminated, replacement, and fracture filling mineralization



STAGE II, IIIa, & IV : vein sulphides

FIGURE 9 PARAGENESIS OF DRIFTWOOD MINERALIZATION



Temperatures of Intrusion and Metamorphism

Intrusion has been into the epizonal environment which is the zone from surface to 4 kilometers. The Driftwood intrusion is believed to be in the deeper part of the epizone and, thus, a depth of four kilometers will be assumed to be the depth of intrusion. At such a depth the temperature and pressure in the country rock would be about one hundred forty degrees centigrade and pressure about 1000 bars if the thermal and pressure gradients of 30 degrees and 250 bars per kilometer were used (Winkler, 1965).

The temperature of the silicate melt can be estimated from the data provided by numerous authors. Temperatures of granitic melts range from 700 to 800°C; syenitic magmas about 900°C (Winkler, 1965); and granodiorite 820°C (Buseck, 1966). In the system albite-orthoclase-quartz the solidus at 1000 kg/Cm^2 water pressure for a melt having the composition of the average of the Driftwood granodiorite-quartz monzonite is about 817°C (Annual Report Geophysics Lab., 1951-52). Thus, 815°C ± 25° can be regarded as a reasonable approximation for the temperature of intrusion of the granodiorite-quartz monzonite stock.

The heat flow from an intrusive body has been calculated by Lovering (1936), and Jaeger (1957, 1959) and applied by Buseck (1966), Winkler (1965), and others to field occurrences. Their calculations determine the temperatures at the contact and at varying distances from the contact as functions of the magma temperature, temperature of the intruded rocks and thickness of the intrusive body.

Loverings calculations were based on general differential equations that relate the heat conductivities of two homogeneous bodies of different compositions and temperatures. Using his method, a magma with a temperature of 815°C intruded into limestone and shale would increase the temperature at the contact by about 440°C and 425°C respectively. However, for the sake of convenience, Lovering assumed the temperature of the intruded rocks to be zero. Thus, if a correction was made for the temperature of the intruded rocks, the contact temperature would be considerably greater than calculated.

An expression containing a correction for geothermal gradient was used by Buseck (1966). The expression is modified from Jaeger (1959) and states that the contact temperature T_c, is:

$$T_c = \frac{\left(\dfrac{K_1 k_o^{\frac{1}{2}}}{K_o k_1^{\frac{1}{2}}}\right)(T_m - T_o)}{\left(\dfrac{K_1 k_o^{\frac{1}{2}}}{K_o k_1^{\frac{1}{2}}}\right) + 1} + T_o$$

where k_o and k_1 are the diffusivites, K_o and K_1 are the thermal conductivites of the intruded rock and granodiorite-quartz monzonite, T_m is the solidifying temperature of magma, and T_o is the initial temperature of the intruded rocks. Assuming a depth of intrusion of 4 km, a 30°C per km geothermal gradient, and a surface temperature of 20°C, and applying the appropriate constants as listed by Lovering (1936), the temperature of intrusion Tm of 815°C, the contact temperature for the Driftwood intrusion is found to be 474°C in limestone; 557°C in shale; 495°C in sandstone, and 517°C in andesite-basalt. These temperatures would be greater if the magma were hotter than 815°C or the thermal gradient was greater than 30°C/Km, or the depth of intrusion was greater than 4 Km. Also the temperatures, as calculated, apply to the contacts of an intrusive body with vertical walls, and any local bends or warps in the contact would give rise to higher temperatures.

The restricting conditions for heat flow calculations are that heating of the intruded rock is due entirely to conduction and no heat transfer by volatile components takes place. Since some metasomatism is evident, there must have been fluid movement. The assumption made is that the latent heat of crystallization opposes and cancels the heat loss through fluid action and the body can be assumed to have cooled by only conduction.

Winkler's treatment of Jaeger's method of calculating heat flow can be used to demonstrate the causes of zonation of the contact metamorphic facies. The temperature gradient is steepest at the intrusive contact but decreases rapidly and levels away from it. Winkler (1965) proposed that at the contact the temperature of the country rock increases by over 60 percent of the temperature of the intrusive magma. At distances corresponding to 1/10 the thickness of the intrusive (1/10 D), the temperature increase in the country rock is about 50 percent of the temperature of the magma, and at a distance of 1/2 the thickness (1/2 D), the temperature increase is about 1/3 that of the magma. Using the assumed values of 815°C as the temperature of the intrusion, a depth of 4 km, a 30°C/Km geothermal gradient, an average thickness (D) of the Driftwood Granodiorite-quartz monzonite of 1000 feet, and contact temperatures (T_c) for the rock types observed as calculated by Buseck's expression, the values are about 550°C for calcerous shale, 495°C for sandstone, and 517°C for andesite-basalt sections. At a distance of 100 feet from the contact (1/10 D), the temperatures are 415°C for calcereous shale, 348°C for sandstone, and 397°C for the volcanics. At an increased distance of 500 feet (1/2 D), the expected temperatures would be about 323°C, 305°C, and 311°C, respectively. The relation for calcareous shale is shown in Figure 10.

The temperature limits for the hornblende hornfels and albite-epidote hornfels facies at a confining pressure of 1000 bars and intrusion depth of four kilometers, as defined by Winkler (1965), have been superimposed on the heat flow

Figure 10: Heating of country rock with calcareous shale composition adjacent to a granodiorite intrusion. (Modified after Winkler, 1965); temperature at contact calculated according to Buseck, (1966).

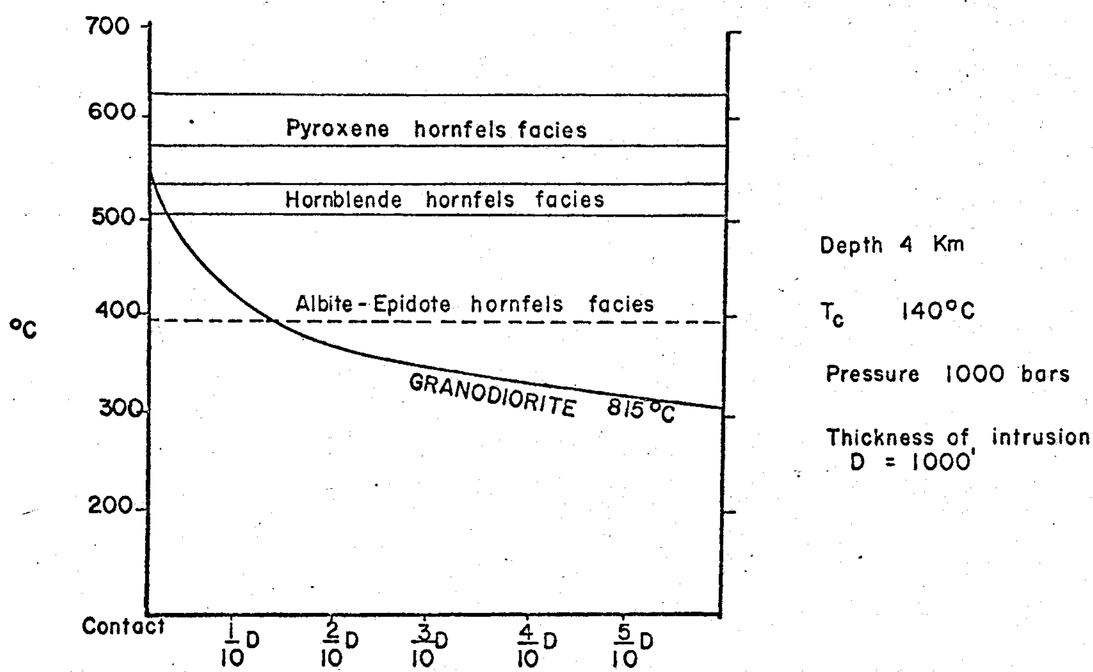


diagram (Figure 10). Clearly, under the conditions stated, it can be seen that a calcareous shale could have contact metamorphism of the hornblende-hornfels facies for a distance of up to $.\frac{02}{10}$ D = twenty feet, and could develop a hornfels with biotite in the albite-epidote hornfels facies over a distance of about 135 feet. Intruded volcanics with andesite-basalt composition would have a contact temperature of about 517°C and, thus, only a very thin zone of hornblende-hornfels facies contact rock could be formed. However, a hornfels of the albite-epidote facies would be expected to form for a distance of at least 100 feet. Sandstone with a contact temperature of 495°C would not be metamorphosed beyond the upper range of the albite-epidote hornfels facies. A hornfels zone close to 100 feet in thickness would be expected.

These theoretical considerations very closely resemble the actual observed alteration pattern. In some outcrops the thickness of the hornfels facies was greater than the theoretical considerations would predict. Such discrepancies would, in fact, be expected in a natural occurrence where the intrusive contact would be irregular and not the ideal dyke-like body on which the calculations are based. In general, however, the assumed temperature of intrusion of 815 ± 25°C, and a depth of intrusion of 4 Km with contact temperatures around 500°C but probably not exceeding 550°C can be regarded as reasonable and consistent with the field relations observed at the Driftwood Property.

Geothermometry

Temperature-pressure conditions for ore formation can be postulated using a number of criteria. In this study no attempts were made to apply or investigate the applicability of the popular geothermometers due to the uncertain status of the various methods. Instead, thermal stability limits and stability ranges of coexisting mineral assemblages were used to reduce the limits of conditions favourable for mineral deposition. In a few cases equilibria relations could be used to define very closely the conditions of deposition.

Anhydrous iron oxides: Magnetite and maghemite are the only two minerals observed. Magnetite occurs in at least two ages - the early-formed, disseminated, magmatic variety in the intrusion, and the secondary replacement type in the hornfels, porphyry, and skarn that was seen to be partly contemporaneous with and partly younger than some of the pyrite and pyrrhotite. No hematite was seen but small amounts of maghemite (γFe_2O_3) were recognized as an alteration product of the magnetite in the skarn (tactite) zone.

Formation of two types of magnetite reflects the interplay of pO_2 and pS_2 during the cooling cycle of the intrusion (Holland, 1959). The disseminated magnetite probably formed as a primary magmatic phase in what can be regarded as a closed system. Later as a result of cooling and possibly as a result of decrease in pO_2 and pS_2, secondary magnetite formed in the intrusion, hornfels, and tactite in the presence of volatiles in an essentially open system. According to Salotti's (1964) diagram for the Fe-S-O system, at temperatures below 675°C the progression from pyrite $\rightarrow$ pyrite + magnetite $\rightarrow$ pyrite + pyrrhotite + magnetite $\rightarrow$ pyrrhotite + magnetite is possible. Thus, magnetite associated with sulphides is capable of forming at both high and low temperatures in accord with the inferred textural evidence.

The conditions of formation of maghemite (γFe_2O_3) are not well known. It is believed to be an intermediate polymorph between magnetite and hematite (αFe_2O_3). According to Kuno (1965) maghemite may form as an alteration process dependant on oxygen fugacity and temperature after magmatic crystallization is essentially complete. Experimental data shows that maghemite can be formed by oxidation of magnetite from 200 to 700°C in both natural and synthetic systems. Thermal studies by Gheith (1952) on magnetites showed exothermic peaks corresponding to the formation of γFe_2O_3 to vary from 280 to 375°C. However, more recent opinions offered by Abdullah and Atherton (1964) and Gross (1965) state that maghemite is most commonly formed after prolonged surface oxidation or by rapid oxidation at low temperatures under aqueous conditions such as in the case of low grade thermal metamorphism.

Sulphides: The earliest sulphides to form were molybdenite along with pyrite and some pyrrhotite. Molybdenite is a high temperature mineral whose maximum temperature of stability is well above the temperature of the granodiorite intrusion. Sulphide deposition that resulted in the formation of molybdenite-pyrite-pyrrhotite in quartz veins can be assigned an upper temperature limit of 742 ± 1°C according to Barton and Skinner (1967) or 726°C according to Kullerud and Buseck (1962) as based on studies of system Mo-Fe-S. The temperatures of formation of molybdenite may, indeed, be well below these maxima as Arutuyan (1966) has synthesized molybdenite at relatively low temperatures. Using sulphomolybdate solution followed by annealing, Arutuyan formed colloform molybdenite at 200 to 300°C and from this a trigonal polymorph (3R) with short runs at temperatures from 350 to 900°C. A transformation into the normal hexagonal molybdenite was accomplished at 600°C over a time of 22 days.

The abundance of pyrite and pyrrhotite and use of phase relations in the system Fe-S are of very little use in the present study for purposes of geothermometry. Besides the uncertain status of the pyrrhotite geothermometer, the structural state of the pyrrhotite is not known and there is a persistant association of chalcopyrite. As stated by Rao and Rao (1968) after the suggestion by Yund and Kullerud (1966), '(the usefulness of pyrrhotite as a geothermometer) when it is associated with chalcopyrite is doubtful.' The only useful information derived from the Fe - S system is that a maximum temperature of formation for the pyrite can be set at 742 or 743 ± 1°C + 14°C per kilobar, (Kullerud and Yoder, 1959; Arnold, 1962; Kullerud, 1967). Above this temperature the sulphides would have been high temperature pyrrhotite in coexistence with a sulphur-rich melt.

The formation of marcasite, as defined in system Fe-S-O-H (Kullerud, 1957, 1967), occurs at temperatures less than 432°C and is pressure dependent. The observed association of pyrite and marcasite at the assumed pressure of

1000 bars, would have a maximum temperature of formation of $428 \pm 2°C$.

The most important system in this study is Cu-Fe-S because of the abundance and consistent association of pyrite-pyrrhotite and chalcopyrite. However, use of phase relations to define conditions of formation is limited due to the complex relations and confusion at low temperatures. The phase relations, as developed by Yund and Kullerud (1966) show a wide range of pyrite-chalcopyrite stability, starting at 739°C. At high temperatures (600 to 700°C or more) extensive solid solution fields are developed. Chalcopyrite coexists with pyrite and pyrrhotite and both chalcopyrite and pyrrhotite have extensive solid solution. As temperature decreases, structural inversions in the chalcopyrite take place and at a temperature of about 550°C the chalcopyrite solid solution is split into two smaller fields of cubanite and chalcopyrite with the lines forming between the cubanite and pyrite. Because of the abundance of iron over copper in natural systems, cubanite would be expected to be commonly formed relative to chalcopyrite (Kullerud, 1967). However, the cubanite is not a readily quenchable phase and at a temperature of 334°C it cannot exist with pyrite and will react to form chalcopyrite and pyrrhotite. Cubanite, furthermore, cannot exist with monoclinic pyrrhotite and thus monoclinic pyrrhotite, pyrite, and chalcopyrite would be the expected assemblage at a temperature less than 310°C, which is the upper temperature boundary for monoclinic pyrrhotite (Kullerud, 1967; Arnold, 1968).

Based on these considerations, the absence of cubanite and the intimate association of chalcopyrite-pyrrhotite in the presence of pyrite in the intrusion, suggest that re-equilibriation of sulphides probably started at high temperatures and continued throughout the cooling history. Deposition in the intrusion could have started at the maximum temperatures of formation of pyrite at $757 \pm 1^{\circ}C$ (at 1000 bars) and chalcopyrite at $739^{\circ}C$, but final temperatures of formation were considerably lower and may even have been below $334^{\circ}C$, the stability limit of cubanite. Such relations are consistent with the occurrence of chalcopyrite-pyrite-pyrrhotite in the relatively low temperature hornfels environment and the paragenesis which shows some of the chalcopyrite and pyrrhotite to be younger than marcasite which has an upper temperature of formation at 1000 bars of $428^{\circ}C$.

The system Fe-As-S offers useful and exact information regarding conditions of formation. Clark (1960) determined the phase relations and found that $491 \pm 12^{\circ}C$ is an invarient point that defines the maximum temperature of stability of pyrite with arsenopyrite. Above this temperature pyrrhotite and liquid form with arsenopyrite. The system is pressure sensitive and the invarient point varies $18^{\circ}C$ per kilobar pressure. The mineral assemblage observed contains pyrite and arsenopyrite which appear to be mutually deposited in the presence of excess iron that formed a younger replacement pyrrhotite and pyrite. The temperature of formation, with a pressure correction for the assumed depth of intrusion, can be determined to have been a maximum of 509 ± 12°C.

The other minerals in the assemblage provide very little detailed information beyond upper temperature stability limits. Galena and sphalerite both have very high congruent melting points. Tetrahedrite and tennantite have upper temperature limits of 555°C and 640°C, respectively (Wernick and Benson, 1957). Virtually no phase data is available for bournonite and aikinite as they are difficult to synthesize and have complex multicomponent compositions. An upper temperature limit for aikinite has been determined to be from 465 to 475°C (Schaber, 1965).

Textural relations and particularly exsolution and unmixing textures have long been considered to provide data regarding temperatures of formation or cooling rates. Edwards (1960) provides temperatures of unmixing for the following mineral pairs:

Chalcopyrite-pyrrhotite	600°C chalcopyrite exsolves 300°C pyrrhotite exsolves
Chalcopyrite-tetrahedrite	?500°C
Sphalerite-Chalcopyrite	550°C chalcopyrite exsolves 350°C-400°C sphalerite exsolves

However, the work of Brett (1964a,b) and others has cast much doubt as to the validity of quantitative data based on textural studies as genetic criteria.

The conditions of formation of the metallic minerals have, thus, had maximum temperature limits or temperature ranges defined. The maximum temperature of formation possible would have been the temperature of crystallization which was assumed to be about 815 ± 25°C at a confining pressure of 1000 bars. Within the intruded rocks mineralization was developed in the hornfels zone, usually within one hundred feet of the contact, where the temperatures were calculated to range from about 400 to a maximum of about 550°C at the contact. The sulphide studies indicate that formation of the observed mineral assemblages occurred at high temperatures. Re-equilibriation throughout the cooling history is considered likely and the paragenesis defines a long history of mineralization with successive stages. Thus, the stages of mineralization called Stages 1, 11, 111, and probably much of Stage IV were formed at elevated temperatures under relatively similar conditions. The only minerals that may have been deposited under lower temperature conditions are the late forming sulphosalts, and some sulphides of Stage IV. Based on studies of other sulphosalt assemblages, the temperature of deposition may have been in the order of 300°C. The results are summarized in Table IV.

Table IV: Temperature data from silicate systems, heat flow calculation, and invarient points from condensed phase diagrams of systems applicable to the Driftwood mineral assemblage.

Mineral or association	System	Maximum temperature of stability or (temperature range)	High temperature products	Remarks and Documentation
Granodiorite-quartz monzonite		815 ± 25°C	silicate melt	Temperature at solidus for compositional average of 18 Driftwood specimens for system albite-orthoclase-quartz; (Annual Rept. Geophys. Lab., (1951-52).
Hornfels contact zone		550°C	hornblende hornfels facies and albite-epidote-hornfels facies.	Contact temperatures. Contact metamorphic zone. Heat flow calculations by Lovering, 1936; Jaeger, 1957, 1959; Buseck, 1966; and Winkler, 1965.
Magnetite	Fe-O	I $\gg$ 675°C	Fe_2O_3+ melt	Primary phase.
		II < 675°C	magnetite plus Fe sulphides.	Sulphide breakdown and S-O exchange due to decrease in pO_2 and pS_2. (Holland, 1959); (Salotti, 1964), (Buseck, 1966).
Maghemite (γFe_2O_3)	Fe-O	?280 - 375°C	Hematite (αFe_2O_3)	Intermediate phase between magnetite-hematite. (Gheith, 1952).
		? 20°C	Magnetite?? Hematite	Surface oxidation. (Abdullah and Atherton, 1964); (Gross, 1965).

Table IV: (continued)

Mineral or association	System	Maximum temperature of stability or (temperature range)	High temperature products	Remarks and Documentation
Molybdenite-pyrite	Fe-Mo-S	742 + 1 C or 726°C	Pyrrhotite + molybdenite + melt.	Low temperature synthesis of molybdenite possible. (Aratuyan, 1966); (Barton and Skinner, 1967); Kullerud and Buseck, 1962).
Pyrite-pyrrhotite	Fe-S	742 or 743±1°C plus 14°C/Kbar = 757± 1°C	Pyrrhotite + melt	Kullerud and Yoder, 1959; Arnold, 1962; Kullerud, 1967.
Marcasite-pyrite	Fe-S-O-H	<432°C = 428 ± 2°C (with pressure correction)	Pyrite	Pressure sensitive. (Kullerud, 1957, 1967).
Chalcopyrite-pyrite-(pyrrhotite)	Cu-Fe-S	739°C	pyrrhotite + melt	Yund and Kullerud, 1966.
Chalcopyrite-pyrrhotite		600°C	pyrrhotite with Cu solid solution	Exsolution of chalcopyrite. Edwards, 1960.
Chalcopyrite-pyrrhotite		334°C	Cubanite	Low temperature inversion of cubanite, Yund and Kullerud, 1966;

Table IV: (continued)

Mineral or association	System	Maximum temperature of stability or (temperature range)	High temperature products	Remarks and Documentation
Chalcopyrite-Pyrrhotite (Monoclinic)	Cu-Fe-S	$310^\circ C$	Cubanite (May be associated with pyrrhotite (hexagonal)	Cubanite unstable in presence of monoclinic pyrrhotite, Kullerud, 1967; Arnold, 1968.
Chalcopyrite-pyrrhotite		$300^\circ C$	?Cubanite or Chalcopyrite with Fe solid solution	Edwards, 1960. Pyrrhotite exsolution. (May be result of cubanite inversion).
Arsenopyrite-pyrite	Fe-As-S	$491 \pm 12^\circ C + 18^\circ C/Kbar = 509 \pm 12^\circ C$	Pyrrhotite + melt	Pressure sensitive system. (Corrected for 4 km depth). Clark, 1960.
Tetrahedrite	Cu-Sb-S	$555^\circ C$	melt	Driftwood mineral may be As - rich.
(Tennantite)	Cu-As-S	($640^\circ C$)	(melt)	Wernick and Benson, 1957.
Tetrahedrite-chalcopyrite		?$500^\circ C$	Tetrahedrite with Cu solid solution	Edwards, 1960.
Sphalerite-chalcopyrite	Cu-Fe-S	$550^\circ C$	Sphalerite with solid solution	Edwards, 1960
	Zn-Fe-S	350-$400^\circ C$	Chalcopyrite with Zn solid solution	
Aikinite	Pb-Cu-Bi-S	465-$475^\circ C$	melt	Schaber, 1965.

SUMMARY AND CONCLUSIONS

The Driftwood Property is underlain by volcanic-sedimentary rocks that were dated as Lower Jurassic and called Takla Group - Upper Division by Lord, 1948. The rocks are more correctly correlated with the Hazelton Group. To the west are Upper Jurassic - Lower Cretaceous sedimentary rocks of the Bowser Group and to the east are Upper Cretaceous and Paleocene strata of the Sustut Group.

A porphyritic Kastberg Intrusion of probable Early Tertiary age has intruded a sedimentary and volcanic section of the Takla Group. The intrusive mass has a highly irregular roof zone with many anastamosing dykes and roof pendants that are exposed along the crest of a ridge. At depth the intrusion is a thick, steeply dipping dyke-like body. The main intrusion is surrounded by many small dykes.

The composition of the stock varies from granodiorite to quartz monzonite and alaskite. Differences in the stock are shown by variations in texture, mineralogy, and chemical composition.

Metamorphism of the intruded rocks has produced an enveloping zone of hornfels about the intrusion. The hornfels is mainly a biotite hornfels of the albite-epidote hornfels facies but small zones of higher grade hornfels in the hornblende hornfels facies can be seen in calc-silicate and mafic hornfels zones. Automorphic alteration within the stock is associated with hydrothermal mineralizing processes and has formed propylitic alteration zones.

The stock is a metal enriched intrusion with mineralization characteristic of porphyry copper and quartz-molybdenum stockwork deposits. Metallic minerals have been deposited as disseminated, fracture filling, and replacement grains and vein constituents in the stock and hornfels. Minor mineralization is found in skarn and breccia zones. Weathering affects are superficial and very few alteration minerals were recognized.

Genesis of the metallic minerals as deduced from mainly silicate-sulphide and sulphide textures and fabrics is epigenetic. The sulphides may be classed, in part, as paramagmatic although a small proportion of the sulphides and magnetite have formed as accessory grains.

A five stage paragenesis is evident. Stage 1 is crystallization of the host rock and formation of accessory magnetite and some pyrite, pyrrhotite, and possibly molybdenite. Stage 11 is veining by molybdenite-bearing quartz veins called "blue quartz" veins. State 111 is the main period of pyrite, pyrrhotite, chalcopyrite deposition in the stock and hornfels and Stage 111a is the closely associated veining with pyrite, pyrrhotite, chalcopyrite, and sphalerite in "white quartz" veins. Stage IV is formation of polymetallic arsenopyrite and sulphosalt bearing quartz-calcite veins. Stage V is alteration of the mineralization and is relatively unimportant.

Intrusion is believed to have been in the epizone at a depth of about four kilometers. Temperature of intrusion is estimated to have been about 815 ± 25°C. Temperatures at the intrusive contact have been estimated by heat flow calculations and are believed to have been about 495° to 550°C. Temperatures of this magnitude are consistent with the grades and widths of the contact metamorphic zones observed.

Temperatures of metallic mineral deposition are difficult to establish but maximum temperatures of formation of some sulphide species and coexisting mineral pairs can be defined using synthetic phase equilibria studies. Maximum temperatures of formation higher than 700°C can be postulated for pyrite, pyrrhotite, molybdenite, chalcopyrite, and magnetite using systems Fe-Mo-S, Fe-S, Fe-S-O, and Cu-Fe-S. Maximum temperatures in the intermediate range from 400 to 600°C can be defined for arsenopyrite-pyrite, pyrite-marcasite, tetrahedrite, and aikinite from systems Fe-As-S, Fe-S-O-H, Cu-(Sb, As,)-S, and Pb-Cu-Bi-S. Low temperature deposition in the order of 300°C is indicated by textural observations coupled with temperatures of exsolution and inversion in re-equilibriating sulphides such as pyrrhotite and pyrrhotite-chalcopyrite (originally cubanite?).

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