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GEOLOGY

of the

Kemano-Tahtsa Area

by

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Geology of the Kemano-Tahtsa Area

CHAPTER I.—INTRODUCTION

LOCATION AND ACCESS

The Kemano-Tahtsa area includes approximately 180 square miles of mountainous terrain between latitudes 53° 30′ and 53° 45′ north and longitudes 127° 30′ and 128° 00′ west. It is 370 air miles northwest of Vancouver and 110 air miles southeast of Prince Rupert and is near the head of Gardner Canal, a 50-mile long fiord that penetrates eastward from the Pacific Ocean into the British Columbia mainland (Fig. 1).

Ground travel in the area is extremely arduous because of the rugged nature of the topography and the dense forest growth in the valleys. Prior to the fall of 1951 the western half of the area, which lies within the Coast Mountains physiographic division of British Columbia, was entirely lacking in transportation facilities. The eastern part of the area, lying in the transition zone between the Coast Mountains and the Nechako Plateau, could be reached from Burns Lake, a station on the Canadian National Railway, via approximately 45 miles of road and 60 miles of lake and river travel. At this time the area was entirely uninhabited, the nearest settlement being an Indian village at Kemano Bay, some 9 miles west of the southwest corner of the map-area at the point of entry of the Kemano River into Gardner Canal.

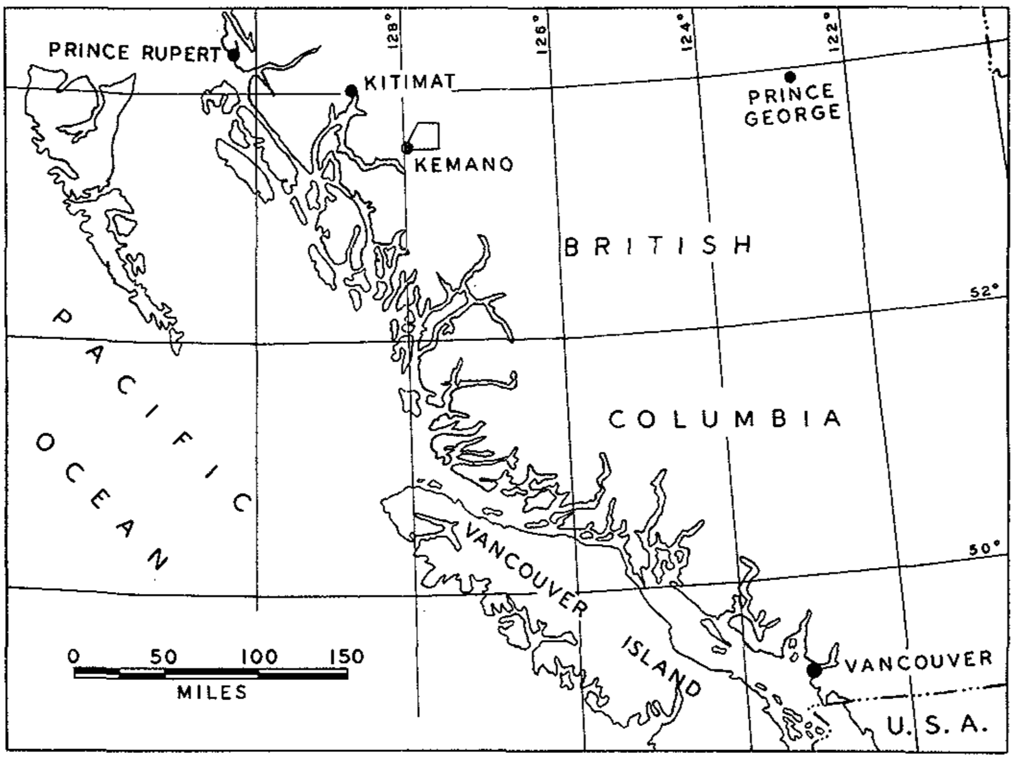

Fig. 1. Index map.

In 1951 the Aluminum Company of Canada began construction of a hydro-electric development that includes a power-house on the Kemano River 10 miles from its mouth and a tunnel extending 10 miles eastward from the power-house to Tahtsa Lake, the westernmost of a chain of lakes draining eastward on the Nechako Plateau. To facilitate construction a number of camps were erected, including Kemano camp at the power-house site, at the junction of Horetzky Creek with the Kemano River; Horetzky camp at the midpoint of the tunnel, near the head of Horetzky Creek; and West Tahtsa camp at the east end of the tunnel, on the west shore of Tahtsa Lake. Roads were built up the Kemano River from Kemano Bay and up Horetzky Creek from Kemano camp to Horetzky camp, and aircraft bases were established at Kemano Bay and West Tahtsa camp.

With these facilities the area became relatively accessible for geological examination. The western half was mapped from Kemano and Horetzky camps, and the eastern half from West Tahtsa camp and from aircraft-supplied tent camps on Sandifer and Nanika Lakes.

PHYSICAL FEATURES

A major divide trends northwest across the map-area, passing approximately 3 miles west of the west end of Tahtsa Lake. West of this divide run-off flows southwest to the Kemano River in steep-sided valleys with gradients of the order of 500 feet per mile, and thence to tidewater at Gardner Canal along a much reduced gradient of approximately 12 feet per mile. East of the divide, drainage flows through a system of lakes and interconnecting rivers with an over-all gradient of only 2.5 feet per mile to the Nechako River, and subsequently enters the Fraser River at Prince George. The divide between easterly and westerly drainage is an approximate boundary-line between the Coast Mountains on the west and the transition zone between the Coast Mountains and the Nechako Plateau on the east.

The Coast Mountains are characterized by narrow ranges that are separated by deep north and northwest-trending valleys and are transected by a number of equally deep northeast-trending valleys. The over-all pattern of valleys is one of elongate polygons and rectangles formed by the three dominant trends. Many of the valleys are drowned, and form the fiords of British Columbia.

The Kemano-Tahtsa area straddles the range that marks the eastern edge of the Coast Mountains between latitudes 53° 30′ and 54° 00′. Within the map-area this range is dissected into a series of narrow subparallel ridges by deep U-shaped valleys that trend southwest and are tributary to the south-trending Kemano Valley. The flanks of the ridges are very steep, but are rounded and relatively even except where alpine glaciers have cut deeply into them to form steep-walled cirques. Headward-eroding cirques have produced sharp ridges characterized by peaks and saddles (Pl. I). The maximum relief is 7,000 feet, near the western border of the map-area where the southwest-trending valleys enter the Kemano Valley. To the east, near the heads of these valleys, the relief decreases to about 4,000 feet.

The Nechako Plateau consists of broad valleys separated by rounded hills and ridges seldom more than 1,000 feet higher than the valley floors. In the transition zone between the Plateau and the Coast Mountains the summit elevations of the flanking ridges rise more rapidly toward the mountains than do the valley floors, producing a gradual increase in relief accompanied by an increase in the proportion of uplands to valley bottoms. At the latitude of the Kemano-Tahtsa area the transition zone is approximately 25 miles wide and includes the eastern 10 miles of the map-area; mountainous uplands with a relief of 3,000 to 3,500 feet occupy 85 to 90 per cent of that part of the map-area. The dominant valley trends are northwest and northeast as they are in the Coast Mountains, but the degree of development of the two is more nearly equal. This has resulted in the formation of separated mountain blocks rather than long continuous ranges as in the Coast Mountains. The blocks are elongated in a northeast direction and are deeply dissected by radial stream systems.

GLACIATION

Alpine glaciers are very common in the western part of the area. Fewer glaciers exist in the eastern part, east of the head of Tahtsa Lake, but perennial snowfields are found on the higher peaks and ridges.

Evidence of the former existence of glacial ice is abundant throughout the area, largely in the form of erosional features. The valleys are invariably U-shaped, although in some of the more narrow valleys this shape has been considerably modified by an accumulation of coarse talus against the steep valley walls. Hanging valleys are numerous, particularly in the western part of the area, and produce several spectacular waterfalls on near-vertical sections of the walls of the Kemano Valley. Grooves and striations are common on the valley walls, usually trending parallel with the valley and oriented horizontally or with a slight plunge down the valley. Rounded and smoothed rock outcrops are conspicuous up to an elevation of about 6,500 feet (Pl. III). Above this elevation exposed rock has been highly shattered by frost action and any smoothed surfaces that may have existed have been destroyed.

With the exception of a few small terminal and recessional moraines related to the present-day alpine glaciers, deposits of glacial materials are rare. No till was observed, but outwash sands and gravels form a delta at the mouth of Horetzky Valley, near the western boundary of the area, and fill the lower part of Laventie Valley, near the eastern boundary of the area.

CLIMATE

The Coast Mountains in these latitudes lack the barrier to moist westerly winds provided by mountainous islands along much of the coast. Consequently the annual precipitation is very high, something in excess of 100 inches. Much of the precipitation is in the form of snow, and on the north and west slopes snowfields persist during the summer at elevations as low as 4,000 feet. The presence of this perennial snow has a marked influence on summer weather conditions. Moist air becomes cooled by the snow and forms a heavy cloud blanket, the base of which normally is at some elevation between 3,000 and 4,000 feet. Inasmuch as most of the rock outcrop is found above the 4,000-foot level, the clouds seriously hamper geological investigations. During the field seasons of 1953 and 1954 respectively, only twelve and eleven overcast-free days were recorded.

FLORA AND FAUNA

A dense forest cover extends up the mountain slopes to a timberline between 3,500 and 4,000 feet in elevation. The forest consists of fir, spruce, hemlock, lodgepole pine, and cedar, and is characterized by thick underbrush growing amidst a lattice of fallen trees. On some of the lower mountain slopes and in all of the valley bottoms, this underbrush, consisting largely of alder, willow, cranberry, salmonberry, raspberry, devil's-club, and fern, is so dense that travel through it is at best difficult and slow, and in some places is next to impossible.

Wildlife is not abundant but includes black and grizzly bear, mountain goat, and, in the eastern part of the area only, a few moose and caribou. Fur-bearing animals have been trapped in the eastern part of the area, but are now rare.

BACKGROUND OF GEOLOGICAL INVESTIGATIONS

In 1924 J. R. Marshall reported on a geological reconnaissance along and adjacent to the shores of Tahtsa and Whitesail Lakes (Marshall, 1924). The general geological features of the area are shown on a map of the Tahtsa-Morice area published in 1936 (Hedley, 1936) and on a preliminary map of the Whitesail Lake map-area published in 1952 (Duffell, 1952).

In 1951 a decision was reached by the Aluminum Company of Canada to begin work on the Kemano hydro-electric project. The construction of this project offered an opportunity to do surface geological mapping in what had been a virtually inaccessible area and to obtain data from a tunnel piercing the easternmost range of the Coast Mountains. In order that this opportunity would not be lost, the National Advisory Committee on Research in the Geological Sciences, the British Columbia Department of Mines, and the Aluminum Company of Canada agreed to sponsor a field programme to be carried on during the period of construction of the project. A total of twelve months' field work was completed between the spring of 1952 and the fall of 1954. During this time all underground excavations were mapped at a scale of 1 inch to 50 feet; an area of 40 square miles along the route of the tunnel was mapped at a scale of 1 inch to one-quarter mile, and an additional area of 140 square miles lying to the north, east, and south of the tunnel was mapped at a scale of 1 inch to one-half mile.

ACKNOWLEDGMENTS

Many persons have contributed to the completion of this investigation, and their assistance is gratefully acknowledged. The field work was financed by the British Columbia Department of Mines, the Aluminum Company of Canada Limited, and the National Research Council of Canada. This work could not have been completed but for the assistance rendered in the field by the technical and administrative personnel of the Aluminum Company of Canada Limited, the British Columbia International Engineering Company, and the Morrison-Knudsen Construction Company.

Petrographic work was done in the laboratories of Princeton University and the British Columbia Department of Mines. Chemical analyses of rock specimens were made by the Analytical Branch of the British Columbia Department of Mines and by Aluminum Laboratories, Limited; spectrographic analyses of trace elements were made by the Analytical Branch of the British Columbia Department of Mines.

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CHAPTER II.—GENERAL GEOLOGY

INTRODUCTION

The Kemano-Tahtsa area is at the eastern border of the Coast intrusions, a belt of composite batholiths underlying the Coast Mountains. Within the area are exposed pre-Middle Jurassic igneous rocks (the Tahtsa complex), Middle and Lower (?) Jurassic volcanic and sedimentary rocks and their metamorphic equivalents (the Hazelton group), Cretaceous sandstones and shales, and post-Middle Jurassic granitic gneisses and massive igneous rocks (the Coast intrusions) (Fig. 2).

The Tahtsa complex is exposed in the central part of the map-area in the core of a large dome. It is overlain unconformably by the Hazelton group, which forms a belt completely surrounding the area of older rocks. To the east, rocks of the Hazelton group are overlain unconformably by late Lower Cretaceous sedimentary rocks, to the north they are truncated by massive quartz diorite, and to the west they are truncated by granitic gneisses. Granitic rocks that intrude the Hazelton group and Tahtsa complex range in composition from hornblende gabbro to quartz monzonite and albite granite, and occur in the form of batholiths, stocks, and tabular masses. All of the igneous rocks younger than the Hazelton group are thought to be related to the Coast intrusions of Late Jurassic and Cretaceous age.

West of the map-area lie granitic rocks of the main mass of the Coast intrusions. To the east lie Jurassic volcanic and sedimentary rocks that are intruded by numerous small igneous bodies and are overlain in places by Cretaceous sedimentary or Cretaceous and Tertiary volcanic rocks.

TAHTSA COMPLEX

The Tahtsa complex, which is pre-Middle Jurassic in age, underlies a roughly oval-shaped area in the central part of the map-area. The rocks comprise an igneous complex of hornblende diorite and quartz diorite cut by quartz monzonite stocks, granodiorite dykes, and basic dykes. The complex is bounded on all sides by younger rocks and its full extent is unknown. However, the area underlain by dioritic rocks is sufficiently làrge (90 square miles) to indicate a batholithic mass.

Diorite

Hornblende diorite constitutes over 75 per cent of the complex. It is extremely inhomogeneous in appearance, showing abrupt and unsystematic changes in texture, grain size, and degree of alteration, and is characterized by the occurrence throughout of numerous narrow veinlets and stringers of quartz diorite (Pl. IV).

Two varieties of diorite can be distinguished on the basis of texture and, to a lesser extent, mineral composition. The dominant variety is granitic in texture and is medium to dark grey in colour where fresh, and greenish grey where it has been altered. It consists of approximately equal proportions of hornblende and plagioclase with up to 10 per cent of quartz which, though rarely visible in hand specimens, is apparent in all thin sections. The grain size is most commonly medium but may range from very fine to coarse in the space of a few feet or less. The sudden changes in grain size are reflected by changes in the colour of the rock in outcrop and contribute to the general appearance of inhomogeneity; the fine-grained phases appear darker in colour than the coarser phases.

The subordinate variety of diorite is dark grey to dark greenish grey, depending on the degree of alteration present, and occurs as large and small irregular masses peripherally gradational into the dominant variety, but nevertheless cut by dykes of the dominant variety. It consists largely of hornblende and plagioclase as does the more abundant variety, but there is an excess of hornblende over plagioclase. Quartz is never visible in hand specimens, and, if present at all, does not exceed 3 or 4 volume per cent in thin section. A feature of this rock which serves to distinguish it from the previously described diorite is the form of the hornblende. Much of the hornblende occurs in euhedral to irregular poikilitic crystals surrounded by a granitic-textured matrix of medium- to fine-grained hornblende and plagioclase (Pl. V). The hornblende crystals may be an inch or more in diameter, and commonly break along cleavage planes, giving the rock a distinctive spotted appearance when light is reflected from its surface.

Microscopically, both varieties of diorite exhibit well-twinned zoned laths of plagioclase averaging andesine-labradorite in composition, and euhedral to anhedral hornblende; quartz, when present, is interstitial to these minerals. Accessory minerals include apatite, sphene, zircon, magnetite, ilmenite, and pyrite. Modal analyses of several specimens are shown graphically in Figure 3.

Most exposures of the diorite are highly sheared and fractured, and a chlorite-epidote alteration that decreases in intensity outward from the fractures has affected practically all of the diorite to some degree.

Quartz Diorite

Quartz diorite is a widespread but relatively minor component of the Tahtsa complex and occurs in a variety of different forms.

It is characteristic of virtually all exposures of diorite as narrow discontinuous straight-walled stringers filling joints and fractures, or as irregular intersecting stringers and patches that appear to be in part of replacement origin (Pl. IV). Locally the quartz diorite is present in sufficient quantity to isolate blocks of diorite and to impart a brecciated appearance to the rock. The diorite blocks have sharp boundaries against quartz diorite and may be either angular or rounded. The quartz diorite surrounding the blocks is usually rather variable in grain size and mineral composition, and may contain many small fragments of diorite. There is no orientation of rock fragments or mineral grains in the quartz diorite. In exposures of this sort the structural features suggest that injection of quartz diorite magma into fractures and transformation of diorite into quartz diorite have both played a part in the development of the rock.

Several isolated and rather small zones of quartz diorite are characterized by a well-developed gneissic foliation or banding which has been deflected around numerous included blocks of diorite. About three-quarters of a mile south of the south end of Siffleur Lake there is an area of mixed quartz diorite and diorite that appears to be transitional between the breccia-like quartz diorite-rich zones and these quartz diorite gneisses. Here the quartz diorite is weakly foliated and some of the dioritic inclusions have been oriented or slightly drawn out parallel to the foliation.

Finally, quartz diorite occurs in the form of smooth-walled dykes from 1 to 50 feet in width, most of which show a well-developed foliation parallel to their walls. These dykes occur throughout the diorite mass, but are most abundant in the northeastern portion.

Specimens of quartz diorite from all the different types of occurrence are very similar in appearance and mineralogy. They are rather leucocratic, are medium to fine grained, and consist dominantly of quartz and plagioclase. Scattered grains

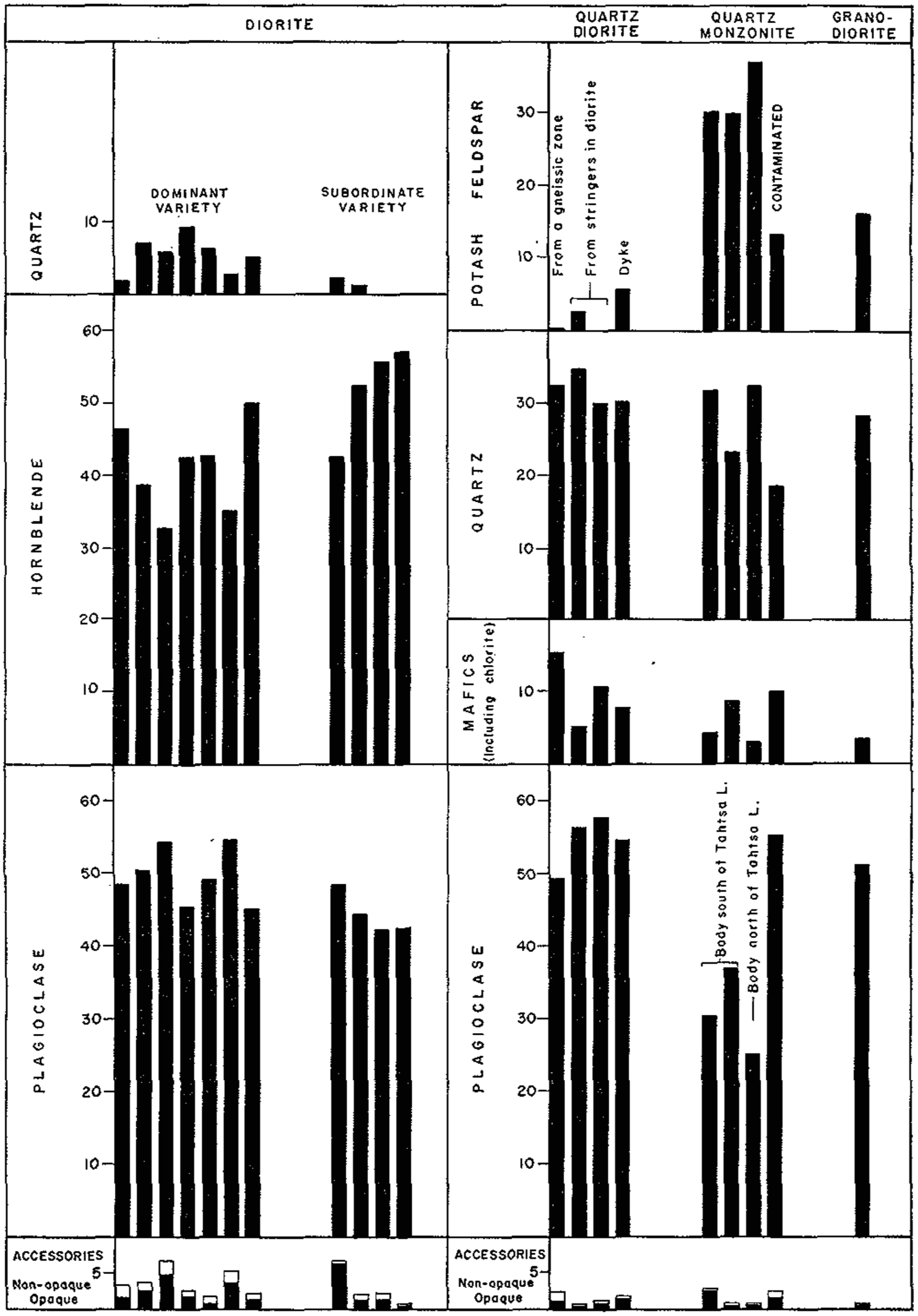


Fig. 3. Modes of specimens from the Tahtsa complex.

of chlorite, biotite, and occasionally hornblende impart a slightly greenish tinge to the rock. Modes of several specimens representative of the various occurrences are shown graphically in Figure 3. The modal characteristics common to all specimens include a high proportion of quartz and low proportions of mafic minerals or their alteration products, of potash feldspar, and of accessory minerals. Rocks of this mineral composition have been given the name of trondhjemite by Goldschmidt (Johannsen, 1932).

Microscopic examination shows that the plagioclase is andesine, which occurs as stubby subhedral to euhedral crystals that are moderately to strongly sericitized but that in many cases still show traces of zoning and twinning. Quartz occurs as small grains interstitial to plagioclase crystals and in part corroding them, and as large irregular unstrained grains that also show some evidence of replacement of plagioclase. When present, the potassium feldspar, a small proportion of which shows microcline twinning, occurs as small irregular unaltered crystals that are definitely corroding both quartz and plagioclase. Mafic minerals are highly altered to a light-green chlorite characterized by the inclusion of tiny specks of epidote and opaque minerals. Occasional unaltered remnants of the original mafic minerals are either biotite or hornblende. Accessory minerals are rare but include apatite, magnetite, zircon, and sphene.

The gneissic quartz diorite differs only in texture. Quartz occurs as aggregates of small strained angular grains with sutured boundaries, and has been drawn out into streaks or lenses that are deflected around plagioclase grains. The plagioclase crystals have become rounded through granulation of the corners and edges of the original stubby laths, and some have been broken. When present, potash feldspar shows no sign of deformation.

Granodiorite

A large number of dyke-like bodies of granodiorite, most of which are less than 50 feet wide, occur in a vaguely defined belt that trends north-northeast across the centre of the outcrop area of the complex. The individual dykes strike approximately parallel to the trend of the belt, but there is considerable local variation in strike with consequent intersection of dykes. Locally the dykes are closely spaced, and wedge- and slab-shaped blocks of diorite have been isolated between parallel and intersecting dykes (Pl. VI). The areas in which granodiorite constitutes 30 per cent or more of the outcrop are indicated on the geological map (Fig. 2). In general, dykes less than 10 or 15 feet in width exhibit sharp contacts with the enclosing rock, but many wider dykes are bordered by a zone in which numerous intersecting apophyses of granodiorite have isolated small angular blocks of the intruded rock. Where large dykes are close together, the septa of country rock between them consist of such injected zones rather than of solid diorite. Evidence of ultimate dispersion of the basic blocks in some of these zones is seen in the occurrence of numerous angular inclusions within many of the dykes.

The granodiorite is light grey to pinkish in colour and consists dominantly of glassy grey quartz and white feldspar. Both plagioclase and potash feldspar are white—the pink colour of some of the specimens is the result of alteration of both plagioclase and potash feldspar. The grain size varies from medium to coarse, but is uniform within individual dykes. There is no relation between the width of a dyke and its grain size. The modal analysis of a specimen of medium-grained granodiorite is shown graphically in Figure 3.

Microscopically, oligoclase occurs as twinned and weakly zoned subhedral to euhedral crystals that are invariably sericitized, in many instances strongly so. Quartz occurs as large anhedral and extremely irregular grains, often showing evidence of replacement of plagioclase crystals, and as small grains interstitial to and in part replacing plagioclase. In some thin sections the large quartz grains are composed of aggregates of small crystals with sutured boundaries, in others they are single crystals. The potash feldspar, chiefly microcline or microcline perthite, is normally less altered than the plagioclase in the same thin section. It occurs as large grains with cuspate borders penetrating into or between plagioclase and quartz grains—as small irregular grains interstitial to and in part replacing plagioclase and quartz—and as narrow stringers cutting these minerals or following contacts between them. Biotite is the only mafic mineral present, and in most sections is altered to an aggregate of chlorite, epidote, opaque minerals, and sometimes calcite. Accessory minerals are not abundant, but include apatite, magnetite, zircon, and rarely ilmenite.

Quartz Monzonite

A large tabular body of quartz monzonite 2 miles wide and at least 5 miles long occurs south of Tahtsa Lake, in the southeastern part of the Tahtsa complex outcrop area. This body trends northeast, approximately parallel to the belt of granodiorite dykes to the northwest. The contacts of the body are not well exposed, but the rocks adjacent to the contact are cut by numerous quartz monzonite dykes.

Hand specimens of the quartz monzonite are grey to rather dark pink in colour and are either medium-grained, fine-grained, or fine-grained porphyritic in texture. Changes in colour and texture within the quartz monzonite mass may be abrupt, but are always gradational. Feldspar is the dominant recognizable mineral in all phases, and forms the phenocrysts in porphyritic specimens. Chlorite is visible as small grains scattered throughout some specimens. Quartz, though not apparent in the fine-grained varieties, can be recognized in medium-grained specimens. Modal analyses of a fine-grained and a fine-grained porphyritic specimen are shown in Figure 3.

Thin sections of the quartz monzonite are characterized by micrographic or vermicular intergrowths of potash feldspar with quartz and plagioclase. The degree of development of these intergrowths is, however, greatly variable—in some sections potash feldspar and most of the quartz occur only as such intergrowths; in others discrete grains of quartz and potash feldspar are numerous, whereas intergrowths are rare and poorly defined. All sections contain euhedral, twinned, and weakly zoned plagioclase crystals averaging An_{10-13} in composition. They are moderately to strongly sericitized, and in sections showing well-developed potash feldspar intergrowths they have sharply defined border zones consisting of vermicular potash feldspar and plagioclase (Pl. VII). No primary mafic minerals are present, but aggregates of chlorite, epidote, iron ores, and minor calcite occur in most sections and are probably alteration products of the original mafic minerals. Magnetite is the most common accessory mineral, and apatite, ilmenite, sphene, and zircon have been observed but are not present in all sections.

The mode of a specimen from a small body of quartz monzonite that outcrops at the eastern edge of the igneous complex 2 miles north of Tahtsa Lake is also presented in Figure 3. This rock is very similar in mineral composition to the quartz monzonite south of Tahtsa Lake, but is quite different texturally in that potash feldspar intergrowths are very rare. The potash feldspar, a microcline microperthite, occurs as large very irregular grains, many of which show replacement textures against oligoclase and quartz. In some cases the relations between potash feldspar and quartz suggest the beginning of a granophyric intergrowth.

A small granodiorite stock near the northern border of the Tahtsa complex consists essentially of a matrix of granophyre enclosing highly altered euhedral plagioclase crystals and patches of green chlorite, some of which contain remnants of hornblende (*see* modal analysis in Fig. 3). Dark inclusions are very common in a wide zone at the boundary of the stock, and range from shadowy schlieren at the inner side of the zone to angular, sharply bounded fragments of recognizable hornblende diorite at the outer side. This granodiorite is considered to be genetically related to the quartz monzonites just described. Conclusive evidence of the relationship is lacking, but the granophyric groundmass is, in this area, restricted to the quartz monzonites. The compositional difference between the granodiorite stock and the quartz monzonite bodies may be due to contamination of quartz monzonite magma by incorporation of dioritic country rock, evidence for which is plentiful in the border zone of the stock.

Basic Dykes

Basic dykes constitute approximately 5 to 10 per cent of the total volume of the Tahtsa complex. They occur throughout the area, but are most apparent in the areas of quartz monzonite and granodiorite intrusion, where they cross light-coloured rocks (Pl. VIII). The dykes are generally randomly oriented, range in width from a few inches to several feet, and in many instances have narrow chilled margins. Occasional local well-defined dyke sets occur.

Basic dykes of at least three ages are represented, the oldest of which cut both varieties of diorite and are cut by the quartz monzonite and granodiorite. Only a few dykes of this age were recognized, one of which is shown in Plate IX. Somewhat younger dykes cut all other rocks of the complex but do not cut the overlying Hazelton rocks; dykes of this age are the most abundant in the complex. Much younger basic dykes are the youngest intrusive rocks in the area, and intrude the Hazelton group and the Coast intrusions as well as the Tahtsa complex.

Megascopically, basic dykes of different ages are indistinguishable. All are dark green to black in colour and weather greenish grey, and all may be aphanitic, fine grained, or porphyritic. Microscopically, they are all characterized by a random felted arrangement of lath-like subhedral to euhedral crystals of plagioclase and hornblende, frequently with phenocrysts of one or both of these minerals. Pyroxene is present in a few dykes of each age, quartz may be present interstitially in minor amounts, and apatite, sphene, and magnetite are the chief accessory minerals. The most appropriate name for these rocks is microdiorite, even though this term usually implies non-porphyritic rocks.

The youngest dykes may be distinguished from the two older types on the basis of the following mineralogical differences:—

(1) The complete alteration of hornblende to chlorite in many of the older dykes and the presence of hornblende remnants in even the most strongly altered of the youngest dykes.

(2) The occurrence of dark-green or olive-green hornblende in all of the older dykes in which hornblende is not completely chloritized, and reddish-brown or greenish-brown hornblende in all the youngest dykes.

(3) The occurrence of bright-green chlorite in many of the older dykes, and pale-green to colourless chlorite in all of the youngest.

(4) When present, pyroxene is a colourless augite in the older dykes and a purplish titaniferous augite in the youngest.

Structure

The chief structural features of the Tahtsa complex are sheared and fractured zones. These are extremely abundant in the areas underlain by diorite, where virtually every outcrop shows some sign of shearing. The sheared zones range in width from a few inches to several hundred feet and are characterized by strong slickensiding and alteration of the rocks involved. Shears and fractures of almost any attitude can be found, but a statistical study made in the Kemano tunnel showed two dominant sets—one striking north-northeast, the other north-northwest, and both dipping to the east at angles from 50 to 70 degrees (Fig. 4). Neither of these trends is well developed in the overlying Hazelton rocks (Fig. 4), and it may be assumed that they reflect pre-Middle Jurassic deformation. The north-northwest shearing is by far the most strongly developed, and is parallel to the gneissic structure in the small areas of quartz diorite gneiss.

The granodiorite and quartz monzonite in the complex are considerably fractured, but are not highly sheared and were probably emplaced after the period of shearing.

Age

The age of the rocks constituting the Tahtsa complex cannot be specifically determined. They are, however, older than the Hazelton group, the lower part of which is Middle Jurassic and possibly Early Jurassic in age, and are therefore no younger than Middle Jurassic. One hundred and fifty miles to the east, dioritic rocks modally identical with the diorite of the complex form batholithic bodies in the Fort St. James map-area. These bodies have been mapped as part of the Topley intrusions, and dated as post-Middle Permian, pre-Upper Triassic (Armstrong, 1949). Tipper reports that igneous rocks similar in all respects to the Topley intrusions occur in the Nechako River map-area, immediately south of the Fort St. James map-area. He believes that the intrusions are younger than the Takla group, which includes Upper Triassic and probably Lower Jurassic sediments. Detritus derived from the Topley intrusions occurs in the lowest division of the Hazelton group, which rests unconformably on the Takla group, and Tipper therefore assigns the intrusions to the Lower Jurassic (Tipper, 1954).

HAZELTON GROUP

The Hazelton group, consisting of volcanic, metavolcanic, and metasedimentary rocks of Middle and probably Lower Jurassic age (Duffell, 1952), overlies the Tahtsa complex. The Hazelton strata are truncated on the north and west by intrusive rocks, but they extend to the east and southeast far beyond the map-area, interrupted only by occasional granitic stocks and by one small patch of Lower Cretaceous sediments, the westernmost part of which projects into the map-area.

The contact between rocks of the Hazelton group and the underlying rocks of the Tahtsa complex is well exposed in several places, and is unquestionably unconformable. South of Nanika Lake massive aphanitic volcanics overlie quartz diorite-veined hornblende diorite, 2 miles east of Sandifer Lake coarse volcanic breccias overlie both diorite and quartz monzonite, and on the north flank of Tahtsa Peak schistose impure limestone lies on a bevelled surface of hornblende diorite cut by granodiorite dykes. The unconformable nature of the contact is further indicated by the absence in Hazelton rocks of the basic dykes that are so common in the Tahtsa complex.

In the eastern part of the map-area the lower 2,000 feet of the Hazelton group is represented, consisting entirely of andesitic lavas, breccias, and tuffs. To the west the group includes several lenticular limestone beds and some rocks which, though considerably metamorphosed, probably represent argillaceous and siliceous sediments. Much of the material of probable sedimentary origin lies stratigraphically below the volcanics which are basal in the eastern part of the area, and possibly represents sediment deposited in an isolated basin at a time when the eastern part of the area was undergoing erosion.

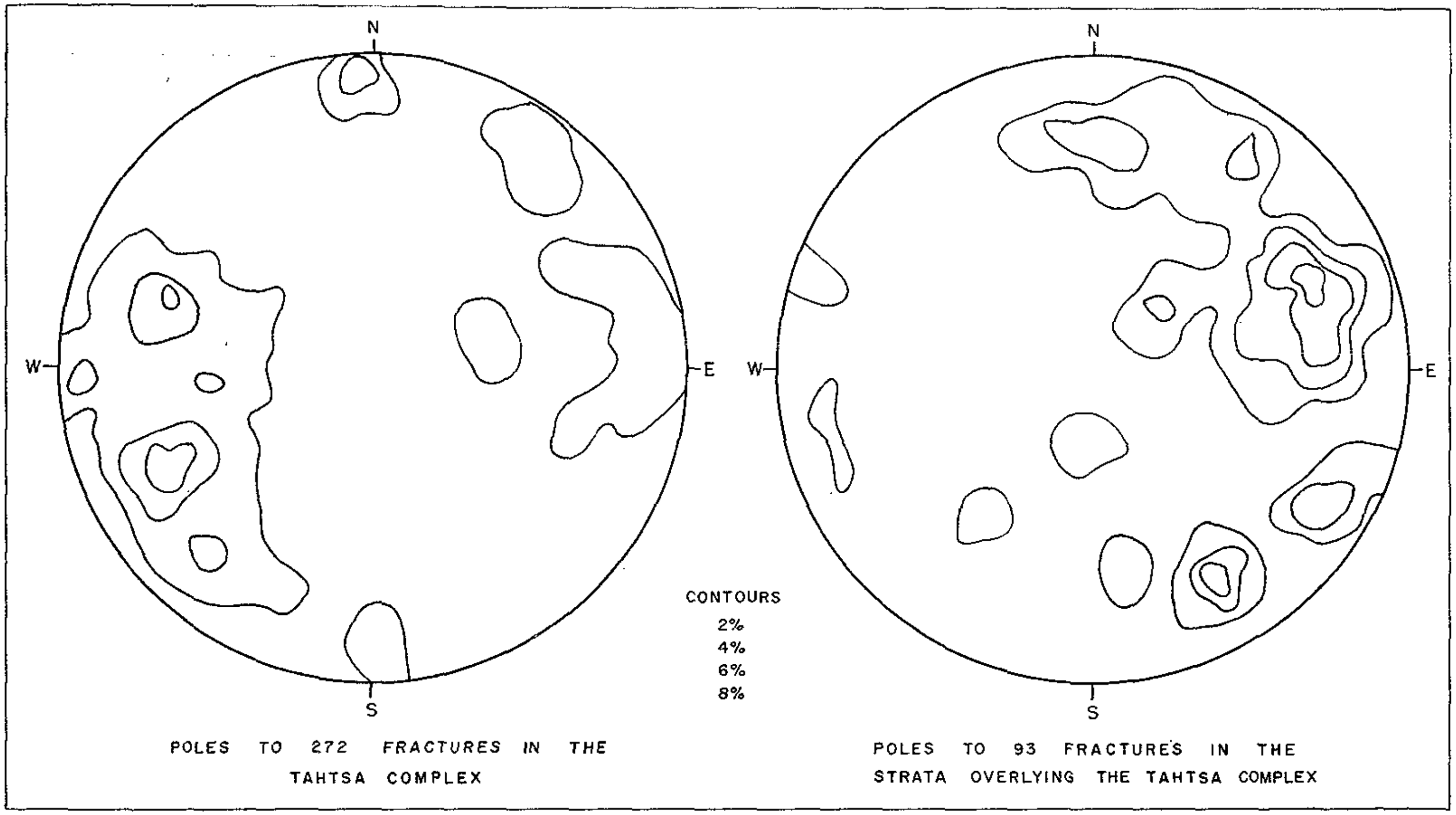


Fig. 4. Orientation of fractures in the Alcan tunnel.

Volcanic Rocks

Massive lavas are the most abundant component of the volcanic rocks underlying the eastern part of the map-area. The majority are light to dark green in colour, though shades of purple and red are not uncommon, and mottled green and purple lavas were observed in two places. Aphanitic and porphyritic textures are usual, with amygdaloidal textures present but very subordinate. The phenocrysts in porphyritic varieties may be plagioclase, pyroxene, or both. Microscopically, groundmass textures are commonly intergranular, felted, or pilotaxitic, though a few specimens consist of small plagioclase laths in a nearly isotropic chlorite matrix that probably represents an original glass. Fresh specimens consist of sodic andesine, augite, magnetite, and rare minor quartz. Most specimens, however, are moderately to strongly altered and consist of sericitized plagioclase, chlorite, and magnetite, with occasionally uralitic amphibole or quartz. In porphyritic varieties the phenocrysts are commonly less altered than the groundmass. Amygdules seen in only one thin section consisted of chlorite and chalcedonic quartz.

The volcanic breccias are generally massive, but locally exhibit a stratification resulting from differences in the dominant size or colour of the fragments in contiguous beds. The breccias consist of angular and subangular green, purple, or red fragments imbedded in a green aphanitic matrix. The lengths of the fragments may be as much as a foot or more, but are more commonly less than 1 inch (Pl. X). Microscopically, the breccias are seen to consist of andesite fragments in a cryptocrystalline to finely granular chloritic groundmass containing numerous discrete grains of plagioclase and some of quartz. In one specimen the groundmass exhibits graded bedding on a microscopic scale.

Tuffs are relatively rare. The few observed are green crystal tuffs consisting of euhedral crystals or angular fragments of andesine and chloritized or uralitized pyroxene and occasional angular fragments of quartz in a cryptocrystalline or finely granular matrix that is very similar to the matrix in the breccias.

Metamorphic Rocks

In the western part of the map-area, rocks of the Hazelton group are metamorphosed to a degree that in many instances obscures their original character, whether volcanic or sedimentary. Two general grades of metamorphism, corresponding to Turner's greenschist and amphibolite facies (Turner, 1948), may be recognized, forming two zones whose distribution is shown on Figure 5. Rocks of the higher-grade amphibolite facies occur in relatively narrow belts adjacent to intrusive bodies. They are transitional into rocks of the greenschist facies, which are in turn transitional into unmetamorphosed rocks.

Most of the rocks of the greenschist facies are light to very dark green in colour, weakly to strongly schistose, and very fine grained. The development of the schistosity, which is parallel to bedding where bedding can be identified, is well illustrated in the vicinity of Sandifer Lake, where greenschist rocks grade into unmetamorphosed volcanics. A complete transition exists from undeformed breccias, through sheared breccias with fragments stretched to several times their original length, to schists with no recognizable fragmental texture. The shearing is represented in thin section by a streaking of the very fine-grained to cryptocrystalline groundmass of both breccias and tuffs, and a deflection of the laminæ so produced around elongated lithic fragments and partly crushed quartz grains (Pl. XI). Extensive mineralogical reconstitution accompanies the shearing, and, together with the granulation of lithic fragments and mineral grains, has produced the present very fine-grained to cryptocrystalline condition of the rocks.

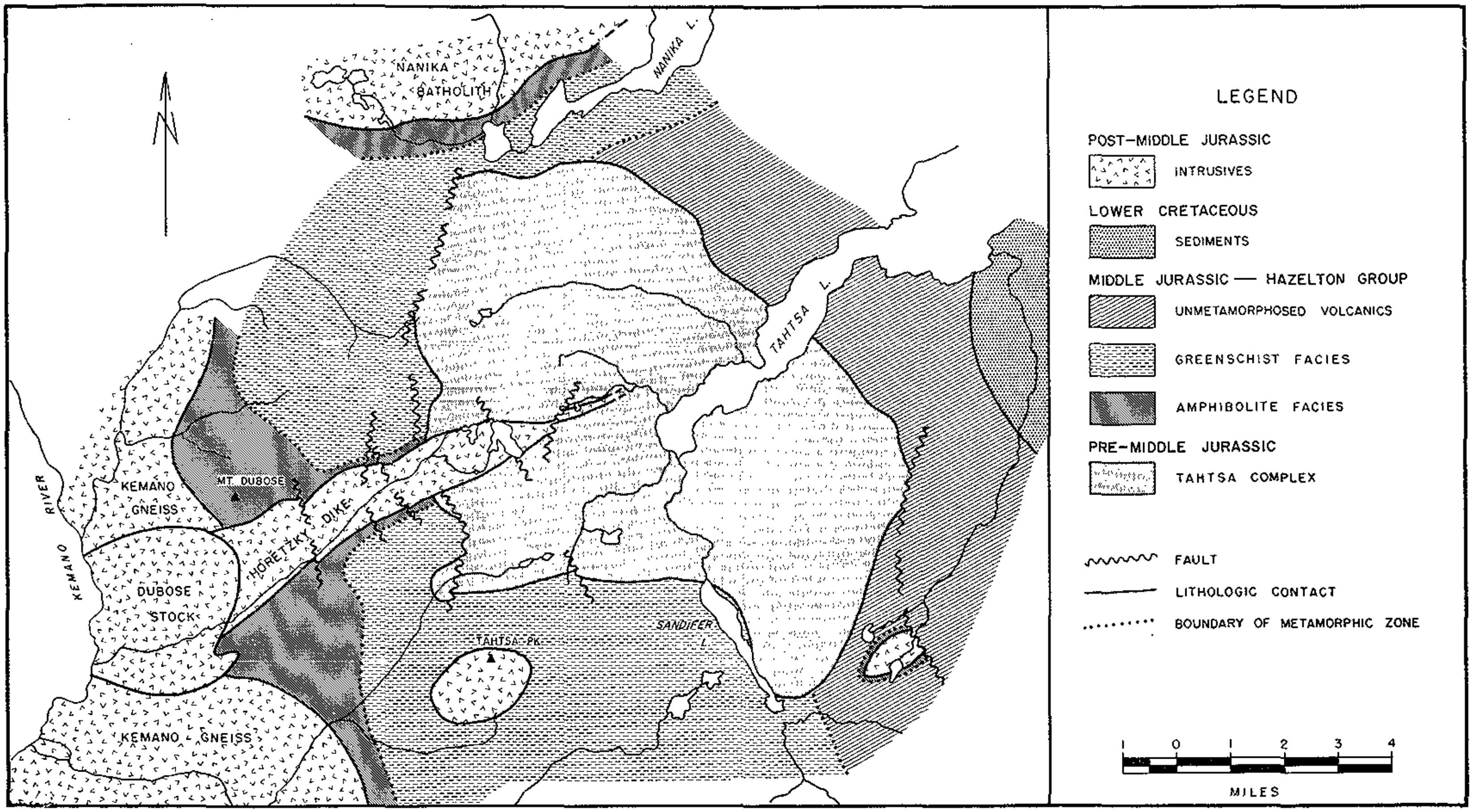


Fig. 5. Distribution of metamorphism.

The sheared volcanic rocks are composed of albite, chlorite, calcite, magnetite, minor quartz, and occasionally abundant epidote. The albite occurs in the groundmass and, in tuffs and breccias, as fragments, many of which contain minute grains of calcite or are partly replaced by coarser aggregates of calcite. Pale-green chlorite occurs as minute flakes scattered throughout the groundmass and as larger flakes and stretched aggregates of small flakes defining the schistosity. Calcite also occurs as small grains scattered throughout the groundmass, but is locally aggregated into coarser-grained clots, particularly where in contact with and replacing albite. Magnetite is rather random in distribution; it is abundant in some specimens and rare in others. Where abundant it is very fine grained and drawn out into streaks in the plane of the schistosity. Recognizable quartz is largely restricted to the tuffs, where it occurs as rounded to angular grains of a size comparable with the feldspar fragments. The quartz appears to have been more susceptible to crushing during the shearing than was the albite, as crushing and peripheral granulation is more pronounced on quartz grains than on albite grains in the same sections. Epidote is present in many of the specimens and may be locally very abundant. It occurs as equidimensional grains or as granular aggregates and is commonly coarser than the other minerals present.

Schistose rocks that probably represent tuffaceous silty and argillaceous sediments occur west of the north end of Sandifer Lake stratigraphically below the sheared volcanics and near the base of the Hazelton section. Similar rocks are characteristic of the lower part of the section all along the southern and western margin of the Tahtsa complex, and are interbedded with tuffs, cherty laminated rocks, and occasional limestone lenses. The argillaceous sediments are similar texturally to the tuffs higher in the section inasmuch as they consist of a sheared and streaky cryptocrystalline matrix containing angular grains of albite and quartz. They differ mineralogically, however, in that the matrix contains abundant sericite occurring as scattered flakes and as aggregates of flakes forming discontinuous laminæ in the plane of the schistosity. Some specimens exhibit alternations of sericite-rich layers with chlorite-rich layers that suggest original alternations of clay-rich layers and andesitic ash. The silty sediments differ from the argillaceous sediments chiefly by virtue of a much greater proportion of quartz in the groundmass, which is coarser than that of the argillaceous sediments. Alternations of sericite-rich and sericite-poor layers in the silty sediments again suggest original alternations of clay-rich and clay-poor material.

Finely laminated cherty rocks outcrop on the flanks of the mountains north and south of Horetzky camp. They are less schistose than most of the other rocks in the greenschist zone, and are composed of laminæ extremely rich in sericite and muscovite alternating with laminæ consisting of cryptocrystalline to fine granular quartz, occasional small calcite grains, and rare, relatively large albite crystals. They probably represent either laminated argillaceous chert or silicified tuff.

Limestone beds outcrop a short distance above the base of the Hazelton group on the north flank of Tahtsa Peak, and on the ridges north and south of Horetzky Creek just east of Horetzky camp. On the ridge north of Horetzky Creek, limestone forms a lens 20 to 30 feet thick at its thickest part and slightly over one-half mile in strike length. The limestone bed on the ridge south of Horetzky Creek is 10 feet thick at the crest of the ridge, pinches out completely on the north side, and increases slightly in thickness on the south side, where it disappears beneath a talus slope. This bed may be continuous with a 50-foot-thick bed outcropping near the foot of the north flank of Tahtsa Peak. If so, the bed is over 2 miles in strike length. The limestone at all three outcrop areas is dense, finely crystalline, white to blue-grey in colour, and in part well laminated. Much of it is impure and contains thin siliceous layers that weather less rapidly than adjacent more pure layers and stand out in relief on weathered surfaces. The impurities consist of sericite and very small grains of quartz and altered feldspar.

In the extreme western part of the greenschist zone, brown biotite and a little blue-green amphibole occur in the generalized assemblages plagioclase-chlorite-epidote-biotite-quartz, and plagioclase-chlorite-epidote-amphibole-minor quartz. The plagioclase is sodic oligoclase and is transitional between the albite plagioclase characteristic of the greenschist facies and the more calcic plagioclase occurring in rocks of the amphibolite facies.

Rocks of the amphibolite facies are light to dark grey or grey-green in colour and lack the schistosity characteristic of the greenschist facies. A planar structure such as a lamination or a parallel arrangement of streaks of mafic minerals produces a gneissic appearance throughout the zone, but only rarely is this accompanied by schistosity. The grain size varies systematically from very fine grained in the outer parts of the zones to fine or medium grained in the inner parts, adjacent to igneous contacts. In the very fine-grained rocks the only minerals occurring in grains large enough to be recognized megascopically are amphibole, biotite, and garnet, all of which form small porphyroblasts. In the coarser rocks the grain is more uniform, and amphibole, biotite, epidote, feldspar, and quartz are the dominant minerals.

Microscopically, crystalloblastic textures are characteristic. In the outer parts of the zones, poikiloblastic porphyroblasts of amphibole and biotite are common, and subhedral to euhedral poikiloblasts of garnet occur locally. In the inner parts of the zones, where the general grain size is larger, mafic minerals typically occur as grains somewhat larger than the associated quartz and feldspar. The increase in grain size toward igneous contacts is accompanied by a progressive change in the composition of the plagioclase from intermediate oligoclase to intermediate andesine.

Two distinct mineralogical assemblages occur in rocks of the amphibolite facies. One consists of quartz, plagioclase, microcline, muscovite, biotite, epidote, and hornblende. These minerals occur in varying proportions, but most commonly the felsic minerals are dominant and hornblende is the least abundant of the mafics. Red garnet, probably almandine, is present in some of the rocks of this type. The second common assemblage consists of hornblende, biotite, epidote, plagioclase, and quartz. Again the proportions are highly variable, but most commonly hornblende is the dominant mineral, and quartz is definitely subordinate in quantity to plagioclase. Magnetite, sphene, and apatite are common accessories in both assemblages. Primary textural features have been completely obliterated, and speculation on the nature of the rocks from which they have been derived must be based entirely on mineral composition. Inasmuch as all of the volcanic rocks east of the zones of metamorphism are andesitic in composition, it has been assumed that rocks whose mineral assemblages are incompatible with derivation from such volcanics are metasediments. More specifically, the occurrence of abundant quartz and the potash-rich minerals microcline and muscovite is taken to indicate a metasediment. Rocks consisting dominantly of plagioclase, hornblende, and epidote, and with only minor quartz and biotite are considered to be metavolcanics. Thus the above two typical mineral assemblages are considered to represent sedimentary and volcanic rocks, respectively.

Several limestone beds occur in the westernmost amphibolite zone. At distances of as little as one-half mile from igneous contacts they are little more than recrystallized, but adjacent to contacts they have been converted to skarn. One exposure approximately 300 feet from the contact of a quartz diorite stock consists of well-defined bands of crystalline limestone, calc-silicate skarn, and quartz-feldspar gneiss that probably represent beds of pure limestone, impure limestone, and clastic sediment, respectively. The most abundant silicates in the skarn are wollastonite, diopside, and garnet, which are accompanied by quartz, calcite, and minor sphene, apatite, and highly altered plagioclase.

Origin of Metamorphism

According to Turner the greenschist facies is characteristic of low-grade dynamothermal metamorphism and is rarely encountered in aureoles of contact metamorphism. The amphibolite facies may represent either thermal (contact) metamorphism or medium- to high-grade dynamothermal (regional) metamorphism (Turner, 1948, pp. 93, 76). The lack of marked schistosity in the amphibolite zone in the Kemano-Tahtsa area indicates that the metamorphism was not accompanied by strong shearing stresses, but was dominantly thermal. It is probable, however, that an earlier regional or dynamothermal metamorphism was widespread and that it has been obliterated in the zones of thermal metamorphism. Some of the planar but non-schistose structures in the amphibolite zone may be interpreted as relicts of the earlier schistosity.

Whatever may have been the source of heat during dynamothermal metamorphism there is little doubt as to the source of heat responsible for the thermal metamorphism. In the western part of the area three intrusive bodies are present: the Kemano gneiss, which underlies much of the westernmost part of the map-area; the Horetzky dyke, which extends eastward from Mount DuBose almost to Tahtsa Lake; and the DuBose stock, which underlies the southwest flank of Mount DuBose (Fig. 13). The greatest width of the amphibolite facies, approximately 3 miles, occurs where the three intrusives coincide and all have contributed to its development. Where the contact metamorphism is attributable only to the Kemano gneiss, the zone is less than 1 mile wide, and where attributable to the Horetzky dyke alone it is less than 1,000 feet wide. It is apparent, therefore, that the DuBose stock has been the chief agent of metamorphism, possibly because the magma from which the stock crystallized was the richest in volatiles which permeated the country rock and promoted recrystallization. This possibility is supported by the relative abundance of hydrous minerals and pegmatite dykes and the prevalence of deuteric and late magmatic replacements in the stock, all of which indicate a hydrous magma.

LOWER CRETACEOUS

Well-bedded Cretaceous sedimentary rocks overlie the Hazelton volcanics in the easternmost part of the map-area. They form the western tip of a 5,000-foot-thick section of sediments that is exposed in an area approximately 12 miles long and 5 miles wide, on the south side of Tahtsa Lake. Marine fossils of late Lower Cretaceous age have been collected near the base of the section (Duffell, 1952).

The contact between the Hazelton volcanics and the Cretaceous sediments was not observed. However, the stratigraphic distance between the base of the Hazelton section and the base of the Cretaceous section is not sufficiently great to accommodate the known thickness of Hazelton strata in the area, and the contact is probably a structural unconformity. Duffell arrived at the same conclusion on the basis of structural data obtained east of the Kemano-Tahtsa area—the Hazelton volcanics are folded along north-trending axes and exhibit both easterly and westerly dips. The Cretaceous sediments, on the other hand, are monoclinal, with an easterly strike and a southerly dip (Duffell, 1952).

The Cretaceous strata consist of a series of interbedded sandstones and shales. In the lower part of the section exposed in the map-area, thick-bedded grey to greenish-grey sandstone predominates, and black shale occurs in occasional intercalated beds that are rarely more than a few feet thick. Higher in the section, black shale is much more abundant, and the sandstone is thin bedded and locally exhibits cross-bedding or ripple marks.

The sandstone is very fine grained, and consists of rather well-sorted angular to subangular grains of cryptocrystalline lithic fragments, fresh to highly altered feldspar, and quartz, in a sparse chloritic matrix. The cryptocrystalline grains are very similar in appearance to the matrix of the tuffs and volcanic breccias in the underlying Hazelton volcanics, and a few contain tiny feldspar laths.

COAST INTRUSIONS

Post-Middle Jurassic igneous rocks of the Coast intrusions occupy the northern and western parts of the map-area and form dykes and stocks in the Hazelton and older rocks. Three separate intrusions outcrop on Mount DuBose. The oldest of the three consists of banded or well-foliated quartz diorite gneiss, the Kemano gneiss, that underlies much of the westernmost part of the map-area and is intrusive into the Hazelton group. The Kemano gneiss is cut by a tabular body of diorite and quartz diorite, the Horetzky dyke, which is itself cut by a body of quartz diorite and granodiorite, the DuBose stock. Two smaller bodies, the relative ages of which can be only partially established, also occur in the western part of the map-area. One is a lenticular mass of hornblende gabbro, on the footwall of the Horetzky dyke in the vicinity of Horetzky camp. The other is a tabular body of granodiorite outcropping on the east side of the Kemano Valley, about 1½ miles south of Kemano camp. The gabbro is older than the Horetzky dyke but is of unknown age relative to the Kemano gneiss; the granodiorite is younger than the Kemano gneiss but is of unknown age relative to the Horetzky dyke and the DuBose stock.

Three other intrusive bodies have been mapped, but they are widely separated and their relative ages are unknown. The largest of the three, the Nanika batholith, is composed of quartz diorite and granodiorite and occupies the northernmost part of the map-area. An oval-shaped stock of albite granite outcrops on Tahtsa Peak in the southern part of the area, and a smaller stock, ranging from quartz diorite at the edges to granodiorite in the centre, outcrops 2 miles east of Sandifer Lake, in the southeast part of the map-area.

Several small masses of relatively fresh quartz diorite or granodiorite that were encountered on traverses in the area of the Tahtsa complex are probably related to the Coast intrusions, but their boundaries were not determined and they are not shown on the geological map (Fig. 2).

KEMANO GNEISS

The westernmost part of the map-area is underlain by crystalline gneisses that are part of a zone of mixed gneiss and granitic rock exposed along the Kemano River for at least 10 miles northwest and southwest of the map-area. The full dimensions of this zone are not known, nor the relations between the gneiss and the batholithic rocks to the west.

The Kemano gneiss is bounded on the east by metamorphic rocks of the Hazelton group. The contact is sinuous, trending in a general northwesterly direction, and although more or less gradational lithologically, it is very abrupt structurally. The major structural features in the Hazelton rocks trend slightly east of north and are truncated by the gneiss contact. The layering or foliation within the gneiss strikes parallel to the contact and dips vertically or very steeply west. The rocks of the Hazelton group have similar attitudes immediately adjacent to the contact, but at distances greater than a few hundred feet from the contact they exhibit north-northeast strikes and low dips. For a distance of approximately three-quarters of a mile from the contact the Hazelton group consists of hornblende-biotite-plagioclase-quartz-epidote rocks of the amphibolite facies. At the contact these rocks may be distinguished from certain phases of the gneiss only by their finer grain size.

The gneiss consists of variable proportions of fine- to medium-grained dark-, medium, and light-grey crystalline rocks. The dark and light phases are strongly foliated and invariably occur together as a banded gneiss. For the most part, the dark phase is dominant and the light phase forms well-defined bands from a fraciton of an inch to several inches wide. The banding is parallel to the foliation, and bands locally pinch and swell and may pinch out completely (Pl. XII). Both dark and light phases have a crystalloblastic texture, and consist of andesine, quartz, biotite, hornblende, minor potash feldspar, and accessory apatite, magnetite, zircon, and sphene (Pl. XIII). The two phases differ from one another only in the relative proportions of the major mineral constituents.

The medium-grey phase is a medium- to rather coarse-grained gneissic quartz diorite with a less strongly developed gneissosity than the light and dark phases. It has the hypidiomorphic texture characteristic of many igneous rocks and is composed of euhedral and subhedral andesine, quartz, biotite, minor potash feldspar, and hornblende, and accessory magnetite, apatite, sphene, and zircon. This phase occurs as concordant bands or as crosscutting dykes in the banded gneiss, and also as sizeable bodies that may contain rotated blocks of banded gneiss.

Significant characteristics of the gneiss include the banding and foliation parallel to the eastern contact; the crosscutting nature of this contact and the metamorphism of adjacent Hazelton rocks; the similarity between the metamorphosed rocks and the light and dark components of the banded gneiss; and the crosscutting nature of a part of the quartz diorite component of the gneiss. Several of these features are duplicated in the contact zones of the Chelan and Colville batholiths in Washington (Waters, 1938; Waters and Krauskopf, 1941).

Horetzky Dyke

A steeply dipping dyke of grey medium-grained diorite and quartz diorite extends some 8 miles east-northeast from Mount DuBose, almost to Tahtsa Lake. The width of the dyke is approximately 8,000 feet at Mount DuBose; it decreases gradually eastward to 4,000 feet at Siffleur Lake, 6 miles to the east, and more rapidly from there to the easternmost exposures where the dyke is only about 500 feet wide. The eastern termination does not outcrop, but the rapid thinning in the eastern 2 miles of its exposed length suggests that the dyke pinches out within a short distance of the last exposures. Surface and underground geological mapping has shown that the dyke dips 75 degrees south at Mount DuBose, but that it decreases in dip gradually to 60 degrees south at the west side of Siffleur Lake. In a segment of the dyke bounded by a fault at Siffleur Lake and another fault about 1 mile east of the lake the dip is 45 degrees or less to the south; east of the latter fault it is again 60 degrees south.

The Horetzky dyke intrudes the Tahtsa complex, the Hazelton group, the small body of hornblende gabbro at Horetzky camp, and the Kemano gneiss. It is intruded by the DuBose stock.

Wherever exposed, contacts between the dyke and the country rock are very sharp. A planar structure may be present in the quartz diorite, parallel to and within a few feet of the contact, expressed chiefly by parallel orientation of tabular inclusions and by schlieren. Angular inclusions correlative with the adjacent wallrock are not common, but occur in several local zones. One such zone includes several blocks 8 to 10 feet in length, as well as numerous smaller angular fragments.

In general, mineral orientation is lacking in the Horetzky dyke, although there is a perceptible alignment of biotite and hornblende grains within a few feet of the hangingwall and footwall contacts. This alignment produces a foliation parallel to the walls and to occasional schlieren and tabular inclusions found in the contact zone. Small rounded dark inclusions of a type not uncommon in granitic intrusions are moderately abundant, at least in the lower 1,000 feet of the dyke, where exposures in the walls of the tunnel give a continuous section. Many of the inclusions are discoidal, and are almost invariably oriented with their long axes subhorizontal. If the orientation of these inclusions was a consequence of magma flow during emplacement, it should, in a tabular body, be parallel with the walls. The existing orientation is therefore better explained as a result of settling, during which there was rotation of the discoidal inclusions into their most stable position.

Where the dyke cuts layered rocks, it is apparent that the country rock has been deformed by the intrusion. The layering is always essentially conformable with the contact even though its attitude may be quite different a short distance away. An excellent illustration of dragging of adjacent rock into conformity with the dyke wall is afforded by the east face of Mount DuBose, where gently dipping strata are steepened and slightly overturned against the footwall of the dyke. A similar drag is well exposed in a small gully northwest of Horetzky camp, and is accompanied by minor folding on axes that are parallel to the contact and almost at right angles to the general trend of folds in the immediate area.

The nature of the offset of the body of hornblende gabbro near Horetzky camp and of the zone of granodiorite at Siffleur Lake indicates that the emplacement of the dyke was accompanied by a dilation of the country rock. However, the zone of deformation bordering the dyke is narrow and the intensity of deformation is less than would be expected had dilation been the result of magmatic pressure alone, and it appears probable that the dyke was emplaced in a tensional opening and that the role of forceful intrusion was minor.

Mineralogical variations across the strike of the Horetzky dyke are shown in Figure 6. The mode at each locality is the average of two or three point-count analyses made on thin sections cut from different specimens collected at that locality. In every case the modes of different specimens from the same locality agree within 3 or 4 volume per cent for the major constituents, and less for the minor constituents. The plagioclase compositions were determined on the universal stage by the Rittman extinction angle method, using the revised extinction angle curves prepared by Tröger (1952). The absolute compositions determined by this method may be somewhat in error, but the relative compositions, and hence the variations in composition shown on Figure 6, should be reliable.

Figure 6 shows that the top fifth and the bottom fifth of the dyke have the mineral composition of diorite, whereas the central part has the mineral composion of quartz diorite. The chief similarities and differences between the two rock types are discussed in the following generalized petrographic descriptions.

In the diorite, the plagioclase occurs in the form of euhedral and subhedral twinned crystals zoned from a rather uniform core of sodic labradorite to an outer rim of sodic andesine. Hornblende is strongly pleochroic, with $a > b > c =$ pale yellow : dark brownish green : dark green; and has an α' index on cleavage flakes of 1.665. It occurs mainly as anhedral grains that are interstitial to or replace plagioclase crystals, but in specimens containing over 6 or 7 per cent quartz some occurs as subhedral and euhedral crystals that may contain uncorroded euhedral plagioclase inclusions. Thin sections of specimens collected from the upper and

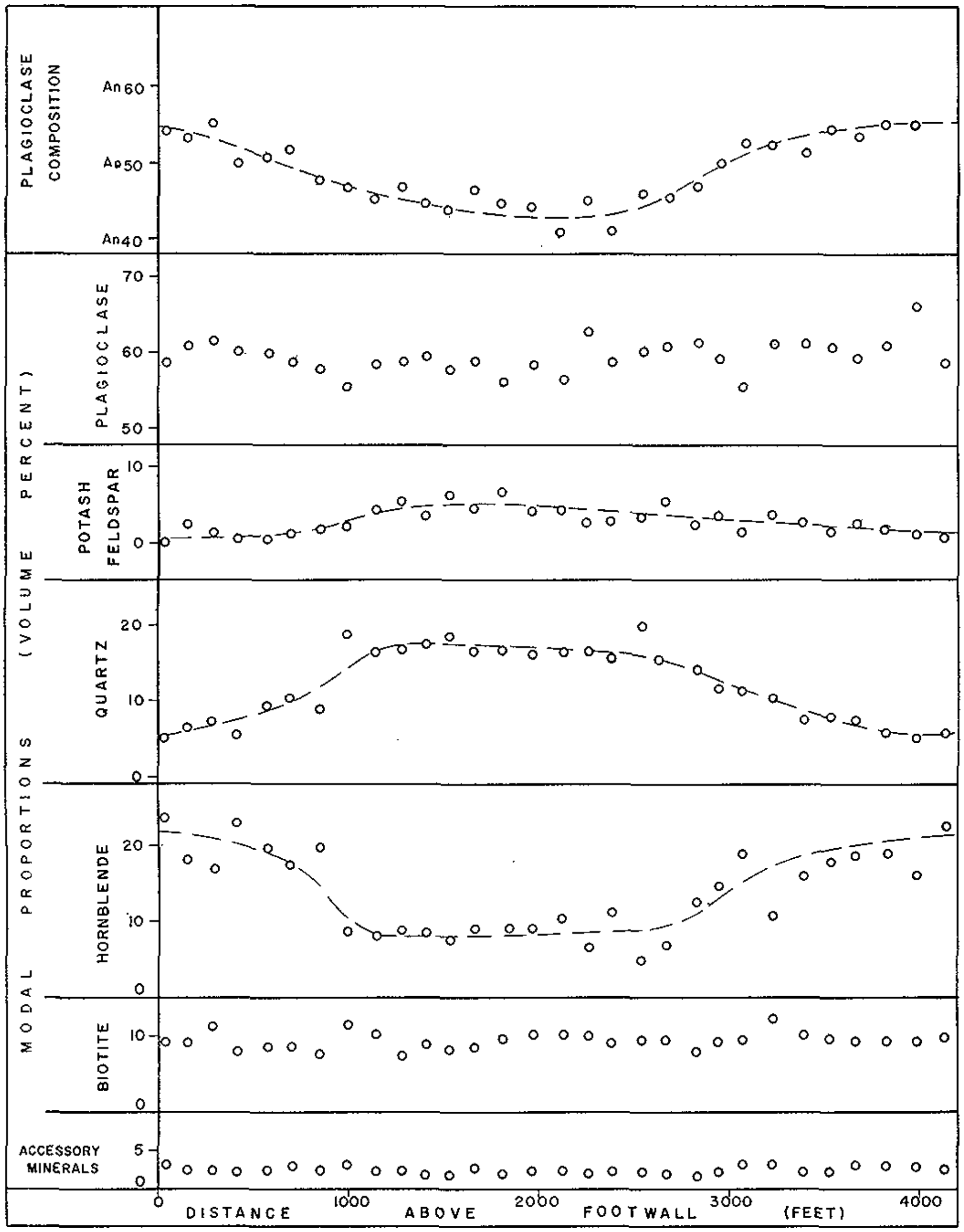


Fig. 6. Mineralogical variations in Horetzky dyke.

lower few hundred feet of the dyke contain some hornblende with corroded cores of augite, and a few contain discrete euhedral augite crystals. Biotite is strongly pleochroic from pale yellow to very dark reddish brown, and has $\beta = 1.645$. It replaces plagioclase, and also hornblende when the two are in contact. Quartz and potash feldspar are present in all specimens of diorite, but the potash feldspar is very minor. Both occur as small irregular grains either interstitial to or replacing the major constituents (Pl. XIV). Accessory minerals include apatite, sphene, zircon, and magnetite which is usually associated with biotite.

The plagioclase in the quartz diorite is identical in form with that in the diorite, but it lacks the uniform cores and is zoned regularly from the centre to the edges of the crystals. It is slightly more albitic in composition, with zoning from intermediate or calcic andesine to calcic oligoclase. The hornblende is slightly different in index, with an α' index on cleavage flakes of 1.656; and in colour, with $a > b > c =$ pale yellow : olive green : dark bluish green. It is considerably different in its mode of occurrence, as it forms euhedral and subhedral grains and rarely shows interstitial or replacement textures against plagioclase. In a few thin sections small euhedral hornblende grains are included in larger plagioclase grains. The biotite in the quartz diorite is virtually identical in colour and refractive index with that in the diorite. Also, much of its replaces plagioclase as it does in the diorite, but some is euhedral, and apparently earlier in the sequence of crystallization than some of the plagioclase. Quartz and potash feldspar are much more abundant in the quartz diorite than in the diorite, but show exactly the same interstitial and replacement relations with the other major constituents as they do in the diorite. The accessory minerals are the same as in the diorite, but magnetite is less abundant and does not show the same close association with biotite.

Both the diorite and the quartz diorite are very fresh looking in hand specimen, and in thin section show very minor alteration. Biotite is usually the most strongly altered, going over to pleochroic, yellow to bright-green chlorite. Hornblende alters to a somewhat paler green, weakly pleochroic chlorite. Plagioclase develops small sericite or paragonite flakes and occasionally small epidote grains. The only strong alteration occurs near fractures, which may be filled with potash feldspar, calcite, or epidote.

Variations in chemical composition across the dyke are illustrated by five chemical analyses in Figure 7. These reflect the mineralogical variations shown in Figure 6. The analyses are few but the variations are significant, particularly the increase in FeO, MgO, and CaO and the decrease in SiO_2, Na_2O, and K_2O toward the contacts.

Variations of this kind are customarily explained by processes of wallrock contamination, multiple injection, and differentiation by fractional crystallization. The last named is the most probable explanation in this case, as the field evidence does not support either contamination or multiple injection, but the manner in which the differentiation may have been achieved is not clear. Inasmuch as crystal settling cannot explain the hangingwall border zone, and there is no crushing and granulation of early formed crystals to indicate crystal pressing, these currently popular mechanisms of differentiation must be ruled out. The symmetrical mineral zoning in the dyke must therefore be the result of some differentiating mechanism not yet understood.

DuBose Stock

The DuBose stock is a roughly circular pluton approximately 3 miles in diameter composed of medium- to coarse-grained biotite-hornblende quartz diorite and granodiorite. Small intrusive masses of granodiorite and quartz monzonite occur in the central part of the stock.

Most exposures of the quartz diorite exhibit a weak orientation of biotite flakes parallel to the walls of the stock. The most reliable determinations of foliation were made in the Alcan Tunnel, the western 9,000 feet of which lies within the stock. The foliation strikes north 10 to 40 degrees west and dips from 75 degrees west to 75 degrees east in the westernmost 7,000 feet of the tunnel, but strikes north to north 10 degrees west and dips 55 to 75 degrees east near the eastern margin of

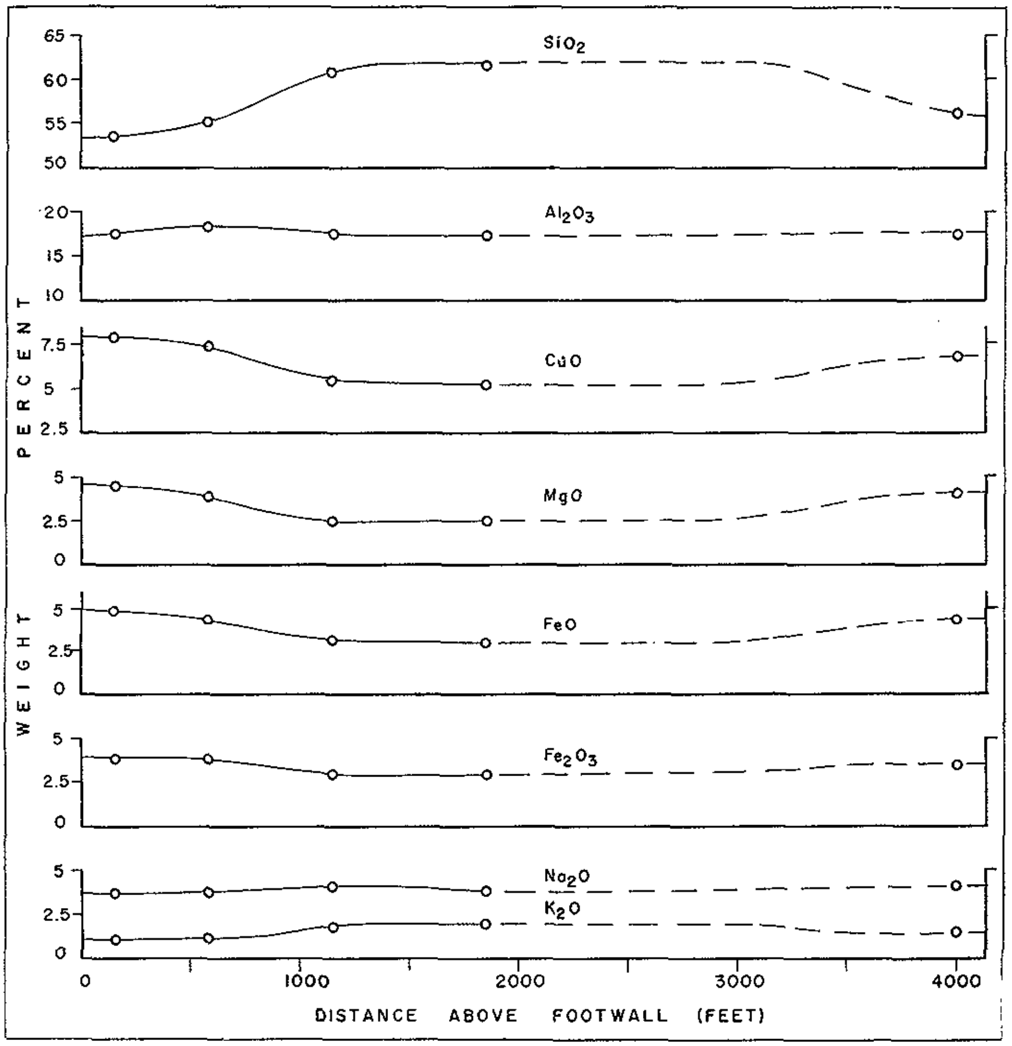


Fig. 7. Chemical variations in the Horetzky dyke.

the stock. The over-all dip of the eastern contact as shown by the correlation of surface and underground data is about 60 degrees east. Attitudes of the other boundaries of the stock are not known, but the few observations of foliation suggest that they dip steeply outward. Mineral lineation is not present in the quartz diorite, but several spindle-shaped dark inclusions observed in the tunnel plunged eastward at 80 degrees.

The DuBose stock intrudes the Hazelton group, the Kemano gneiss, and the Horetzky dyke, but the only well-exposed boundary is that between the stock and the Horetzky dyke. This boundary, observed on Mount DuBose and in the Alcan Tunnel, consists of a zone approximately 3,000 feet wide in which large blocks of quartz diorite identical with that of the Horetzky dyke are enclosed in quartz diorite characteristic of the stock. The blocks are wedge-shaped and bounded by straight contacts that are gradational with the enclosing quartz diorite across zones ranging in width from an inch or less to several feet. Most of the blocks are very large, with dimensions measured in hundreds of feet. Some small angular blocks occur, but invariably very close to a large block. The quartz diorite surrounding the large blocks is banded or strongly foliated parallel to the boundaries of the blocks, indicating that there was relative movement between the two before complete crystallization of the enclosing rock. In several places the banding is considerably contorted.

The contacts with the Kemano gneiss and the Hazelton group are poorly exposed, but there is no apparent deformation of the intruded rocks adjacent to the stock. This lack of deformation, coupled with the occurrence of large xenolithic blocks within the stock, points to a mechanism of magmatic stoping as the mode of emplacement.

The quartz diorite and granodiorite of the DuBose stock are rather light grey in colour, medium to coarse grained, and in general weakly foliated. Quartz and feldspar are the major constituents. Biotite and hornblende constitute 10 to 20 per cent of the rock, with biotite usually the more abundant, and scattered grains of light-brown sphene are conspicuous in some specimens. These rocks can readily be distinguished from those constituting the Horetzky dyke by their foliation, generally coarser grain size, lower mafic content, and the dominance of biotite over hornblende.

Modes of a number of representative specimens from the DuBose stock are shown in Figure 8. The modes show gradations from quartz diorite to granodiorite, represented primarily by an increase in the amount of potash feldspar, but to some extent also by a decrease in total mafic content and an increase in the biotite : hornblende ratio. Inasmuch as the potash feldspar is the same colour as the plagioclase, distinction between quartz diorite and granodiorite can rarely be made on the basis of hand-specimen examination, but microscopic examination has indicated that the granodiorite phases are less abundant than the quartz diorites, and are distributed at random throughout the stock.

In the central part of the stock a megascopically distinguishable variety of granodiorite-quartz monzonite occurs in the form of small intrusive masses that, although very irregular in detail, are tabular in over-all aspect. Most of the contacts with the enclosing quartz diorite-granodiorite are sharp, but locally they are gradational. The small bodies crosscut the foliation of the enclosing rock, and are themselves foliated parallel to their boundaries except where the contacts are gradational. In an underground exposure an angular, wedge-shaped block of the normal quartz diorite of the stock was seen engulfed in intrusive quartz monzonite; the attitude of the foliation in this block indicated rotation of the block. Where the contacts are gradational, the granodiorite-quartz monzonite of the small masses is foliated parallel to the foliation of the intruded rocks, and in these cases the younger rock can be recognized by its finer grain size and its very low content of hornblende. Modes of several specimens of the granodiorite-quartz monzonite are presented in Figure 8.

All of the rocks comprising the DuBose stock are texturally similar, and are quite different from those of the Horetzky dyke. Euhedral and subhedral crystal outlines are very rare; rather, the boundaries of grains of the major constituents are very irregular and are characterized by interpenetrations of one into another. Extremely common are fine-grained granular zones that enclose single larger grains or groups of grains, and are composed of quartz and plagioclase intimately veined by potash feldspar and locally extensively replaced by that mineral. Similar textures in rocks from the Idaho batholith have been described by Anderson as "pseudocataclastic," and attributed to post-crystallization replacement activity (Anderson, 1934). Another textural peculiarity of all of the rocks is an abundance of myrmekite. The myrmekite has clearly been formed by the development

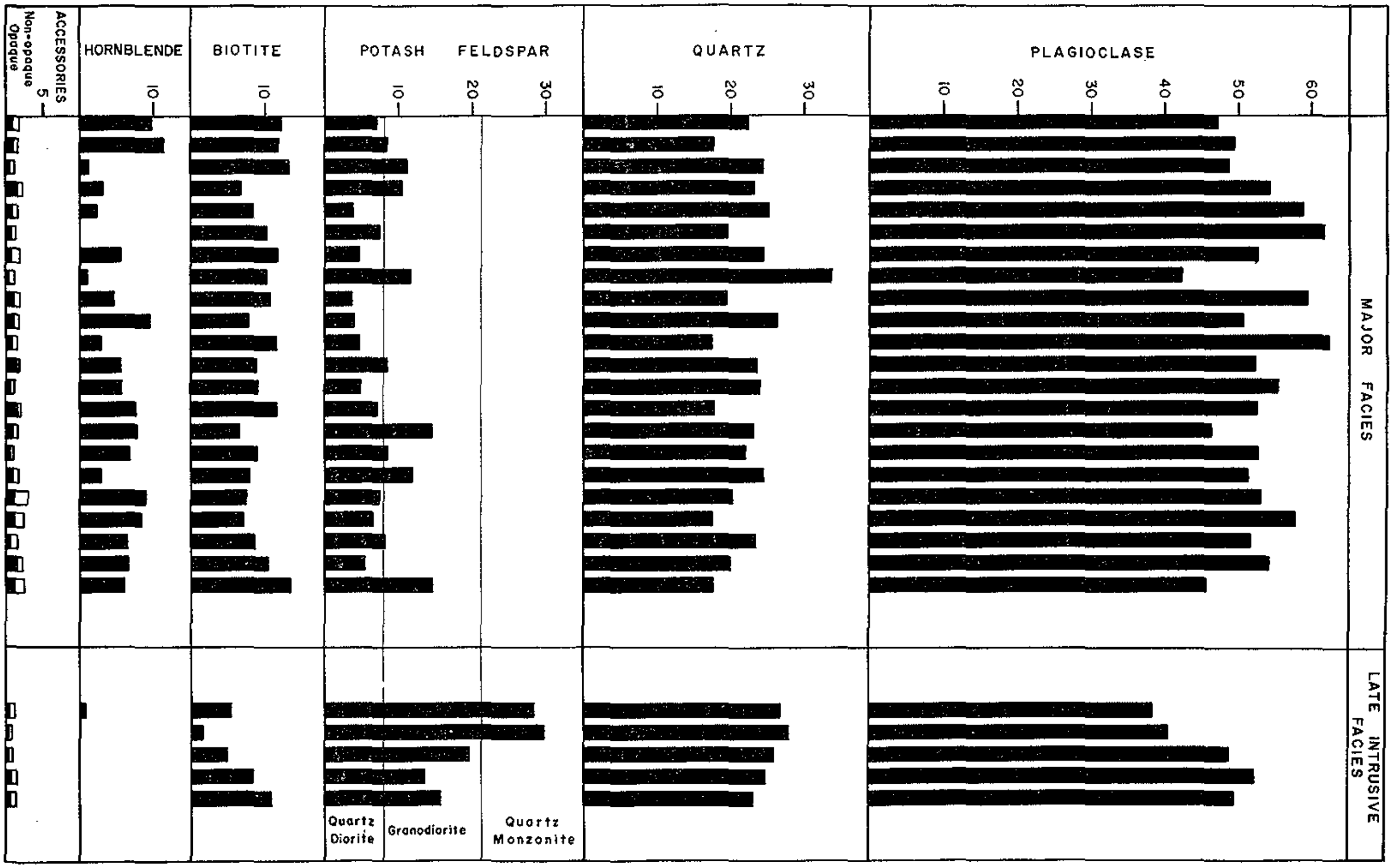


Fig. 8. Modes of specimens from the DuBose stock.

of vermicular quartz in plagioclase feldspar, this replacement taking place where the plagioclase is being replaced by potash feldspar.

The most abundant mineral is plagioclase feldspar. It occurs as zoned and twinned crystals that range in average composition from andesine in the quartz diorite to oligoclase in the granodiorite and quartz monzonite, but that commonly include zones of both andesine and oligoclase. The grains tend to be rectangular in shape, but growth interference by other plagioclase crystals, and embayments of quartz, potash feldspar, and biotite have produced irregular rather than euhedral grain boundaries. Quartz occurs as large and small grains, all exceedingly irregular in shape and most showing evidence of replacement of plagioclase at mutual contacts. The smaller grains are for the most part interstitial to the plagioclase, but many of the larger grains contain corroded inclusions of plagioclase and appear to have developed through replacement of plagioclase. The hornblende, a deep green variety with α' on cleavage fragments between 1.660 and 1.680, is the only essential constituent of the rocks that shows any consistent tendency toward euhedral outlines. A small proportion of the hornblende is subhedral or euhedral, and many of the irregular grains would be euhedral or subhedral were it not for embayments of quartz and plagioclase. Small inclusions of quartz and plagioclase are common, and represent an early generation of these minerals. Pleochroic straw-yellow to very dark brown biotite occurs in all specimens as ragged grains growing along and across contacts between other minerals, particularly plagioclase. Frayed ends projecting into plagioclase grains are common, as are lath-shaped biotite flakes that transect one or more plagioclase grains. Boundaries between biotite and quartz tend to be rather regular, but apparent penetrations both of quartz into biotite and of biotite into quartz may be observed. Potash feldspar is present in some proportion in all of the rocks. It corrodes all other essential minerals, and, in sections in which the potash feldspar is abundant and forms large grains, it may contain corroded inclusions of plagioclase, quartz, hornblende, biotite, and myrmekite (Pl. XV). Most of the potash feldspar is untwinned, a small proportion has microcline twinning, and a few small isolated grains are perthitic. The microcline twinning characteristically occurs as indistinct patches in otherwise untwinned grains, most of which have a patchy extinction that may represent more poorly developed microcline twinning. The accessory minerals include apatite, sphene, magnetite, zircon, allanite, and a little ilmenite. The sphene commonly occurs as large anhedral to euhedral skeletal crystals, and the allanite as inclusion-free euhedral crystals frequently rimmed by epidote.

Dykes are extremely common throughout the DuBose stock, which in this respect is set apart from the other intrusions in the area. Most are granodiorite or quartz monzonite aplites, pegmatites, or the basic dykes described on page 15. There are, however, a number of dykes of granodiorite and a few of quartz diorite.

The aplites are by far the most abundant. They occur as sharp-walled dilational dykes, of which few are more than 6 inches wide, and the majority occupy one or the other of two well-defined fracture sets (Fig. 9). Detailed mapping of the many excavations in the vicinity of the underground power-house at Kemano has shown that most of the dykes have strike and dip dimensions of the order of a few hundred feet or less. In thin section the aplites exhibit the same textures and mineral assemblages as the granodiorites of the stock, but have greater proportions of quartz and potash feldspar and a smaller proportion of biotite.

Pegmatite occurs in two forms—as borders of aplite dykes, and as simple dykes a few inches or rarely 12 to 18 inches wide and a few hundred feet or less along strike and dip. The majority occupy fractures of the same two sets as the aplite dykes. Both types of pegmatite are similar petrographically. They consist of large grains of potash feldspar and quartz with occasional inclusions of single

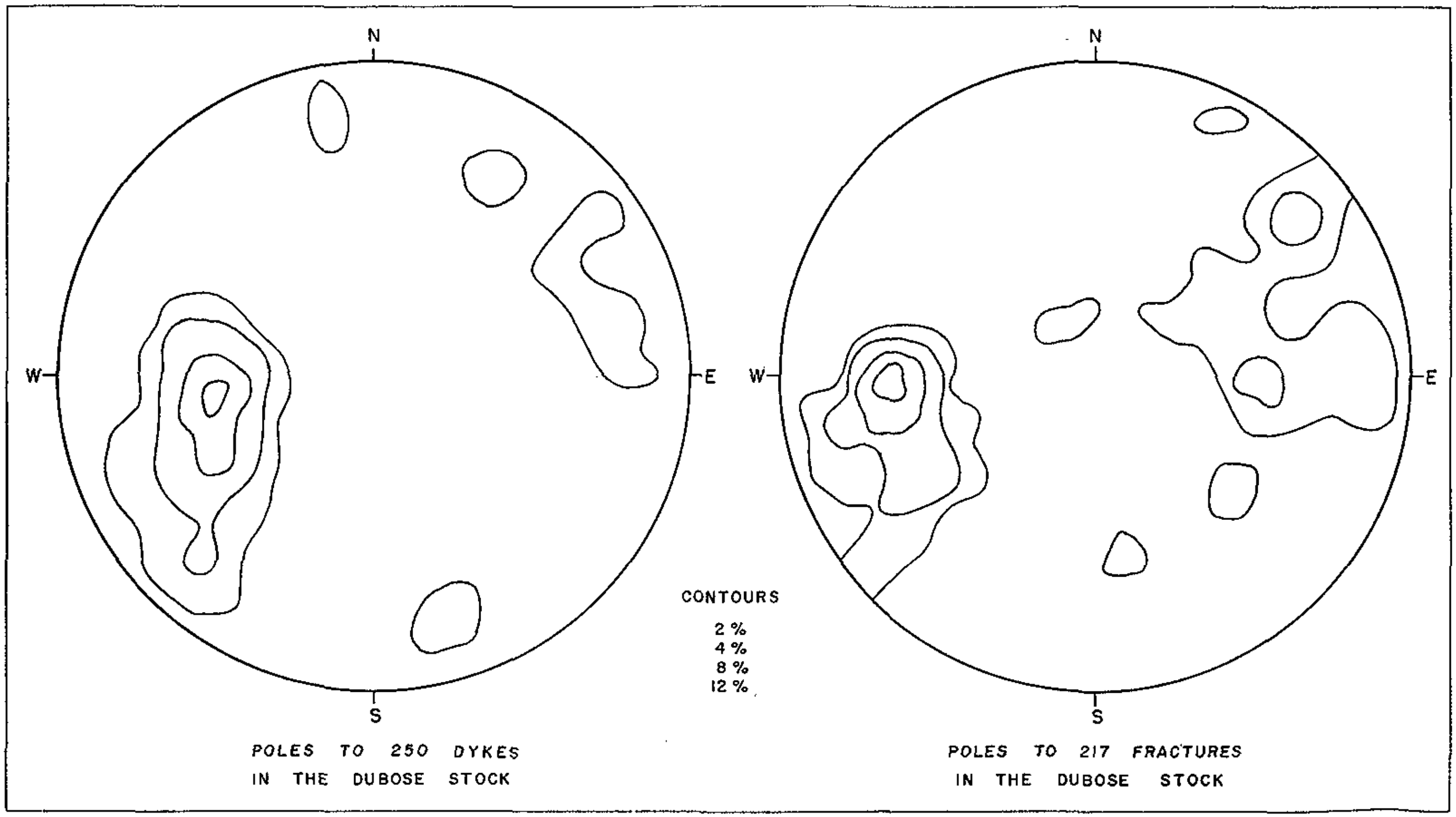


Fig. 9. Orientation of dykes and fractures in the DuBose stock.

grains or aggregates of grains of the minerals occurring in the enclosing rock. At contacts between pegmatites and their wallrocks, potash feldspar and, to a lesser extent, quartz embays and replaces the wallrocks and occasionally forms large grains separated from the body of the dyke by narrow strips of wallrock. Although proof is lacking, it appears probable on the basis of their petrographic characteristics that the pegmatites developed through the replacement of older rocks.

The granodiorite and quartz diorite dykes occur as do the aplites, and have compositions and textures identical with those of the rocks of the main mass of the stock.

Nanika Batholith

The Nanika batholith is a composite intrusion that projects into the Kemano-Tahtsa area from the north. Only one traverse penetrated any distance into the batholith. This traverse crossed approximately 1 mile of rather uniform hornblende-biotite quartz diorite at the border of the batholith, then entered a slightly more coarse-grained, strongly foliated granodiorite and continued in this rock to the end of the traverse, some 3 miles from the contact. The quartz diorite and granodiorite are separated on the line of the traverse by a narrow septum of hornfelsed Hazelton rocks, and there is no direct evidence as to their relative ages. However, by analogy with the sequence of intrusion elsewhere in the area, and in the Coast intrusions in general, the quartz diorite is probably the older. Inclusions and dykes are not common in the batholith.

The southern contact of the batholith was crossed by several traverses. It is extremely sharp and dips vertically or steeply south. Locally the wallrocks are cut by sharp-walled quartz diorite apophyses of the batholith. The Hazelton rocks strike and dip parallel to the contact of the batholith in a belt about three-quarters of a mile wide. South of this belt the Hazelton rocks dip north at moderate angles from the dome of the Tahtsa complex, and thus form an east-west asymmetrical syncline whose axis lies just south of Nanika Lake. This syncline is almost perpendicular to the trend of the regional folding in the area, and there is little doubt that it formed as a consequence of the forceful intrusion of the batholith.

Modal analyses of the quartz diorite and granodiorite comprising the part of the Nanika batholith within the map-area are presented graphically in Figure 10. The average mineralogical composition of the Horetzky dyke is also shown, and is almost identical with the average composition of the quartz diorite of the Nanika batholith.

The quartz diorite is fine to medium grained, grey in colour, and is composed of plagioclase, quartz, hornblende, biotite, very minor feldspar, and accessory apatite, magnetite, sphene, and zircon. The plagioclase forms euhedral to subhedral twinned crystals zoned in composition from calcic to sodic andesine, with occasional cores of sodic labradorite. Green hornblende occurs as euhedral to subhedral crystals, in part replaced by dark reddish-brown to straw-yellow biotite that also occurs as subhedral tablets apart from hornblende. Quartz is interstitial to and locally replaces plagioclase and hornblende; potash feldspar is interstitial to or replaces all of the major minerals.

The granodiorite is also medium grained, but is coarser than the quartz diorite. It exhibits a well-developed foliation, and is composed of plagioclase, quartz, biotite, hornblende, and potash feldspar, with accessory apatite, magnetite, sphene, and zircon. The megascopic foliation is the expression of a highly cataclastic microtexture that largely obscures mineral interrelationships. Quartz is the most profoundly affected, occurring as small angular undulatory grains aggregated into streaks wrapped around larger grains of plagioclase or hornblende (*see* Pl. XVI). All of the major constituents except potash feldspar show some fracturing or granulation.

The plagioclase in the granodiorite is slightly more sodic than that in the quartz diorite, ranging in composition from intermediate or calcic andesine in the centres of crystals to calcic oligoclase at the edges. Hornblende and biotite are very similar, in colour at least, to the hornblende and biotite in the quartz diorite; potash feldspar is much more abundant and the larger grains show a patchy extinction and occasional patches of grid twinning.

Minor Intrusions

Several small post-Hazelton intrusive bodies, all less than 3 square miles in surface exposure, outcrop in the Kemano-Tahtsa area. The bodies, none of which can be precisely dated relative to the larger igneous masses, range from hornblende gabbro to granodiorite and albite granite.

Hornblende gabbro constitutes a lenticular body that crosses the contact between metamorphosed Hazelton rocks and the Tahtsa complex at the footwall of the Horetzky dyke. A number of narrow dykes of hornblende gabbro are associated with the body. The gabbro is intruded by the Horetzky dyke and by several apophyses from it, and a small patch of the gabbro is exposed at the hangingwall of the dyke about one-half mile south of Horetzky camp in a location that indicates that emplacement of the dyke was accompanied by dilation of the enclosing rocks. Two modal analyses of the hornblende gabbro are presented graphically on Figure 11. The rock is composed essentially of hornblende and andesine-labradorite plagioclase, and can be distinguished from the hornblende diorite of the Tahtsa complex by a lack of quartz, a lack of strong alteration of most of the hornblende and plagioclase, and a lack of the general shearing characteristic of the older rocks.

A roughly elliptical stock about 1 mile by one-half mile intrudes Hazelton volcanic rocks east of Sandifer Lake. The stock is surrounded by an aureole of contact metamorphism several hundred feet wide in which the volcanics have been converted to hornblende-plagioclase hornfelses. Sparse chalcopyrite mineralization has been reported in a zone in the contact aureole on the north side of the stock (Duffell, 1952). Strong sericitization accompanied by introduction of epidote, chlorite, quartz, and pyrite, in small pods, and siderite and pyrite in narrow veinlets was observed on the south side. The stock exhibits a compositional zoning from medium-grained quartz diorite at the border to porphyritic granodiorite in the centre, a zoning that is illustrated by the modal analyses shown in Figure 11.

Another small stock, oval in shape and just over 2 square miles in area, intrudes Hazelton rocks on the south flank of Tahtsa Peak. Several dyke-like apophyses extend a short distance westward from the west end of the stock. The stock is composed of rock which, unlike any other igneous rock in the area, contains very sodic plagioclase (An_5 to An_{14}) and no potash feldspar. Modal analyses of two specimens of the rock, an albite granite, are shown graphically in Figure 11.

A dyke of porphyritic granodiorite intrudes the Kemano gneiss a short distance south of Kemano camp. The dyke has a strike-length of 2½ miles within the map-area and is nearly one-half mile wide. The contacts are generally concordant with the foliation of the gneiss but are locally discordant. The granodiorite of the dyke is similar mineralogically to that in the central part of the DuBose stock, but differs texturally in that myrmekite is less abundant and much of the potash feldspar occurs as large subhedral grains containing numerous rounded remnants of quartz and plagioclase. Modal analyses of two specimens from the dyke are shown graphically in Figure 11.

Chemical Variations

Chemical data and diagrams prepared from them are included in two appendices. Appendix I lists all chemical analyses of igneous rocks, norms calculated

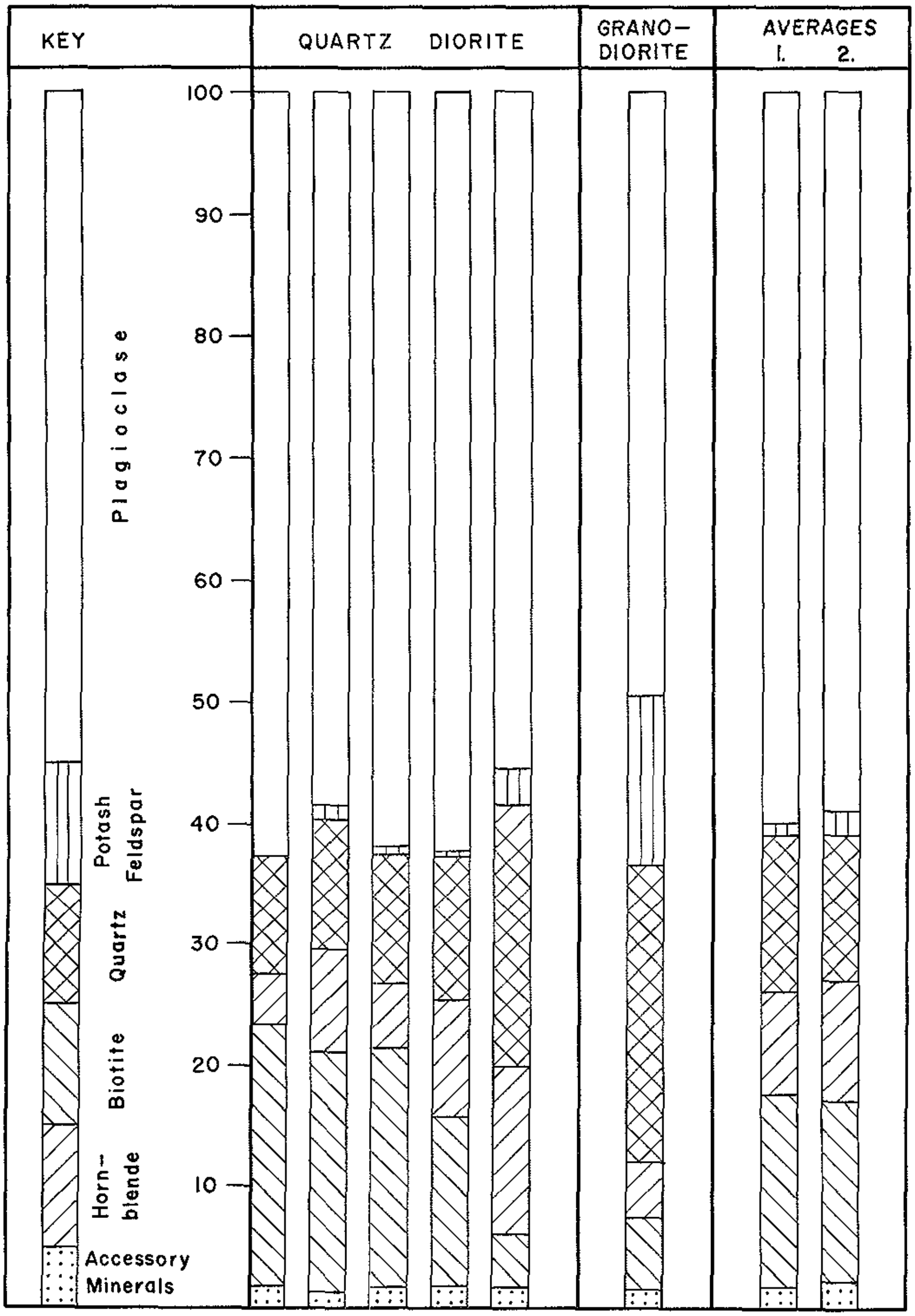


Fig. 10. Modes of specimens from the Nanika batholith.

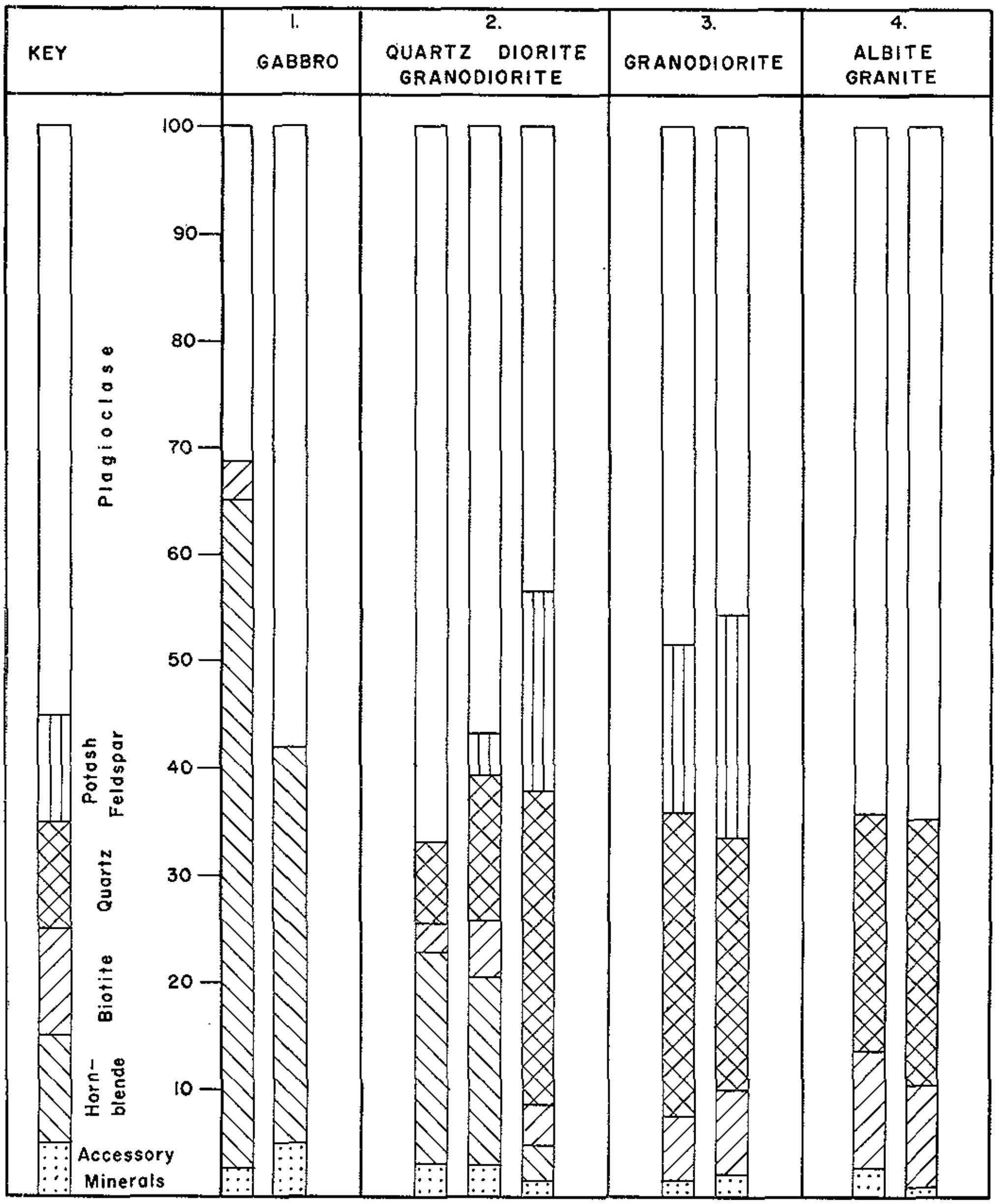


Fig. 11. Modes of specimens from minor intrusions.

from them, and a Larsen variation diagram (Fig. 15). Appendix II lists trace element determinations made by spectrographic analysis, and a limited amount of checking of the results by X-ray and by chemical analysis. One diagram (Fig. 16) shows variation in trace elements across the Horetzky dyke, and a second (Fig. 17) shows the relationship between trace element composition and bulk chemical composition in the DuBose stock and the Horetzky dyke. The diagrams are presented without comment because it is felt that the analyses are too few to permit definite conclusions to be drawn from them.

STRUCTURE

The structure of the Tahtsa complex has already been considered (p. 15). The following discussion relates to the Hazelton and younger rocks.

The Hazelton strata have been regionally folded about north-northeast trending axes, locally folded adjacent to intrusive masses, and have been domed. The precise delimitation of most regional folds is virtually impossible because of a lack of persistent marker horizons and because of complications introduced by small-scale dragfolding and crenulation in the zone of metamorphism. The fold axes shown on Figure 2 have been located by generalization of structural attitudes measured in the field. The major folds are symmetrical, or are slightly asymmetrical with the steeper limb on the east side, and are of approximately the same order of magnitude throughout the area.

In the western part of the map-area, dragfolding is general and there is much small-scale disharmonic crumpling of foliation planes, but comparable deformation is absent in the eastern, unmetamorphosed part of the area. This small-scale complexity cannot be explained as a function of different stress application in the two parts of the area, as the general character of the major fold structures is the same throughout the area as a whole and for many miles beyond the eastern boundary (Hedley, 1936; Duffell, 1952). It must therefore be explained as a function of differences in behaviour of the rocks under similar applied stresses. Inasmuch as the boundary of the zone of small-scale deformation coincides with the boundary of the zone of metamorphism, it is reasonable to relate both to the same cause and to suggest that the complexity in the western part of the area is a reflection of higher temperatures during deformation and that the regional folding was accompanied by igneous intrusion to the west.

Deformation adjacent to the Horetzky dyke and the Nanika batholith has already been mentioned (*see* pp. 25 and 33). Local low-amplitude folds parallel to the dyke contacts imply lateral thrusting during intrusion, and dragging of adjacent strata into conformity with the contact implies tangential stress. There is little evidence for lateral forces related to the emplacement of the Nanika batholith. Rather, the general updragging of strata into conformity with the contact that has resulted in the formation of a syncline a short distance to the south suggests that the batholith was emplaced by vertically directed forces, possibly accompanied by an upward displacement of the roof. Approximately 1 mile west of Nanika Lake a limestone lens that is folded according to the regional pattern is deflected near the batholithic contact in such a way as to suggest that the regional folding preceded emplacement of the batholith.

A broad dome occupies the central part of the map-area. It is somewhat elongated, with its long axis aligned slightly west of north, and plunges more steeply at the north end than at the south end. The elongation is oblique to the trend of regional folding but is parallel to the trend of the Coast intrusions and related structures. The discordance in trend between the long axis of the dome and the regional folds in Hazelton strata indicates that the dome and folds were formed independently. Evidence as to the relative ages of the structures is provided by the relation between the dome and the plunges of the folds. The fold axes are draped over the dome parallel to its surface, and plunge at angles determined by their position on the dome. At the south end of the dome, where the strike of the fold axes is nearly parallel to the direction of dip of the surface of the dome, the folds plunge southward at 30 to 40 degrees, an angle only slightly less than the dip of the surface of the dome. On the west flank of the dome, where the fold axes strike at considerable angles to the direction of dip of the surface of the dome, the fold axes plunge gently. The magnitude and direction of the plunge at any point reflects the component of the dip of the flank of the dome in the direction of the fold axis. It thus appears that the folds plunge as a result of the doming, and that the doming is younger than the folding.

There is a strong likelihood, shown by the attitudes of the late Lower Cretaceous sediments at the east edge of and beyond the map-area, that the Hazelton folding is pre-Lower Cretaceous in age and the doming post-Lower Cretaceous. East of the map-area the Lower Cretaceous rocks strike nearly west and dip southward (Duffell, 1952), and hence they were not involved in the folding of the underlying Hazelton strata. Within the map-area the Lower Cretaceous rocks strike slightly west of north and dip eastward in conformity with the attitude of the east flank of the dome.

A number of faults are shown in Figure 2. These represent only a few of many strongly oxidized zones of shearing, most of which probably represent faults but which do not cross lithologic boundaries and produce no recognizable displacement. Only those that are very strongly developed or that show evidence of displacement are shown on Figure 2. Most strike slightly west of north, and, on the west side of the dome, dip steeply west.

The apparent displacement on these faults is small, and in most cases the true relative movement cannot be determined. However, two faults—one forming part of the eastern boundary of the Tahtsa complex, and the other forming part of the western boundary—show a relative downward displacement of the side of the fault away from the dome. The dislocation on the remainder of the faults shown can be interpreted to represent a similar sense of movement. For this reason, and because of the general parallelism between the strike of the faults and the long axis of the central dome, it appears that the faults are gravity faults developed concurrently with the dome. If so, the dome was probably produced by upward-directed forces and not by horizontal compression.

Doming and faulting of overlying strata frequently accompany the forcible emplacement of intrusive bodies (Noble, 1952), and it is believed that forcible emplacement of a magma below the present levels of exposure has produced these features in the Kemano-Tahtsa area. This belief is supported by the occurrence of a forcefully emplaced pluton, the Nanika batholith, which lies immediately to the north of the dome structure and in line with its long axis.

The normal fault that forms part of the western boundary of the Tahtsa complex is older than the Horetzky dyke; the remainder of the faults in that vicinity are younger. Inasmuch as all of the faults are similar in attitude and sense of displacement, they are all probably similar in origin, and it follows that if a deep-seated emplacement of magma was responsible for the dome and associated faults, it must have taken place concurrently with the intrusion of the Horetzky dyke.

The foregoing structural interpretations imply two episodes of intrusive activity—one earlier than late Lower Cretaceous sedimentation, and one later. Direct evidence in support of this implication is not present in the map-area, but 25 miles to the north, major post-Hazelton pre-Lower Cretaceous intrusive activity is indicated in the Terrace map-area (Souther, 1955), and a few miles to the east, Lower Cretaceous sediments are intruded by granitic rocks (Duffell, 1952).

CHAPTER III.—ENGINEERING GEOLOGY

The Nechako-Kitimat project of the Aluminum Company of Canada Limited is outlined in Figure 12. It comprises a 300-foot-high dam on the Nechako River, a 10-mile-long tunnel from Tahtsa Lake to the Kemano River valley, an underground power-house at Kemano, a 50-mile-long transmission-line from Kemano to Kitimat, and an aluminum smelter and port facilities at Kitimat. Construction was begun in the autumn of 1951, and the first aluminum ingot was poured in the summer of 1954.

In the pre-construction phase of the project, geological reports of several potentially suitable project-sites on Vancouver Island and the mainland coast of British Columbia were prepared and were given considerable weight in the evaluation of these sites. Subsequent to the selection of the Nechako-Kitimat area, geology played an important role in the selection of a dam-site on the Nechako River. A number of otherwise suitable sites were rejected on geological grounds before the present site was located. Again, at Kemano a geological evaluation of data obtained from an exploratory tunnel and a programme of diamond drilling were a major factor in the selection of the precise location of the power-house excavations.

During the construction phase of the project, geology was put to little or no practical use. Although the underground excavations were mapped on a scale of 50 feet to the inch as the various headings were advanced, the geological data were never correlated with engineering data. Difficulties that arose in connection with the excavation and support of openings were looked upon as engineering problems and were handled as such without consideration of their geological background.

A total of nearly 3½ million tons of rock was removed from the following excavations:—

(1) *Power Tunnel.*—This tunnel is 10 miles long, has a 25-foot arch for most of its length, and conducts water from the west end of the reservoir system at Tahtsa Lake to the top of the penstocks. It was driven simultaneously from four headings, one from each end and two from an adit on Horetzky Creek at approximately the midpoint.

(2) *Penstocks.*—Two circular penstocks, inclined at 48 degrees and excavated to a 15-foot diameter, conduct the water from the power tunnel at an elevation of 2,595 feet above sea-level to the power-house at an elevation of 205 feet. The penstocks were driven as 6- by 10-foot pilot raises from the power-house level and from an intermediate level at an elevation of 1,685 feet, and were later enlarged from the top down to the full 15-foot diameter.

(3) *Power-house System.*—This consists of penstock branches, turbine manifold, 20- by 35- by 465-foot valve chamber, 80- by 120- by 700-foot power-house chamber, tailrace manifold, and tailrace, access, cable, and ventilation tunnels.

The major features of the tunnel, penstocks, and power-house are shown in plan, profile, and cross-section in Figure 13. Granitic rocks of the Coast intrusions enclose all power-house and penstock excavations, 4 miles of the western half of the power tunnel, and approximately 1 mile of the eastern half. Metamorphosed rocks of the Hazelton group enclose approximately 1⅓ miles of the tunnel in the vicinity of the Horetzky adit, and rocks of the Tahtsa complex enclose approximately 3⅔ miles of the eastern half of the tunnel. The physical characteristics of each of these rock types are different and are reflected by differences in wallrock behaviour in the excavations.

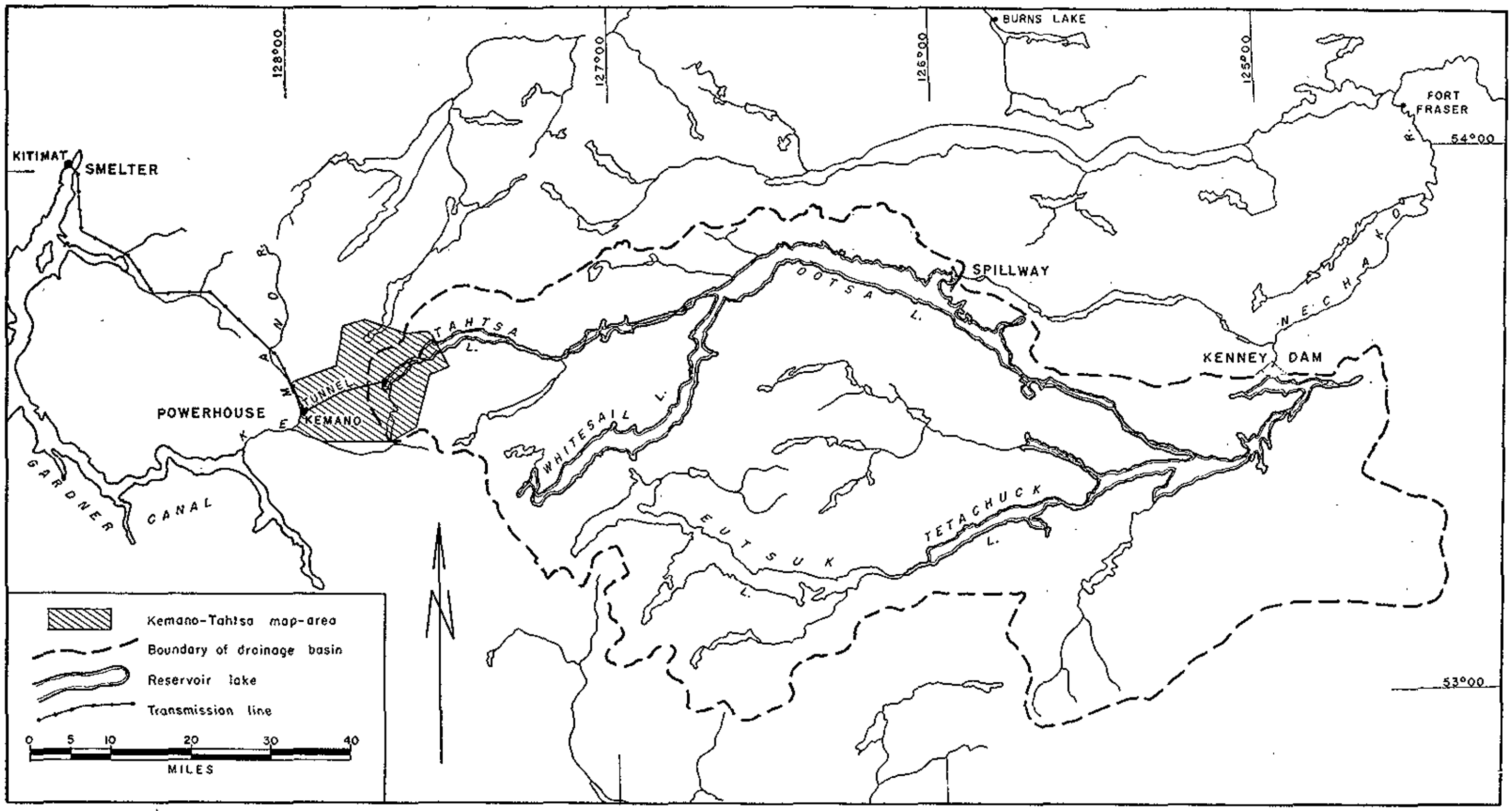


Fig. 12. Nechako-Kitimat project of the Aluminum Company of Canada.

Rocks of the Coast intrusions are rather uniform, hard, and tough. Bit and powder consumption was high, but most of the drilling rounds broke cleanly to give relatively smooth walls very close to the planned neat-line. Faults are represented by sheared and slickensided zones that are rarely more than 50 feet wide and most commonly less than 10 feet wide, and little support was required even in large openings except where these shear zones were encountered. Joints and gougy fractures are common and can be classified into a number of sets, any of which may be well defined locally. The joints and fractures were in general beneficial, inasmuch as they promoted primary breaking for the most part to a size that could easily be handled by loading-machines, but locally they led to difficulties. For example, in several places in the power tunnel a well-developed set of joints is roughly parallel with the tunnel. At these places drilling rounds tended to break to the joints rather than to the outside holes, resulting in departures from the planned neat-line. Again, in some of the larger excavations in the power-house area, intersecting joints and gougy fractures defined wedge-shaped blocks that tended to slide along joint or fracture surfaces and required roof-bolt support to prevent caving.

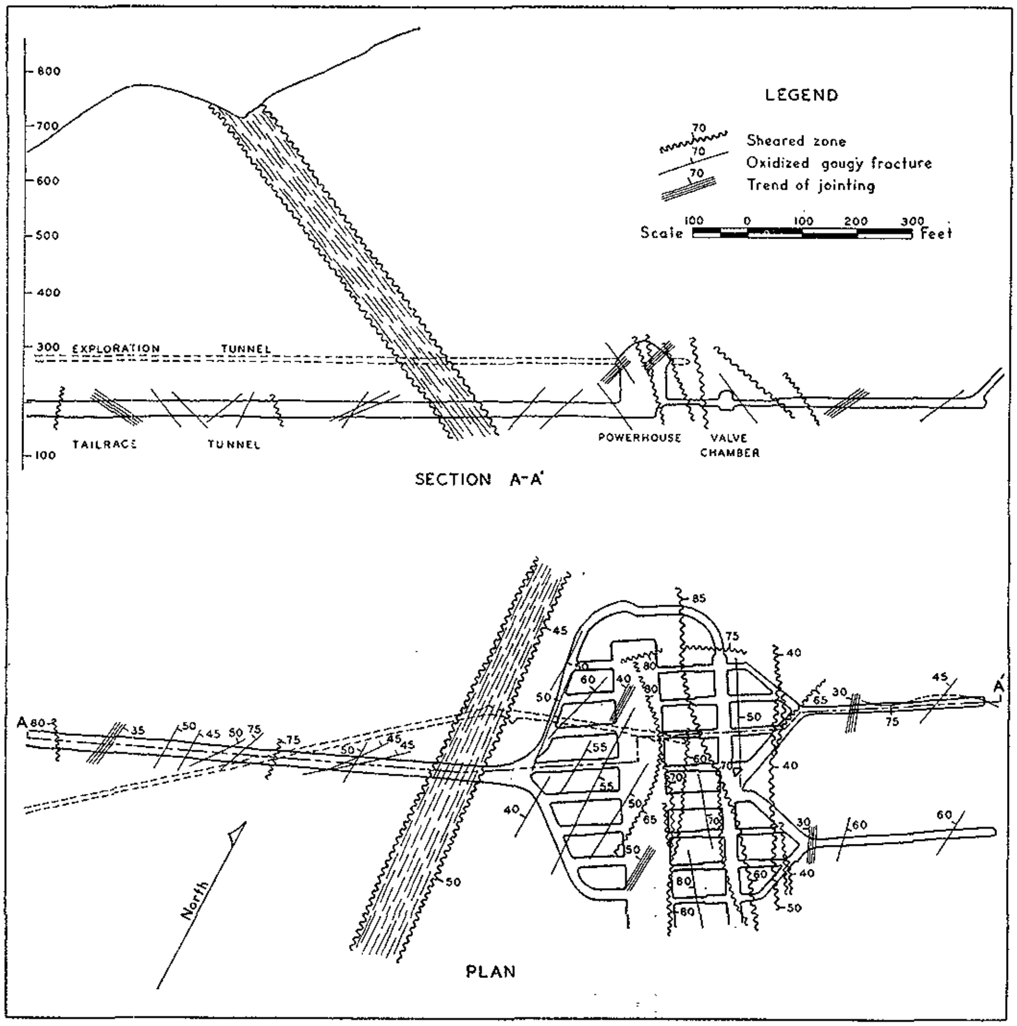


Fig. 13. Plan and section of Kemano power-house.

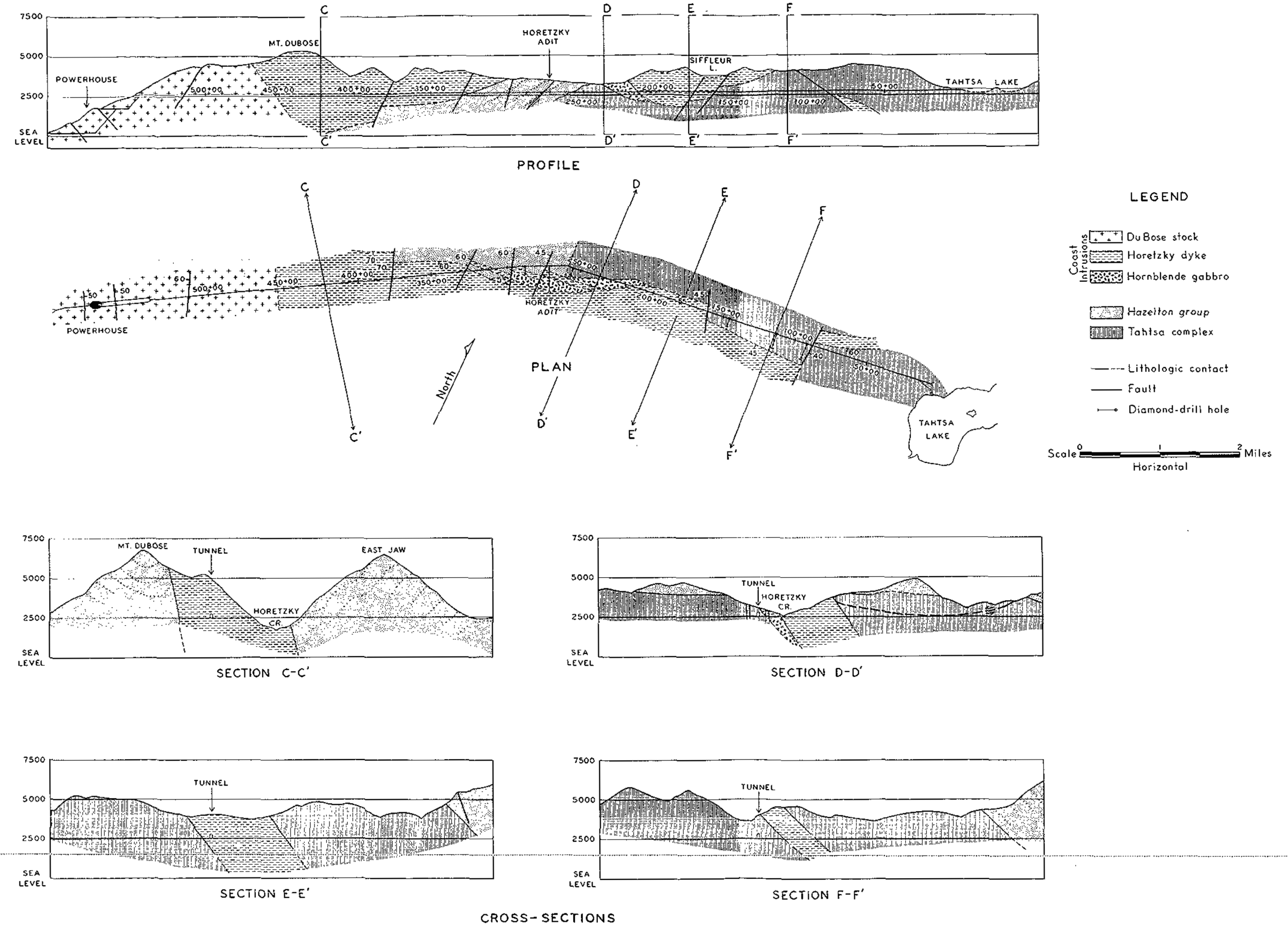
The most serious mining problem in granitic rocks of the Coast intrusions arose during excavation of the arch of the power-house chamber. A steeply dipping zone of gouge-filled shears striking nearly parallel with the power-house intersects the arch near its centre line (Fig. 14). When excavation was attempted according to the proposed method (by diamond-drilling blast holes between transverse slots 110 feet apart and blasting successive concentric rings into a central longitudinal passage), it was found that where the zone of shears intersected well-developed joints and fractures, an unstable back subject to caving resulted. The problem was met by cutting a vertical longitudinal slot to the neat-line of the arch in the weakened zone and seating roof-bolts in the back. The excavation was then continued by blasting vertical slices from both sides of the slot and roof-bolting the back as it was exposed. The roof-bolts maintained the back until the final concrete lining of the arch was poured.

Rocks of the Hazelton group that are penetrated by the power tunnel near the Horetzky adit are in the contact metamorphic zone adjacent to the Horetzky dyke. They are hard but brittle, and bit life was much longer than in granitic rocks. Fracturing is general throughout, and most of the fractures are slickensided and either gougy or calcite filled or are plated with a thin film of a zeolite mineral. Two sets of fractures can be recognized, but the majority of the fractures are randomly oriented. Several major faults cross the tunnel in the section penetrating Hazelton rocks, and are represented by gougy sheared zones up to 400 feet wide bounded by zones of intense fracturing up to 500 feet wide. The fractures in these zones do not belong to well-defined sets but are oriented at random and cut the rock into variably sized blocks which, because of the slickensiding, tend to separate and cave.

Because of this widespread shearing and even more widespread fracturing, powder consumption was low, but overbreak and caving were common and a considerable amount of steel-set support was required, much of it lagged on both back and sides. In addition, a large proportion of the unsupported part of this section of the tunnel was given a thick coating of gunite to seal off the fractures.

The easternmost part of the power tunnel is in rocks of the Tahtsa complex. These rocks exhibit considerable variations in lithologic character, but their physical properties in so far as tunnel excavation and support are concerned are determined by the degree of shearing, fracturing, jointing, and alteration rather than by the original nature of the rock. Both shearing and fracturing are widespread. The shearing occurs in well-defined zones 2 to 20 feet wide associated with seams of soft gouge, and in zones 200 to 500 feet wide that lack appreciable gouge and are gradational into fractured but only locally sheared rock. Alteration is general in the sheared zones, and probably contributes to the fact that bit life in rocks of the complex was relatively long in spite of the fact that they are dominantly granitic. The fractures include representatives of three sets that are variably developed throughout this section of the tunnel, and a large number of randomly oriented fractures that are most abundant adjacent to the wide zones of shearing. The systematically oriented fractures are tighter and more widely spaced than the fractures in rocks of the Hazelton group, and may be devoid of filling or contain fillings of calcite, quartz, pyrite, or a zeolite mineral. The randomly oriented fractures adjacent to sheared zones are closely spaced, frequently slickensided, and produce a type of blocky ground subject to caving when left unsupported.

The sheared and highly fractured rocks encountered in the section of the tunnel penetrating the Tahtsa complex created considerable difficulty in the maintenance of the tunnel opening. Some of the weakest ground encountered was found in the easternmost 2,500 feet of the tunnel, beginning at the West Tahtsa portal. Of this portion an aggregate of 2,100 feet was mapped as highly sheared or fractured, and 2,300 feet was supported with wood or steel sets at the time of



GEOLOGY OF THE ALCAN TUNNEL

Figure 14

excavation. The placing of this amount of support not only greatly lowered the rate of advance, but was very costly, and the diameter of the tunnel arch was reduced in an effort to lessen the amount of support required. The reduction in tunnel diameter happened to coincide with a decrease in the degree of shearing and fracturing, and the next 900 feet of the tunnel, with an arch diameter of from 16 to 21 feet, penetrated only 150 feet of moderately fractured rock and one gougy shear 8 feet wide. This section was unsupported though the back was gunited, and the betterment of conditions encouraged an enlargement of the tunnel to a 22½-foot arch diameter, which was maintained for the next 5,000 feet with no support other than a coat of gunite on the back. However, this 5,000-foot unsupported section included 1,500 feet of sheared or highly fractured rock and five gougy shears 10 feet or more in width, and several rock falls occurred well after the face had been advanced. In the final 5,000 feet of the heading driven from the West Tahtsa adit, the 22½-foot arch diameter was maintained but the tunnel was fully supported with steel sets. This 5,000-foot length included 2,100 feet of sheared or highly fractured rock and three gougy shears 10 feet or more in width.

A comparison of the three types of rock encountered in the power tunnel is made in the following table:—

	Distance Penetrated by Tunnel (Ft.)	Amount of Shearing or Strong Fracturing		Amount with Steel-set Support		Amount with Concrete Lining		Bit Life (Ft.)	Powder Consumption Lb. per Cu. Yd.
		Ft.	Per Cent	Ft.	Per Cent	Ft.	Per Cent		
Coast intrusions	19,031	2,070	11	1,632	8.5	2,198	11.5	240[1]	5.4
Hazelton group	7,310	3,375	46	3,657	49	3,725	51	600[1]	2.7
Tahtsa complex	17,744	7,425	42	8,487	48	9,216	52	600[2]	3.2

[1] 2-inch collar.
[2] 1.34-inch collar.

The rocks of the Coast intrusions are by far the most satisfactory from an engineering point of view, and those of the Hazelton group are apparently the least satisfactory. The slight superiority of rocks of the Tahtsa complex over those of the Hazelton group cannot, however, be accepted as a generality. The rocks requiring support in the tunnel are those that are highly sheared or fractured. Surface geological mapping has established that strong shearing is a characteristic feature of the Tahtsa complex, and that strong shearing or fracturing is not particularly common in rocks of the Hazelton group. Where encountered in the tunnel, the Hazelton rocks are indeed highly sheared and fractured, but they are very close to the footwall of the Horetzky dyke and their physical condition may well be a result of the emplacement of the dyke. If so, the behaviour of Hazelton rocks in excavations farther removed from the dyke could be quite different from that observed in the tunnel. The surface studies suggest that this is the case, and that, in general, rocks of the Hazelton group should be superior to those of the Tahtsa complex in underground excavations.

APPENDICES

APPENDIX I.—CHEMICAL ANALYSES AND NORMS OF IGNEOUS ROCKS

The analyses represent the following rock types:—

Analysis	Specimen No.	Laboratory No.	Description
A	RS-820	6374M	Hornblende diorite from the Tahtsa complex (subordinate variety).
B	RS-809	6373M	Hornblende diorite from the Tahtsa complex (dominant variety).
C	9-52-5	6376M	Granodiorite from the Tahtsa complex.
D	D-2	5758M	Diorite from the Horetzky dyke, 30 feet above base.
E	D-6	5771M	Diorite from the Horetzky dyke, 570 feet above base.
F	D-30	5760M	Diorite from the Horetzky dyke, 3,980 feet above base.
G	D-10	5770M	Quartz diorite from the Horetzky dyke, 1,140 feet above base.
H	D-15	5759M	Quartz diorite from the Horetzky dyke, 1,840 feet above base.
I	An-7	5954M	Quartz diorite from the Horetzky dyke in tunnel.
J	An-5	5953M	Quartz diorite from the DuBose stock.
K	An-1	5757M	Quartz diorite from the DuBose stock.
L	An-3	5952M	Granodiorite from the DuBose stock.
M	An-2	5773M	Quartz monzonite from the DuBose stock.
N	8-54-78	....	Quartz diorite from the Nanika batholith.
O	8-54-75	....	Quartz diorite from the Nanika batholith.
P	8-54-79	....	Quartz diorite from the Nanika batholith.
Q	RS-250	5772M	Hornblende gabbro from a minor intrusion near the Horetzky Creek adit.
R	9-53-34	6377M	Granodiorite from a minor intrusion south of Mount DuBose.
S	8-54-32	....	Albite granite from a minor intrusion near Tahtsa Peak.

Chemical Analyses

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
SiO_2	46.70	52.10	72.35	53.86	55.00	56.02	61.00	61.36	61.42	62.92	62.60	65.86	72.90	53.88	55.80	56.22	47.30	69.24	70.64
TiO_2	0.69	0.95	0.31	0.91	0.78	0.88	0.59	0.56	0.67	0.50	0.59	0.49	0.08	0.76	0.72	0.69	0.86	0.44	0.40
Al_2O_3	16.59	15.90	14.17	17.72	18.20	17.25	17.37	17.18	16.82	16.52	16.87	16.14	14.43	17.96	17.85	17.42	15.16	16.05	14.47
Fe_2O_3	5.63	5.16	1.62	3.80	3.86	3.20	2.89	2.86	2.64	1.94	2.35	1.67	1.13	3.29	3.53	1.86	4.44	1.26	1.05
FeO	4.73	4.85	1.19	4.78	4.21	4.32	3.00	2.94	3.03	2.56	3.04	2.10	0.72	4.38	4.06	5.17	6.28	1.16	1.91
MnO	0.16	0.15	0.05	0.15	0.16	0.13	0.12	0.12	0.11	0.11	0.11	0.09	0.03	0.14	0.12	0.14	0.10	0.04	0.08
MgO	7.89	5.45	0.97	4.50	3.80	3.77	2.41	2.42	2.57	1.75	2.28	1.76	0.53	4.12	3.34	3.08	9.06	1.13	0.59
CaO	8.82	8.38	1.38	7.88	7.34	6.70	5.46	5.16	5.26	5.36	5.36	4.38	1.85	7.46	5.86	6.39	10.02	1.94	1.43
Na_2O	2.10	3.53	4.28	3.70	3.64	4.13	4.12	3.61	4.33	4.48	3.90	3.81	3.27	3.12	3.33	3.56	2.62	4.26	4.86
K_2O	1.00	0.77	1.95	1.10	1.13	1.52	1.79	1.86	1.86	1.70	1.72	2.44	4.21	1.40	1.43	1.62	1.10	3.27	1.87
BaO	—	—	—	0.05	0.05	0.05	0.09	0.06	0.08	0.08	0.06	0.09	0.17	—	—	—	0.04	N.R.	N.R.
P_2O_5	0.18	0.13	0.10	0.48	0.33	0.31	0.23	0.22	0.21	0.25	0.25	0.19	0.07	0.37	0.39	0.34	0.07	0.15	0.07
H_2O+	3.56	2.30	0.96	1.04	1.22	1.36	0.88	1.40	0.82	0.78	0.92	0.66	0.48	2.46	1.78	1.74	2.34	0.54	{ 1.02
H_2O-	0.60	0.31	0.35	0.15	0.26	0.25	0.21	0.20	0.30	0.37	0.12	0.21	0.06	—	—	—	0.26	0.20	}
CO_2	0.62	0.40	*Nil*	0.03	0.08	0.05	*Nil*	0.04	*Nil*	0.70	0.08	0.09	0.05	0.05	0.08	0.06	0.14	*Nil*	0.52
ZrO_2	—	—	—	—	—	—	—	—	—	N.R.	N.R.	N.R.	0.10	0.02	0.01	0.02	0.13	N.R.	0.01
V_2O_3	—	—	—	—	—	—	—	—	—	—	—	—	—	0.02	0.01	0.01	0.13	N.R.	0.01
S	—	—	—	*Nil*	0.01	*Nil*	0.01	*Nil*	*Nil*	0.09	*Nil*	*Nil*	0.01	—	—	—	0.13	N.R.	N.R.
Totals	99.27	100.38	99.68	100.15	100.07	99.94	100.17	99.99	100.12	100.11	100.25	99.98	100.09	99.43	98.31	98.32	100.18	99.68	98.93

Norms

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Q	1.7	5.2	35.7	5.4	8.4	6.6	15.1	18.4	14.0	18.2	18.5	25.4	33.6	8.4	13.3	9.6	—	26.0	31.8
or	6.1	4.4	7.8	6.7	6.7	8.9	10.6	11.1	11.1	10.0	10.0	14.5	25.0	8.3	8.3	9.4	6.7	19.5	11.1
ab	17.1	29.9	36.2	31.4	30.9	25.1	34.6	30.4	36.7	37.7	33.1	32.0	27.8	26.2	28.3	29.9	22.0	36.2	40.9
an	32.8	25.3	8.9	28.4	29.8	24.2	23.9	23.6	20.8	20.0	23.6	19.7	9.2	30.9	25.6	27.0	26.4	8.9	3.9
C	—	—	2.7	—	—	—	—	0.6	—	—	—	—	1.0	—	—	—	—	2.1	3.1
di	4.9	10.4	—	5.8	3.3	5.8	1.1	—	3.6	—	0.4	1.1	—	2.5	—	2.0	18.0	—	—
hy	20.6	12.1	2.8	12.9	11.5	10.7	7.8	8.4	7.3	6.8	8.4	5.7	1.3	13.3	12.0	13.7	2.9	3.3	3.6
ol	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12.5	—	—
mt	8.1	7.4	2.3	5.6	5.6	4.6	4.2	4.2	3.7	2.8	3.5	2.3	2.1	4.9	5.1	2.8	6.5	1.9	1.6
il	1.4	1.8	0.6	1.7	1.5	1.7	1.0	1.1	1.2	0.9	1.1	0.9	0.2	1.5	1.4	1.4	1.7	0.8	0.8
ap	0.3	0.3	0.3	1.3	0.7	0.7	0.7	0.7	0.3	0.7	0.7	0.3	—	1.0	1.0	0.7	—	0.3	—
cc	1.4	0.9	—	—	0.2	—	—	—	—	1.6	0.2	—	—	0.1	0.2	0.1	0.3	—	1.2
Z	—	—	—	—	—	—	—	—	—	—	—	—	0.2	—	—	—	—	—	—

Analyses A to M, Q, and R by British Columbia Department of Mines. Analyses N, O, P, and S by Aluminum Laboratories Ltd.
N.R.=Not reported.

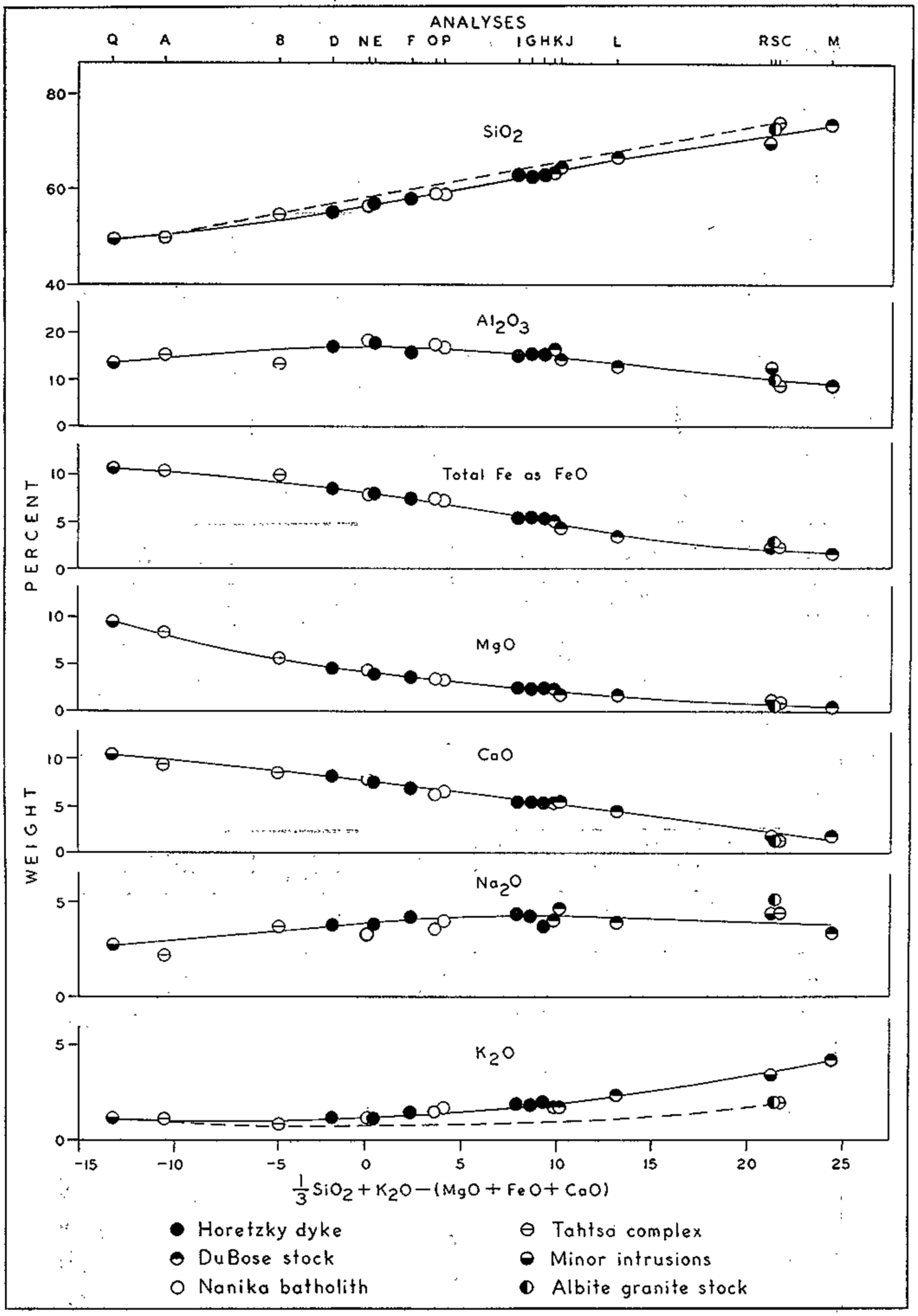


Fig. 15. Chemical variation diagram.

APPENDIX II.—ANALYSES FOR TRACE ELEMENTS

Analyses 5932M to 5936M from DuBose stock; Analyses 5937M to 5951M from Horetzky dyke.

SPECTROCHEMICAL ANALYSES

Analysis No.	Values in Parts per Million												
	Mn	Sr	Ba	Cu	Zn	V	Co	Ni	Cr	Ga	Pb	Sn	Mo
5932M	1,700	860	230	450	120	88	17	14.0	8.0	19	13	10	3.8
5933M	480	320	780	660	100	18	4	3.0	0.7	6	7	3	2.2
5934M	1,600	670	310	570	110	88	15	10.0	8.0	15	11	5	3.6
5935M	1,300	780	780	600	88	68	11	8.0	3.0	14	9	11	3.6
5936M	1,700	1,100	500	480	50	93	17	15.0	13.0	17	18	14	2.6
5937M	1,000	400	520	320	38	90	15	5.0	3.0	16	9	6	3.4
5938M	1,850	860	330	230	42	93	14	8.0	5.0	8	4	2	3.6
5939M	1,300	220	330	630	240	85	14	14.0	22.0	18	18	8	4.2
5940M	2,400	1,100	820	530	82	170	33	32.0	52.0	13	7	3	7.4
5941M	2,300	1,000	580	570	86	180	32	33.0	82.0	15	8	6	7.4
5942M	2,000	900	520	550	64	150	26	22.0	28.0	14	8	5	5.0
5943M	1,400	500	440	330	62	83	15	13.0	7.0	11	8	4	3.6
5944M	2,100	800	350	280	79	80	14	7.2	3.0	10	5	4	4.2
5945M	1,500	630	660	330	63	93	15	8.2	7.0	13	21	6	4.8
5946M	1,800	640	520	360	90	83	13	4.6	3.0	13	10	5	4.2
5947M	2,100	820	440	750	130	140	25	16.0	8.0	18	28	10	6.0
5948M	1,800	900	660	360	56	140	27	21.0	52.0	16	10	6	8.2
5949M	1,800	1,000	600	550	100	150	29	31.0	57.0	15	6	5	9.2
5950M	2,300	1,200	600	660	120	180	29	27.0	57.0	16	13	10	8.0
5951M	2,300	600	460	560	120	130	20	4.8	2.5	13	6	6	6.8

CHECK ANALYSES

Original Analysis No.	Values in Parts per Million						
	X-ray Analyses				Chemical Analyses		
	Mn	Sr	Ni	Mo	Co	Cr	Mo
5940M	1,100	600	32	24	15	27	0.5
5941M	1,200	580	23	22	17	60	0.6
5942M	1,100	530	21	17	14	26	0.3
5943M	1,000	480	9	16	7	12	0.4
5944M	900	550	16	6	8	7	0.3
5945M	1,000	500	21	23	7	15	0.3
5946M	1,000	500	15	17	7	4	0.5
5947M	1,100	580	21	18	10	12	0.3
5948M	1,000	520	25	16	11	35	0.7
5949M	1,000	580	28	19	11	35	2.8
5950M	1,000	620	30	18	13	24	1.8

All analyses by Analytical Branch, British Columbia Department of Mines.

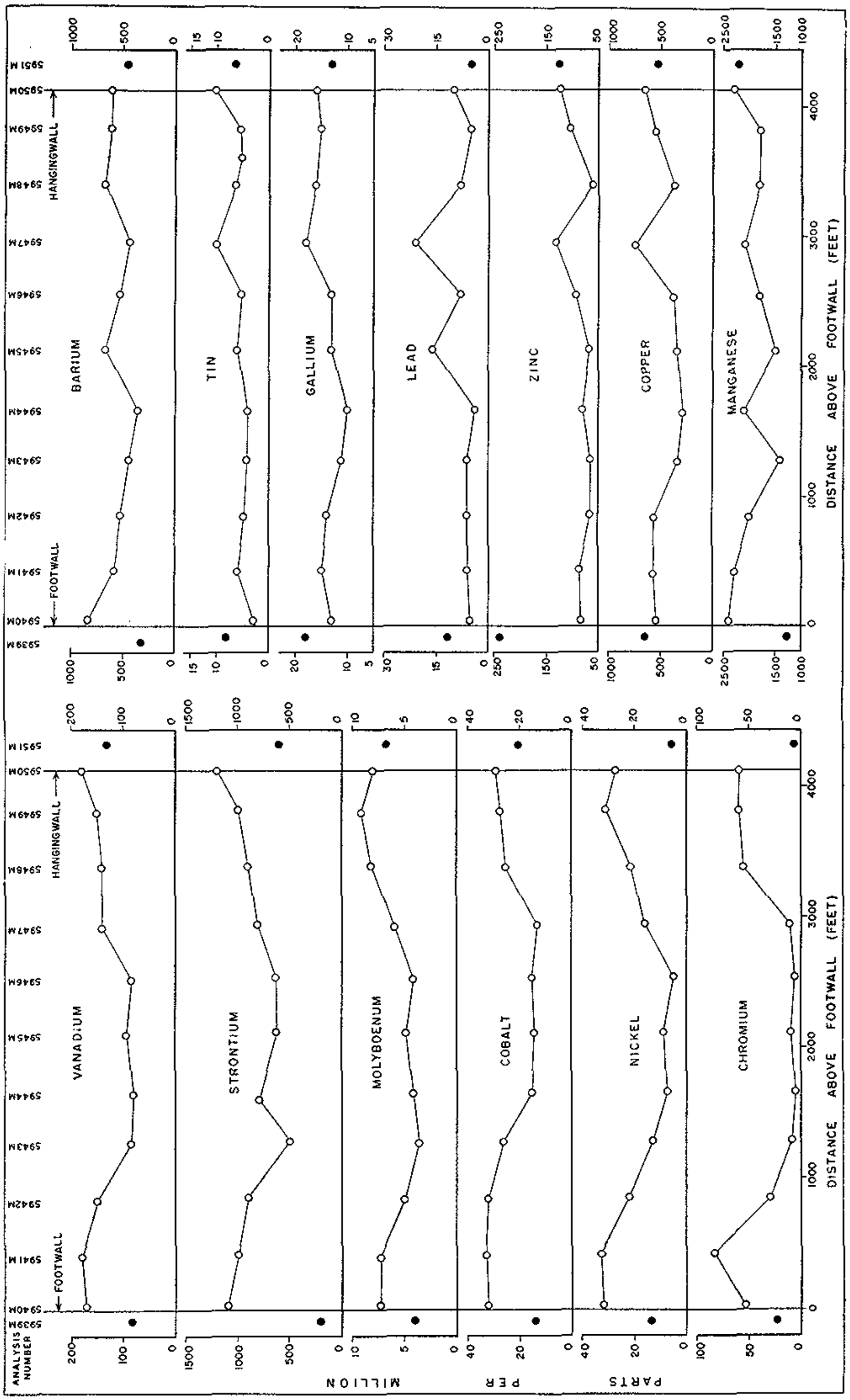


Fig. 16. Trace element variation in Horetzky dyke.

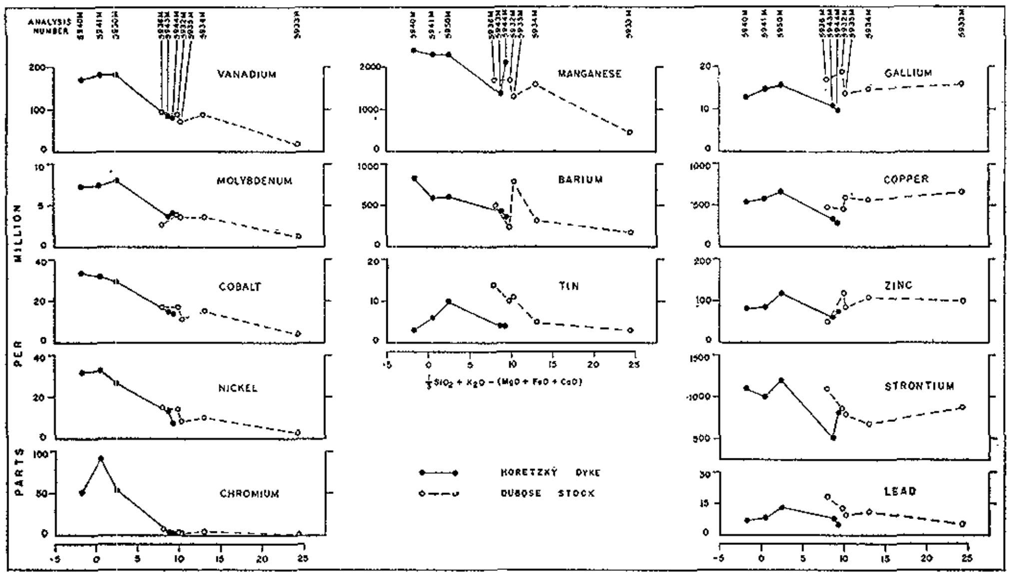


Fig. 17. Trace element variation diagram, Horetzky dyke and DuBose stock.

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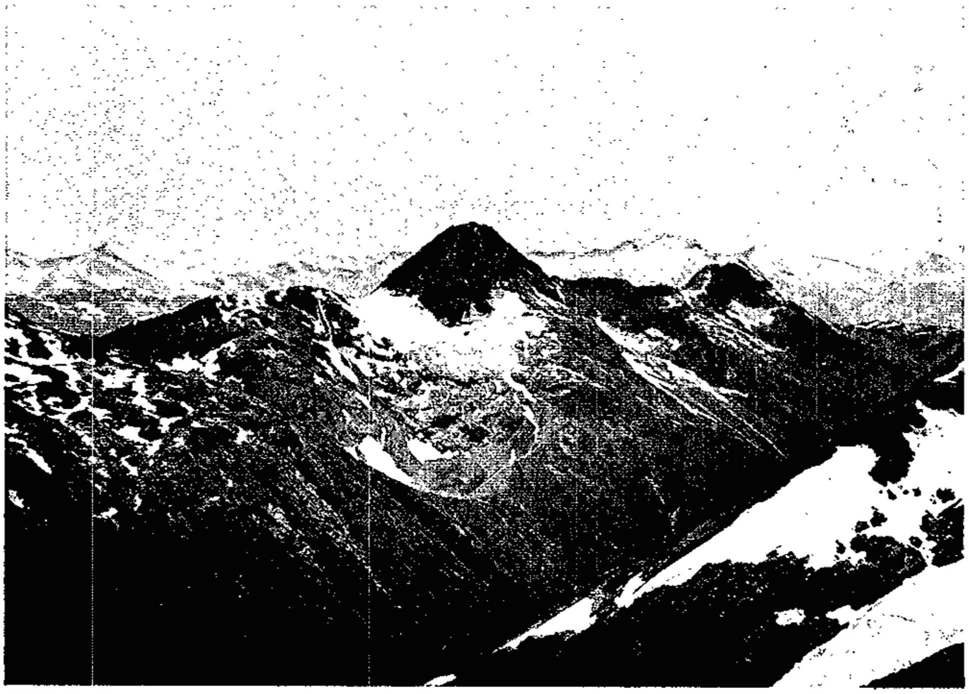


Plate I. The ridge on the south side of Horetzky Valley, illustrating the sharp ridgelines marked by peaks and saddles that are typical of the western part of the map-area. Looking southwest.

Plate II. Looking west down Horetzky Valley. Horetzky camp in centre front.

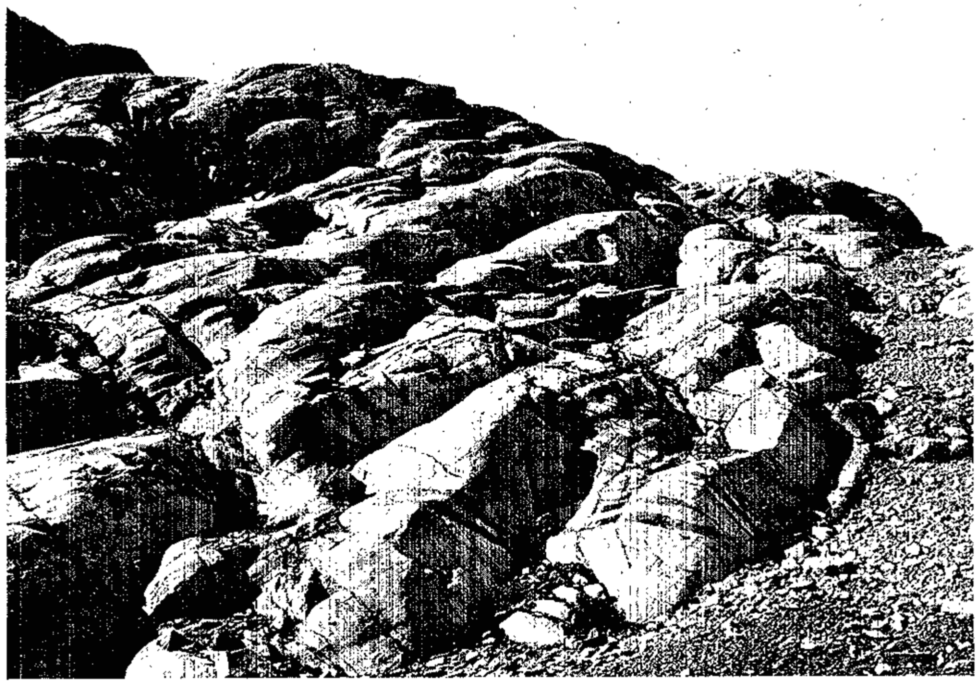


Plate III. Glaciated outcrop near the head of Horetzky Valley.

Plate IV. Tahtsa complex. Irregular stringers and patches of quartz diorite in diorite.

Plate V. Tahtsa complex. Photomicrograph of diorite showing a large euhedral hornblende crystal with several small plagioclase inclusions. (X 13—plane light.)

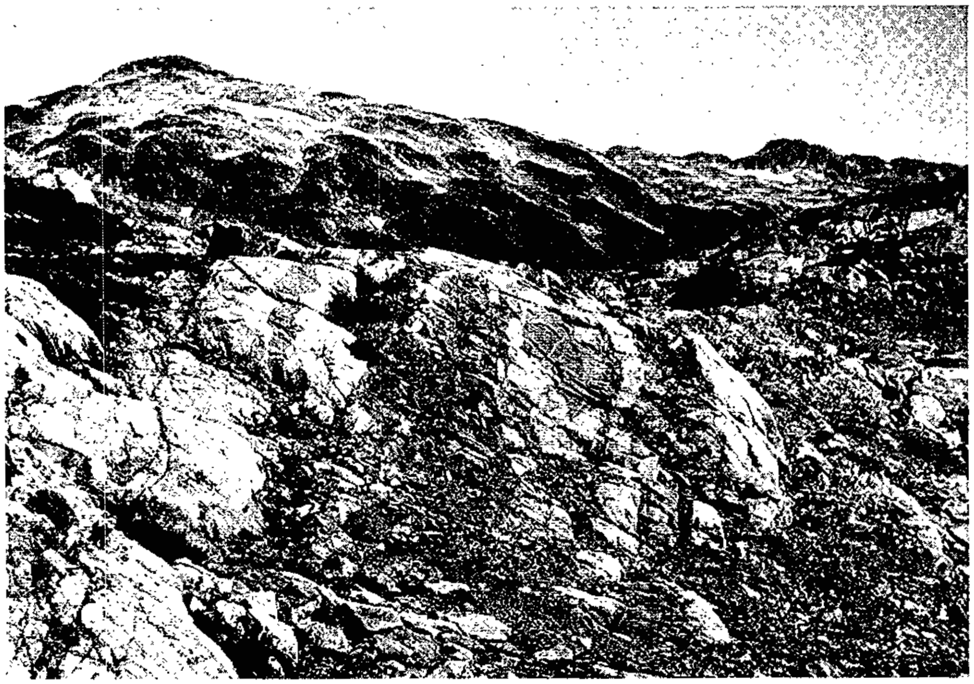


Plate VI. Tahtsa complex. Slabs of diorite (dark) isolated between closely spaced granodiorite dykes (light).

Plate VII. Tahtsa complex. Photomicrograph of quartz monzonite showing a border zone of vermicular potash feldspar and plagioclase on a plagioclase crystal. (X 90—crossed nicols.)

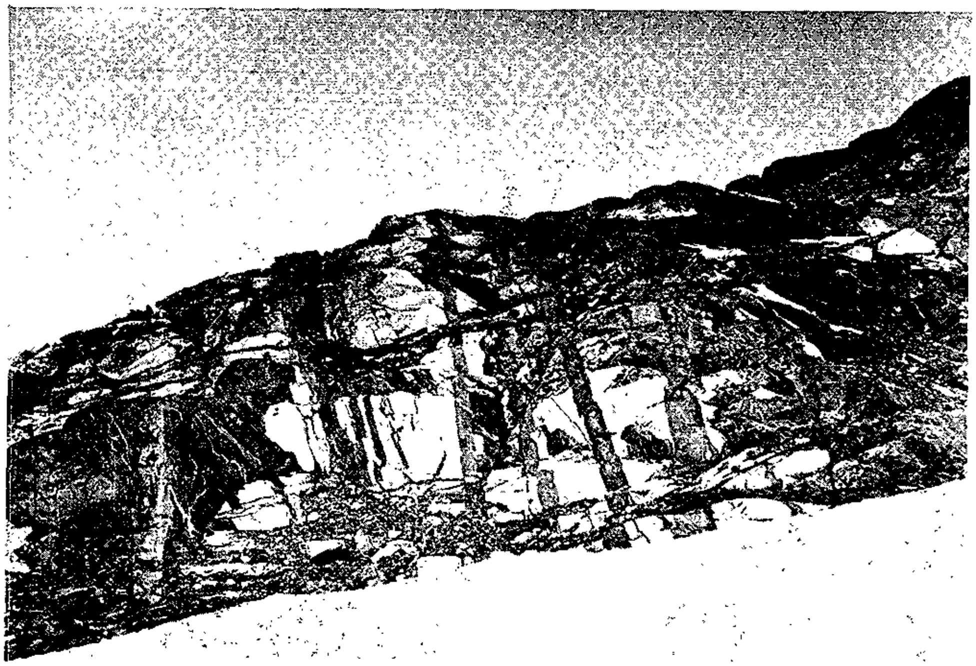


Plate VIII. Tahtsa complex. Basic dykes cutting diorite and granodiorite.

Plate IX. Tahtsa complex. Early basic dyke deformed by pregranodiorite stresses. Note the younger, undeformed basic dyke near the right side of the photograph.

Plate X. Hazelton group. Exposure of typical volcanic breccia. Note the range in size of the fragments and the dominance of the smaller sizes.

Plate XI. Hazelton group. Photomicrograph of sheared volcanic breccia showing elongation of fragments. (X 8— plain light.)

Plate XII. Kemano gneiss. Outcrop of banded gneiss showing pinching and swelling of the light bands.

Plate XIII. Kemano gneiss. Photomicrograph of the dark phase of the gneiss showing the characteristic granular texture. (X 11—crossed nicols.)

Plate XIV. Horetzky dyke. Photomicrograph of diorite showing euhedral and subhedral plagioclase crystals and interstitial quartz. (X 34—crossed nicols.)

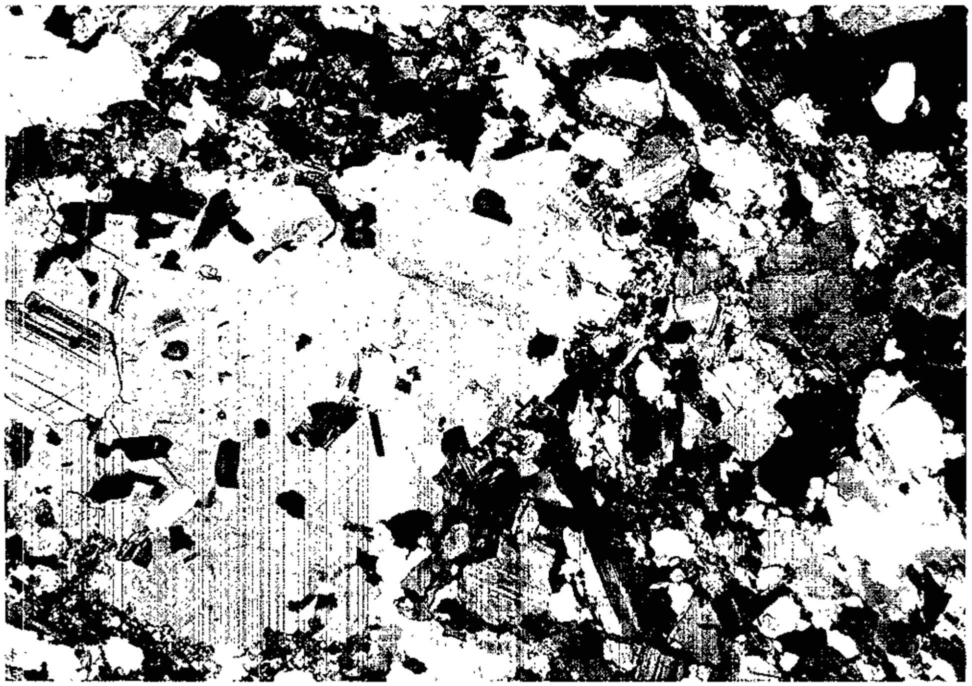
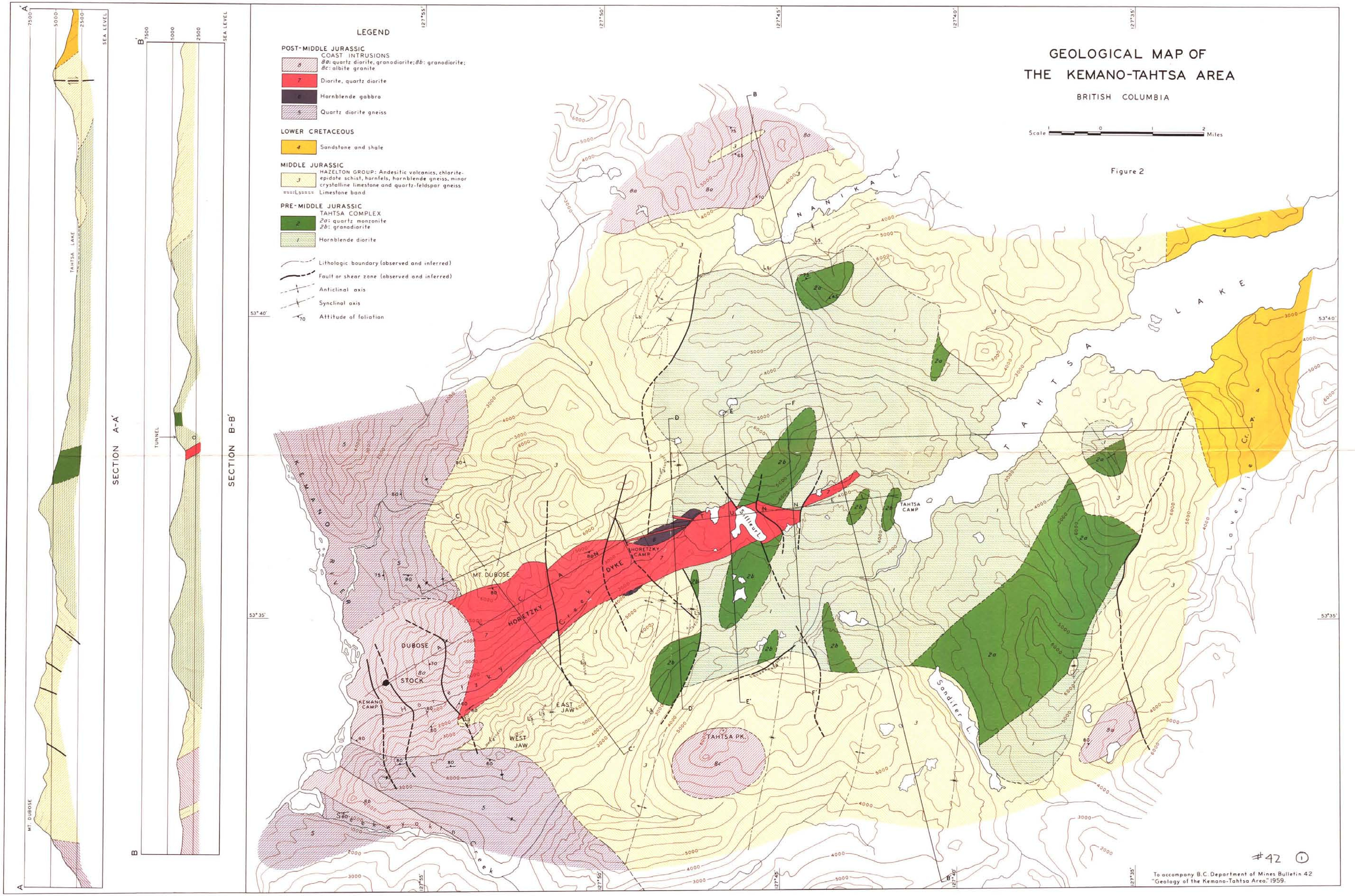


Plate XV. DuBose stock. Photomicrograph of a large potash feldspar grain (light grey) containing residual grains of plagioclase, quartz, and biotite. Note the pseudocataclastic texture of the surrounding finer-grained material. (X 34—crossed nicols.)

Plate XVI. Nanika batholith. Photomicrograph of the cataclastic texture of the granodiorite. (X 38—crossed nicols.)


GEOLOGICAL MAP OF
THE KEMANO-TAHTSA AREA
BRITISH COLUMBIA
Scale
Miles
Figure 2
LEGEND
POST-MIDDLE JURASSIC
COAST INTRUSIONS
8a: quartz diorite, granodiorite; 8b: granodiorite; 8c: albite granite
Diorite, quartz diorite
Hornblende gabbro
Quartz diorite gneiss
LOWER CRETACEOUS
Sandstone and shale
MIDDLE JURASSIC
HAZELTON GROUP: Andesitic volcanics, chlorite-epidote schist, hornfels, hornblende gneiss, minor crystalline limestone and quartz-feldspar gneiss
Limestone band
PRE-MIDDLE JURASSIC
TAHTSA COMPLEX
2a: quartz monzonite
2b: granodiorite
Hornblende diorite
Lithologic boundary (observed and inferred)
Fault or shear zone (observed and inferred)
Anticlinal axis
Synclinal axis
Attitude of foliation
SECTION A-A'
SECTION B-B'
SEA LEVEL
TAHTSA LAKE
MT. DUBOSE
TUNNEL
NANIKA L.
TAHTSA LAKE
TAHTSA CAMP
HORETZKY CAMP
HORETZKY DYKE
Creek
MT. DUBOSE
DUBOSE STOCK
KEMANO CAMP
KEMANO RIVER
EAST JAW
WEST JAW
TAHTSA PK.
Sandifer L.
Lovell Cr.
Sea Creek
#42
To accompany B.C. Department of Mines Bulletin 42 "Geology of the Kemano-Tahtsa Area." 1959.