SOUTHERN END OF THE COAST PLUTONIC COMPLEX

J.A.RODDICK W.H.MATHEWS G.J.WOODSWORTH

INTRODUCTION

The area is near the oceanward margin of the Cordilleran orogenic belt and is characterized by a complex succession of eugeosynclinal sediments and volcanic rocks associated with metamorphic and plutonic rocks reflecting long-continuing tectonic activity and repeated geomorphic instability. Sharp contrasts exist between contemporaneous successions now within short distances of one another.

A spreading oceanic ridge on the Pacific ocean floor meets the continental margin near the north end of Vancouver Island, where three lithospheric plates meet. They are, from west to east, the Pacific Plate, Juan de Fuca Plate, and North America Plate. Strike-slip faults separate the Pacific and North America Plates north of the triple point which lies west of the north end of Vancouver Island. To the south, the northern end of the Juan de Fuca Plate intervenes between the two major plates, and seems to be breaking up following the cessation of oblique northeasterly subduction. These processes appear to have persisted during much of the Cenozoic Era, and their effects were felt to a greater or less degree across the Cordilleran orogenic belt. Some geophysical data suggest that the crust may change abruptly from a continental thickness and composition beneath the mainland to a thinner crust approaching oceanic composition beneath southernmost Vancouver Island. Thus Couch (1958) concluded from a study of gravity that the Moho discontinuity lies 27 km beneath Vancouver Island, deepening to 3[illegible] km beneath the Coast Mountains north of Vancouver, and to 4[illegible] km farther northeast. On the other hand seismologists failed to receive retnrns from a recognizable Moho from explosions set off at opposite ends of Vancouver Island (400 km apart) and

TRIP 9

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JOINT ANNUAL MEETINGS
VANCOUVER B.C., APRIL 1977

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J.A. RODDICK

W.H. MATHEWS

J.G. WOODSWORTH

PRICE

$2.00

hence concluded that the Moho may lie at least 56 km deep (Tseng, 1968).

Though the broader units in the region are of tectonic origin, the detailed topography is an expression of erosion. The major mountain valleys were developed, probably since Miocene time, by subaerial and glacial action controlled partly by weak sediments or fracture zones in crystalline rocks. Valleys such as those of Harrison Lake and Fraser River north of Hope, are located on major fault zones. Valleys such as Howe Sound, however, transgress bedrock structures and seem to have been established as more or less direct routes for streams and glaciers to the lowlands.

The mountain valleys, though probably first developed as stream-cut trenches, clearly display the effects of glaciation. Longitudinal profiles are irregular and lack concordance with any common base-level (Howe Sound, for example, has a bedrock floor at least locally about 800 meters below sea level, whereas the valleys to the east terminate in Burrard Inlet in which the bedrock floor is less than 100 meters below sealevel). Valleys are deep close to their heads and transverse valleys are common, allowing a reticulate pattern fot former glacial distributaries and leading to a fringe of islands on the coastal margins of the mountain belts. The common U-shaped cross-section of valleys, however, appears to be a composite feature, produced by deposition of glacial and fluvioglacial deposits on the valley floors and against steep ice-cut bedrock walls.

Mountain summits are principally of three types: ragged horns; domes, evidently rounded by overriding glacial ice; and relics of a former uplifted erosion surface (plateau) of low relief. The horns are confined to the higher summits and the altitudinal boundary separating these from the domes is interpreted as the gently sloping upper limit of late Pleistocene ice. Summits only slightly below this limit,such as The Lions, near Vancouver, are but slightly rounded horns. The plateau summits are most common on southern Vancouver Island, but a few survive within the Coast Moantains and have been correlated with a surface underlying late Miocene basalts on the northeastern side of the mountain belt. If this correlation is correct the plateau surface was eroded to low relief, and presumably also to low elevation by late Miocene time. A post-Miocene differential uplift can thus be inferred ranging from 1 to 2 km along the southern margin of the Coast Mountains to more than 2.5 km near their northeastern edge. On the other hand terrestial sedimants believed to be of Miocene age survive 200 to 1400 m below present sea level under the western Fraser lowland, and there at least, post-Miocene uplift must have been slight or absent.

Raised deltas, shorelines, and associated glaciomarine deposits are widespread up to 180 meters above present sea level, brought to their present positions by postglacial isostatic rebound (Mathews et al, 1970).

The Coast Plutonic Complex forms a long (1700 km) narrow (96 km) plutonic and metamorphic terrane dominated by intermediate and basic granitic rocks. The flanking strata consist mainly of Mesozoic volcanic and sedimentary rocks, although Lower Paleozoic rocks occur in southeastern Alaska, in the San Juan Islands and in the adjoining Northern Cascade Mountains, and Upper Paleozoic rocks are also known in those places as well as on Vancouver Island and along the eastern flank of the Coast Mountains. The Coast Plutonic Complex was the site of scattered plutonic activity in pre-Mesozoic time, but the nature of the belt then is not known. Late Triassic time was one of major basaltic volcanic activity from Vancouver Island in the west to the Interior Plateau in the east. A significant change occurred in the Early Jurassic when basaltic volcanism gave way to andesitic volcanism on Vancouver Island. Although adjacent areas indicate plutonism and uplift in the northern part of the Coast Plutonic Complex in Late Triassic time, the first major berst of intrusive activity came in the Jurassic and the belt became a major positive feature flanked on the east by two troughs which later (in mid-Jurassic time) broke up into three successor basins. They display a gradual transition from marine deposition in the Jurassic to nonmarine deposition in the mid-Cretaceous accompanied by an increasing volume of granitoid debris derived from the Coast Plutonic Complex. Plutonic activity reached its height in the Cretaceous and continued into the early Tertiary, but was followed by scattered plutonic intrusions, at least up to the end of Miocene time.

The Coast Plutonic Complex consists mainly of plutonic rock, gneiss and migmatite which together form a very heterogeneous matrix in which discrete and partly discrete plutons of various sizes can be delineated. The most common granitic rock in the Coast Plutonic Complex is quartz diorite. It was estimated in the Vancouver area (Roddick, 1965) that if all the granitic rock were homogenized the resultant rock would be a biotite hornblende quartz diorite containing about 5% K-feldspar. An unusually high concentration of modal points fall in the basic quartz diorite and diorite fields. Rocks more acid than mid-quartz monzonite (adamellite) are rare. Chemical analyses of the common rock types across the Coast Mountains between latitudes 53° and 54°N show that the two most common rock types, quartz diorite and granodiorite, as well as the granitoid gneisses, each have average chemical compositions equivalent to tholeiitic andesite (average series) according to the classification of Irvine and Baragar (1971), rather than andesite of the calc-alkaline series which might be expected. Although the quartz diorite and granodiorite are subalkaline rocks, the diorites have an average composition equivalent to hawaiite, an alkaline rock which is a member of the alkali olivine basalt series.

As the pendants within the Coast Mountains have yielded few fossils, most of the evidence bearing on the timing of plutonism comes from radiometric age determinations. For the region between latitudes 52° and 55°N the earlier pattern of three distinct belts is changing as additional determinations are made. The eastern belt remains well-defined in the 43 to 50 m.y. range and constitutes all of the Coast Plutonic Complex lying east of the central axis, but the two western belts have merged into a single belt with Early Cretaceous ages on the west through to Late Cretaceous ages on the east.

The isotopic age pattern in the southern Coast Mountains between latitudes 49° and 51°N is similar but not identical to the northern region. The eastern belt spans a greater range, 35 to 80 m.y. , and the western transitional belt shows somewhat less scatter, ranging from 75 to 158 m.y.

About half of the 143 K-Ar age determinations in the Coast Mountains fall within the Late Cretaceous, and about one quarter fall within the Early Tertiary. These ages may be interpreted as probable minimum final cooling ages for large parts of the Coast Plutonic Complex, and indicate at least that the western part cooled before the eastern part. Most of the 31 hornblende-biotite pairs which have been run are more or less concordant, with the hornblende age being greater than biotite in most places. The range of discordancy does not appear to be significantly greater to the west, and in this respect differs from the extension of the Coast Plutonic Complex into southeast Alaska as reported by Smith (1975).

When all of the K-Ar dates in the Coast Mountains are considered only one substantial gap is revealed; it lies between 115 and 140 m.y. and covers pre-Aptian Early Cretaceous and the last stage of the Jurassic. The 90 to 110 m.y. dates which are common in the Coast Mountains are lacking on Vancouver Island, whereas Late Jurassic dates which are common on the Island are represented only locally in the Coast Mountains.

Zircons from gneissic plutonic rock from the southern Coast Mountains at Pemberton and Cheakamus Canyon yielded somewhat discordant U-Pb values and indicate concordia intercepts at 330 m.y. or 540 m.y. , the range being a function of the choice of time at which the isotopic systems were disturbed, 0 m.y. or 90 m.y. ,respectively.

Bodies of volcanic, sedimentary and metamorphic rocks ranging in age from at least as old as Permian to mid-Cretaceous are found as pendants within the Coast Plutonic Complex throughout its length. They form a somewhat larger proportion of the crystalline belt between latitudes 53° and 55°N than elsewhwere. Most of these bodies are Mesozoic and are metamorphosed to greenschist or amphibolite grade, but a few are only slightly altered and locally contain fossils. In the southern Coast Mountains volcanic rocks, mainly andesitic to basaltic, are more abundant than sedimentary strata in most pendants.

The Pleistocene stratigraphic record of this area, as revealed in surface exposures, is restricted to the last two glaciations, one interglacial between them, and one previous to the penultimate glaciation. Earlier glaciation occurred (deposits are known in Washington State to the south) but in British Columbia such deposits have either been eroded away or effectively buried. The last interglacial beds have yielded radiocarbon dates from 47,000 years to about 25,000 years b.p. near Vancouver, and the earliest post-glacial dates range from 14,000 years b.p. in Washington to about 12,500 years b.p. in southwestern British Columbia. Ice lingered in, or readvanced into, the eastern Fraser Lowland, and about 11,000 to 10,500 years b.p. created a large floodplain with a conspicuous ice contact face. At about the same time, ice created a major submarine moraine in upper Howe Sound. Before 9,500 years ago, the ice disappeared from what had been the central area of the ice sheet in the interior of British Columbia.

The last glaciation of this area can thus be correlated with the 'classical Wisconsin' of eastern North America. The penultimate glaciation of southwestern British Columbia may be early Wisconsin, but in the absence of definitive radiometric dates, or even of a record of late soil development which might give some estimate of subsequent time, no firm correlation is yet possible. The same problem arises for the nonglacial sediments beneath the early till.

The principal source of ice sheets was undoubtedly in the vicinity of the high summits of the Coast Mountains and the Cascade Mountains where small glaciers exist today. Detritus from these mountains make up a significant proportion of the glacial deposits, and a few unique rock types can be traced back to outcrops within these mountains. It is also likely, however, that when the ice sheet was well developed its nourishment was influenced by its own configuration, regardless of the topography which it largely buried. In the waning stages of glaciation, moreover, the large reservoirs of ice, notably east of the Coast Mountains, continued to drain outward even after the mountain sources had ceased to be significant as areas of accumulation.

DAY 1

STOP 1: OUTCROP NEAR SANDY COVE
(5.1 miles; 1.0 miles to next stop.[1])

About three quarters of a mile west of Sandy Cove part of the Coast Plutonic Complex is well exposed in a south-sloping outcrop about 45 by 60 meters. Until a few years ago this was the site of a gravel pit excavated into an early postglacial raised delta of Cypress Creek which flows to the sea about 1/4 mile (0.4 km) west of here. The site was subsequently acquired by Canada Dept. Of Environment for an oceanographic institute and cleared for a still-abortive building program. In the meantime a detailed undergraduate thesis on the outcrop was written by V. Ahlborn (1971), from which most of the following data was taken (Fig. 1).

The dominant rock here is a medium to coarse-grained quartz diorite cut by three andesitic dykes.

The quartz diorite consists mainly of plagioclase An^{31-37} (about 55%), lesser quartz (20-25%), minor perthite (5%), biotite (5%) and hornblende (5%) plus chlorite, apatite, sericite, epidote, and zircon. In thin section the texture is seen to be formed by large irregularly-shaped plagioclase megacrysts and some hornblende megacrysts, set in a much finer-grained granular matrix of hornblende, plagioclase, biotite, quartz and accessory minerals. The plagioclase megacrysts contain numerous inclusions of the matrix granules and evidently formed later. Thus, although the geometry is similar to a cataclastic or protoclastic texture, the texture is best described as pseudocataclastic. Foliation is developed locally, especially near andesite dykes. Hornblende megacrysts give the rock a lineation plunging slightly to the southwest and concordant with the orientation of elongated amphibolitic inclusions which form about 2% of the rock.

The amphibolitic inclusions are irregularly distributed, as is common throughout the Coast Plutonic Complex. Most are lenticular but some are subangular; outlines vary from smooth to irregular, distinct to gradational. Some of the larger

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[1] Mileage measured from Marine Drive and Taylor Way, West Vancouver.

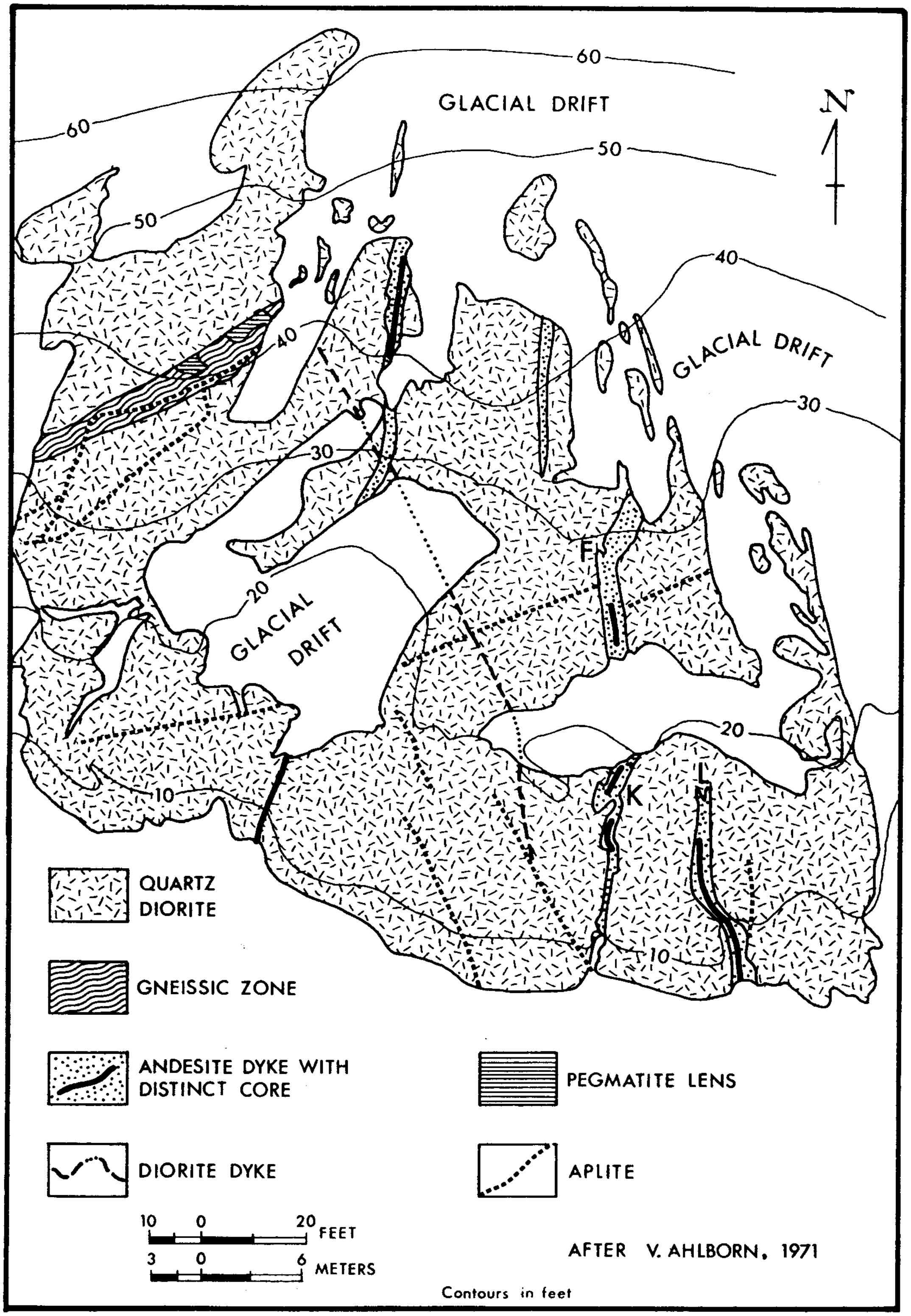

Figure 1: Glaciated outcrop near Sandy Cove, after Ahlborn (1971).

inclusions are fragmented and penetrated irregularly by granitoid material which is mafic-poor and K-feldspar rich. Plagicclase crystals An^{26-40} resemble those in both the quartz diorite and in dykes in their zoned appearance but may differ in composition.

A gneissic layer 3 to 6 feet wide (1-2 m) crosses the upper part of the outcrop, and appears to be an integral part of the quartz diorite to the south into which it grades; the finely laminated northern edge of the layer forms a sharp contact with the quartz diorite inclusions in the northern quartz diorite and is possibly a synplutonic fault. The hornblende/biotite ratio in the two quartz diorites varies but is generally greater north of the gneissic band than south of it. Inclusions near the gneissic zone are aligned parallel with it on the south side but trend northerly north of it. Several pegmatitic lenses occur within the gneissic zone.

A diorite dyke up to about 1 1/2 feet (45 cm) wide cuts northwesterly across the center of the exposure, cutting a northeasterly trending aplite vein.

Andesite dykes, up to 4 feet (1.2 m) wide, trend northerly across the quartz diorite, cutting and displacing the diorite dyke. Intricate contacts (see below) are locally developed with the adjacent quartzdiorite. In many places these dykes contain cores of younger material.

The andesite dykes consist of hornblende, zoned plagioclase, and some quartz megacrysts embedded in a matrix of plagioclase laths and elongate hornblende crystals. The mineralogy of the host and core dykes are similar but not identical; the core dykes contain more hornblende and opaque minerals, less zircon, and no quartz. The zoned plagioclase An^{56-65} of the core dykes is more calcic than that of the host dykes An^{40-50} and less saussuritized. The matrix of the host dykes displays an irregular interlocking texture whereas the matrix of the core dykes shows an acicular texture unaffected by recrystallization. The eastern of the three dykes at its southern end shows a sharp offset as if cut by a left-hand fault, but on close inspection no fault can be found with either dyke or host and, moreover, the dyke core shows no such offset. Near here are conspicuous epidote veins and associated altered zones up to 1 inch (2.5 cm wide). These veins do not persist into the plutonic rock except locally as hairline fractures flanked by pale rusty alteration. Slender spurs extending from this dyke at three places are commonly broken. The dyke contains a 9-inch (23 cm) inclusion of quartz diorite about 15 feet (5 m) from its southern end. The upper end of the dyke (point L on Fig. 1) together with a mafic inclusion in the quartz diorite show particularly intricate relationships.

The central dyke also displays deflection with a left-hand granodiorite just north of Caulfeild retain their original orientation, and some appear to have remnants of Caulfeild gneiss adhering to them. He postulated that the dykes had originally intruded the gneiss, most of which had later been removed by delicate magmatic stoping during intrusion of the granodiorite. He favoured a magmatic origin for the granodiorite based mainly on dilation-offset shown by granodiorite dykes, rotated slabby xenoliths, and inclusions of widely different fabrics in close proximity to one another. H. H. Read disagreed (in Phemister, 1945, discussion) with Phemister's interpretation of the origin of the granodiorite and argued that the evidence favoured granitization, and that the pre-batholithic dykes could be more easily preserved if the gneiss were removed by selective replacement. Roddick and Armstrong, on the basis of work in the surrounding region (1959), concluded that the dykes were 'synplutonic' in the sense that they intruded the granitic mass as well as its inclusions and pendants when the plutonic rock had sufficient strength to sustain fractures, yet was in a stage of active crystallization. The dykes intruded at different times and into plutonic terranes in different stages of evolution, and thereafter partook in the subsequent recrystallization that completed the plutonic evolution. Synplutonic dykes are an intriguing feature of the Coast Plutonic Complex but those at Caulfeild lack the features of the better examples that can be seen elsewhere.

An universal stage study of the zoned plagioclase in the plutonic rock at Caulfeild and vicinity by Greenwood and McTaggart (1957) showed a general similarity in sequence and zone composition, not only between adjacent crystals but between those up to 3 miles (4.8 km) apart, indicating that the system in which the feldspar crystallized extended at least that distance. Although the work of Greenwood and McTaggart did not resolve the problem of the origin of the Caulfeild plutonic rock, Ross (1957) favoured a magmatic origin because of the presence of synneusis 'twins' in the plagioclase. Roddick (1965) on the basis of an earlier study of plagioclase zoning in quartz dioritic rocks about 35 miles (50 km) to the east concluded also that there existed a general similarity in the zoning of widely separated crystals but emphasized that even crystals nearly adjacent may show fundamental differences in detail. Having studied an area of about 3400 mi^2 (9000 km^2) north and east of this stop, Roddick concluded on the basis of several independent lines of study that the plutonic rocks formed at depth by metasomatism and subsequently moved upward in salt-dome fashion at less than magmatic temperatures and in a state wherein they could both sustain fractures and in due course anneal them by recrystallization.

<u>INTER-STOP COMMENT.</u> Howe Sound between Horseshoe Bay (mile 10.5) and the next stop has a water depth of about 800 feet (250 m), steep sides, and a flat bottom. It is underlain by as much as 2400 feet (750

m) of soft sediment, probably Quaternary, resting on an irregular bedrock surface (St. John, 1972).

STOP 3: GAMBIER GROUP, ANTICLINE IN ARGILLITE BEDS

(22.1 miles; 3.6 miles to next stop.)

The sedimentary rocks exposed at this stop are in fault contact at highway level with the volcanic rocks at the last station, but higher on Brunswick Mountain to the east they appear to overlie that sequence. The sedimentary rocks consist chiefly of thinly-bedded argillite, siltstone and greywacke. The beds, some ripple-marked, form an anticline trending WNW, that is intruded near its crest by a granophyric dyke (partly sill) about 15 feet (4.6 m) wide. From a slaty argillite about 1 mile (1.6 km) north of here H. W. Tipper collected some ammonites which were identified as *Cleoniceras (Grycia?) perezianum* (Whiteaves) of Early Cretaceous (middle Albian) age by J. A. Jeletzky of the Geological Survey.

STOP 4: QUARTZ DIORITE AT PORTEAU

(25.7 miles; 7.8 miles to next stop.)

At this stop a well-foliated quartz diorite is exposed in a large cliff and in a small quarry. The plutonic rock is a good example of that found in many places along the western side of the Coast Mountain Belt. It consists of a coarse-grained, hornblende>biotite quartz diorite with 5 to 10% lensoid amphibolitic inclusions and minor banding, both of which parallel the foliation. The structure trends NNW, concordant with the regional trend of the Coast Crystalline Belt and dips 40° to the east. In thin section the quartz diorite is seen to have a strongly developed cataclastic texture. The main minerals, in order of abundance are sodic andesine, quartz, hornblende, biotite, K-feldspar and minor opaques. Oscillatory zoning is common in the plagioclase, but many of the crystals have been broken, leaving incomplete fragments. Although synneusis envelopes have not developed, the plagioclase has partly recrystallized since, or more probably during, shearing, resulting in agglomerates of broken crystals. Many of the plagioclase crystals show rounded surfaces against recrystallized cataclastic material, and assume an augen appearance; some are bent.

The quartz crystals are irregular in detail but generally rounded and invariably loaded with 'ghost' granules. These are interpreted as crystals formed by incomplete annealing of fine-grained granular mortar quartz and not as incipient cataclasis. Identical texture can be traced from the large crystals into fine quartz mosaics, and, where fractures (rare) have developed in the large crystals, they ignore the borders of the 'ghost' granules.

The fine-grained cataclastic material is mostly quartz but mafic minerals are also present in this interstitial material. Hornblende is more abundant and forms larger crystals than biotite. Some of the hornblende and most of the biotite form irregular shredded shapes.

The dark inclusions are amphibolitic. In contrast with the plutonic rock, they are finer-grained, much richer in hornblende and poorer in quartz. Quartz and feldspar porphyroblasts developed in the inclusions have cataclastic-textured borders. One of the larger inclusions exposed on the highway outcrop also shows smaller inclusions within it.

The dark layers in the quartz diorite are also amphibolitic and similar in composition to the inclusions, but they have a stronger internal foliation marked mainly by anastomosing trains of small hornblende crystals and tiny biotite flakes. Plagioclase megacrysts contain abundant micro-inclusions of plagioclase, quartz and mafic minerals. The micro-inclusions in one crystal are aligned at about 70° to the foliation in the matrix, indicating porphyroblastic growth after development of foliation in the amphibolite and subsequent rotation of the crystal. Some of the dark bands are bordered by epidote layers.

The quartz diorite is cut by a narrow, 1-2 inch (2.5 cm) wide, dark dyke-like body which has the appearance of a synplutonic dyke. It is irregular in texture and contains porphyroblasts of quartz and plagioclase. In thin section, however, the rock looks less like a dyke. It consists mainly of fine-grained, well-foliated siliceous material that is made dark by abundant carbonaceous debris; no mafic minerals are present. The material is thought to represent not a dyke but a recrystallized shear zone. It trends northeasterly and cuts the foliation in the quartz diorite.

The quartz diorite is cut by numerous epidote veins, flanked in most places by zones of low-temperature hydrothermal alteration.

The ice-polished surface, freshly exposed by road construction, displays well developed glacial striae and crescentic gouges indicating southward movement of ice.

Marine investigations in Howe Sound west of this point have revealed an enormous but totally submerged recessional moraine known to contain in its uppermost part ill-sorted sandy gravels as well as till or stony marine clay. A raised delta 1 km to the north has yielded shells and wood with radiocarbon ages of 11,390 and 10,690 years B.P. Respectively, corresponding to a sea level at about the present 200 foot (60 m) contour.

INTER-STOP COMMENT. The deposit of sand and gravel at mile 30.0, part of a raised delta or kame terrace, originally contained over 44 million tons, and is being rapidly quarried (1-2 million tons per year) for use in the Vancouver area. The townsite and concentrator of Britannia mine (now inactive) is passed at mile 30.4. Discovered in 1888, this mine had a history of production from 1905, when it was worked at a rate of 200 tons per day, to 1974, with peak production in the 1930s at almost 6000 tons per day. It has yielded more than 1.1 billion pounds of copper, 270 million pounds of zinc, 34 million pounds of lead, almost 500,000 ounces of gold and almost 6 million ounces of silver. Pyrite, chalcopyrite, and lesser sphalerite form stringer lodes, massive replacements, and combinations of the two, in chloritic and sericitic schists in a steeply dipping northwesterly trending shear zone in volcanic rocks believed to be mainly Lower Cretaceous. Orebodies have been found through a vertical range of more than 1300 meters and a horizontal range of 3 km (Sutherland Brown and Robinson, 1971; Sutherland Brown, 1975).

STOP 5: VIEW OF MOUNT GARIBALDI
(33.5 miles; 27.7 miles to next stop.)

From this stop a view (Fig. 3) can be obtained in clear weather of Mount Garibaldi fifteen miles (25 km) to the northeast, a very late Pleistocene volcano of the Pelean type (Mathews, 1952), believed to have been built in large part on residual ice of the last glaciation at an early stage in its recession, while all land below the present 4,400 foot (135 m) contour was buried. Subsequent melting of the ice permitted the flanks of the cone to collapse except for a limited segment which had been built on high, ice-free land. A section of Pelean tuff breccias 2300 feet (700 m) thick, is exposed on the southwest face. The somewhat more resistant vent-filling forms the south peak of the mountain. Younger lava flows mantle the slide scar on the northwest face, and form the north peak. The rocks of Mount Garibaldi are dacitic, closely resembling in chemical composition the quartz diorites on which they lie.

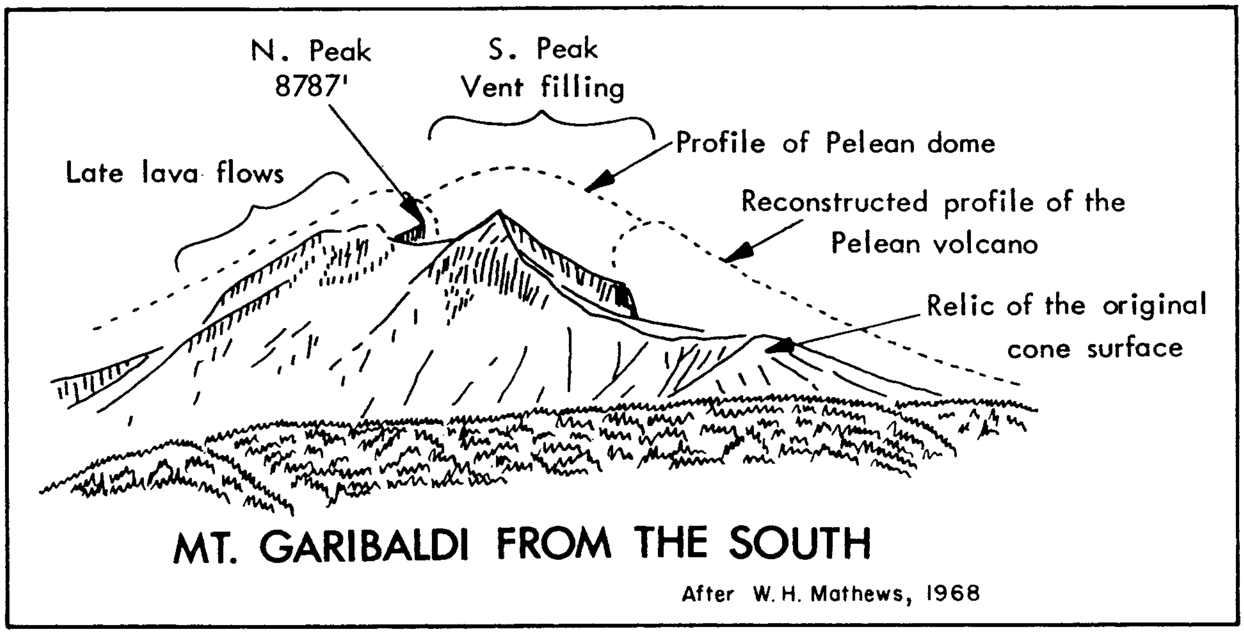

Figure 3: Mount Garibaldi from the south (after W.H.Mathews, 1968)

LUNCH AT SHANNON FALLS

STOP 6: RUBBLE CREEK LANDSLIDE
(61.2 miles; 1.3 miles to next stop.)

The clearing here is left from a borrow pit operation providing earth fill for the Cheakamus dam (Terzaghi, 1960a, 1960b, Nasmith, 1972) about 1/4 mile (0.4 km) northwest of here. All material finer than 6 inches was used in construction, but blocks larger than this were dragged to the side of the pit or left in place. The largest blocks here are up to 14 feet (4.3 m) across. A representative suite of rocks, typical of the head of the valley, 3 miles (5 km) southeast of here are present: red and grey to black dacite (about 95% of the debris), greenish sandstone (lithic wacke) with rare shell fragments, and granitic rocks (from the glacial drift). The assemblage has been transported by landsliding to this site.

An area acquired for residential development 1/2 mile (0.8 km) south of here was condemned because of threats of a repetition of landsliding from precipitous cliffs still existing at the head and on the south wall of the valley, and was subject of a legal battle in 1973. The judge, Justice Thomas Berger, ruled against the developers on the grounds of 'safety first'. Questions raised during the court hearings prompted a further study by Dennis Moore leading to an MASc thesis quoted as follows:

'during the late winter of 1855-56 or early spring of 1856 about 33,000,000 cubic yards of volcanic rock slid from the high cliff known as The Barrier. This debris travelled down a rather sinuous path along Rubble Creek valley to its confluence with Cheakamus River about 4 miles from the Barrier and about 3400 feet lower.

The initial material appears to have travelled as a high velocity tongue of debris which swept from one side of the valley to the other as the debris stream rounded curves eventually to be deposited on Rubble Creek fan. Velocities calculated from the superelevation of the debris as it rounded three different curves indicate that the debris was moving between 88 and 110 feet per second. A minimum velocity of 80 feet per second was calculated using the principle of conservation of energy where the debris overtopped a small hill at the apex of the fan. All of the trees in the path of this slide were uprooted and carried away. The trees adjacent to the slide were scarred and bruised by moving debris.

The initial high velocity tongue was apparently followed by mud flows which deposited large rounded boulders and poorly sorted, volcanic debris on an area of the fan which was not covered by the initial slide. This material was apparently slow moving, as it piled up high on the uphill side of some trees which later died and fell across the top of the debris.'

STOP 7: CONGLOMERATE AT PARKING LOT (START OF GARIBALDI PARK TRAIL)

(62.5 miles; 6.2 miles to next stop.)

Visible up Rubble Creek valley from here is The Barrier, source of the 1856 landslide. Debris of this slide, reworked in places by stream action, covers the valley floor here from wall to wall, and a veneer of the same debris can be recognized on the valley slopes up to a relatively sharp limit from a few feet to as much as 300 feet (100 m) above the valley bottom.

About 100 yards above the parking lot on an old trail up the valley are exposures of conglomerate, washed clean of debris by Rubble Creek. This is the basal part of a thick (probably exceeding 5,000 feet (1.5 km)) clastic succession, which includes much green sandstone (seen at the last stop as fragments in the slide debris) some of which contains marine fossils. Inocerami and belemnites(?) suggest an Early Cretaceous age. Abundant granitic detritus, mostly of cobble size, within the conglomerate demonstrate that plutonic rocks had already been exposed somewhere nearby. Granitic rock, presumed to underlie the conglomerate here crops out on the opposite side of the creek downstream from this stop. Late Cretaceous or younger granitic rocks occur 3 to 4 miles northeast and east of this point.

<u>STOP</u> <u>8:</u> BRANDYWINE BASALT 'ESKER'
(68.7 miles; 3.2 miles to next stop.)

The railroad cuts through a late Pleistocene steep-sided lava flow which forms a conspicuous elongate ridge. Well developed columnar jointing (even better exposed 30 years ago before the cut was widened - see Fig. 4) is everywhere nearly perpendicular to the present upper, lateral, and basal surfaces

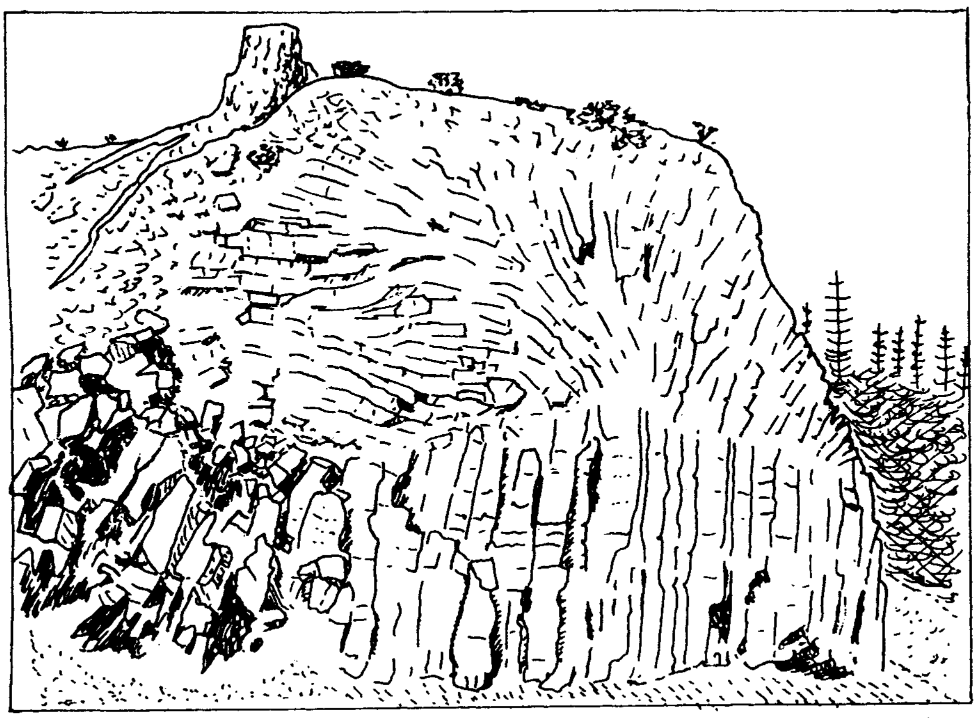

Figure 4: Columnar jointing pattern in north wall of railroad cut at Brandywine Falls. From a 1946 photo.

of the flow, suggesting that these surfaces correspond to or closely parallel the original cooling surfaces of the flow. To explain the restricted width compared with its much greater length, the columnar joint pattern, and the lack of any existing material to confine the lava laterally, it has been suggested (Mathews, 1958, p. 189) that it developed during the waning stages of glaciation by the passage of lava along a tunnel or trench thawed in the ice. If so, the resemblance to an esker is more than accidental.

STOP 9: CALLAGHAN CREEK BASALT QUARRY

(71.9 miles; 7.5 miles to next stop.)

Write-up by Nathan Green.

Olivine-augite basalts were erupted within the glacially-scoured Callaghan Creek and Cheakamus River valleys during four episodes of late Pleistocene volcanism. Within the B. C. Railway quarry, blocky plagioclase-phyric basalts, which represent the final stages of the volcanism, rest upon 1 to 3 m of baked glacial tills and lacustrine silts. A C^{14} age of 34,200 years, obtained from carbonaceous material found in a thin lens of silt between two flows, corresponds to the Olympia Interglacial period. Individual flow-units are characterized by unusually restricted lateral extent (30 to 50 m), anastomosing and meandering flow patterns, and fanned entablature columns which present a dome-shaped cross-section. One to two metre zones of platy, vesiculated lava or "spiracles" traverse the columnar basalts immediately overlying the tills. These features may have formed when meltwater or ice, trapped beneath the lava, was vaporized.

About 8 km north of this stop is the Northair gold mine, which began production in 1976 at a rate of about 300 tons per day. The mine is hosted by andesitic to dacitic pyroclastic rocks of probable Early Cretaceous age which have been regionally metamorphosed to greenschist facies. Galena, sphalenite, chalcopyrite, pyrite, gold, and argentite occur in steeply-dipping quartz-carbonate zones.

OVERNIGHT AT WHISTLER

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DAY 2

STOP 10: SOUTHWEST MARGIN OF SPETCH CREEK PLUTON
(121.4 miles; 11.9 miles to next stop.)

This outcrop of Spetch Creek granodiorite is fairly representative of the plutons lying east of the axis of the Coast Plutonic Complex, but is slightly richer in mafic minerals, particularly hornblende.

Spetch Creek pluton extends 20 miles northwesterly from near Joffre Creek and is up to 10 miles wide. Except for its southern end, the pluton is intrusive into an Upper Triassic volcanic sequence, which includes one or more granite-bearing conglomerate horizons. Most of it consists of a clean, homogeneous, medium- to coarse-grained granodiorite, which is massive except near Lillooet Lake, where it is foliated parallel with the shore. Average composition of 22 specimens of Spetch Creek pluton is 12 percent mafic minerals (range, 8 to 22 percent) with biotite generally dominant, 8 percent K-feldspar (range 0 to 24 percent), 22 percent quartz (range 2 to 40 percent), and the remainder mainly plagioclase. Here it contains minor sphene. In most outcrops, amphibolitic inclusions form less than 1 percent of the rock; locally they form as much as 5 percent. Here and there epidote, aplite and pegmatite veins cut the granodiorite. The mean specific gravity of the 22 specimens collected is 2.70. A K-Ar age determination on biotite from this pluton yielded 84 m.y.

In thin section the rock at this ontcrop shows markedly poikiloblastic K-feldspar. The plagioclase (An^{30}) shows poorly developed normal zoning. Many of the crystals show a complex internal structure suggesting that some of the present crystals formed from older smaller crystals without entirely destroying them. Sericitic cores are seen in a few crystals, and some sericite patches are unrelated to the present plagioclase structure and appear to be older than the last recrystallization of the rock.

About 100 yards of outcrop shows an irregular gradation from clean Spetch granodiorite to a dioritic complex which borders the east side of a lange belt of Upper Triassic(?) volcanic rocks. The dark fine-grained rock in the dioritic complex consists mainly of equant plagioclase and some quartz crystals, with about 25% hornblende, tremolite, chlorite, minor biotite and opaques. The rock does not have a cataclastic texture, and, in thin section only a moderate alignment of mafic minerals.

At the outcrop near the northeast corner of Lillooet Lake, the clean phases of the plutonic rock are quartz diorite similar to the granodiorite, except for the lack of K-feldspar. It contains, however, more and coarser hornblende. The plagioclase (An^{36}) is slightly more calcic.

The contact with the belt of volcanic rocks is not exposed, but the latter are heavily pyritized near it.

INTER-STOP COMMENT.

Lillooet Lake and its sedimentation has been recently investigated by Gilbert (1973, 1975). Lillooet River, the principal stream feeding the lake, has a source area of 3580 km^2, of which 7% is glacier covered. Suspended sediment in this stream commonly ranges between 600 and 1200 mg/l during the summer months, sufficient to render the river water denser than the surface water of the lake and produce interflows or underflows. The delta front of Lillooet River has advanced approximately 1 km between 1858 and 1969. Varves, averaging 100 mm thick on the delta front, and declining to 18 mm some 5 km to the southeast, have accumulated within the lake. Deposition within the lake has been estimated to be 1.1 million cubic meters/yr since 1913, corresponding to a denudation rate in the basin upstream of 280 mm/millennium. An accoustic reflecting horizon within the sediments is interpreted as the 'Bridge River' ash (actually from an eruptive center 40 miles up Lillooet River) dated at 2400 B.P. If so the long-term rate of denudation is about half the modern rate.

STOP 11: PEMBERTON DIORITIC COMPLEX
(133.3 miles; 6.8 miles to next stop.)

The Pemberton complex is a very heterogeneous unit which detailed work could probably subdivide. It consists mainly of irregularly textured diorite which may either grade up into quartz diorite or down into amphibolite, or be in sharp contact with these lithologies. The rock is commonly gneissic and contains abundant epidote veins and layers. The ampbibolite layers or screens are invariably parallel with the amphibolitic screens. Besides the screens the diorite exhibits locally numerous elongated amphibolitic inclusions and schlieren.

Although not well-shown here, some of the epidote appears to be older than the diorite. Amphibolitic layers and inclusions with epidote cores seem to have resisted dioritization more successfully than uncored amphibolite.

In thin section the rock is seen to consist mainly of plagioclase and hornblende (partly converted to chlorite), with minor biotite, magnetite and sporadic quartz. The plagioclase is irregular in shape and poorly zoned except in rare instances. Many contain remnants of a pre-existing, more calcic plagioclase which in places form a skeletal outline of former zones. Anorthite content ranges from about An^{40} to An^{48} for the recrystallized plagioclase, and about An^{60} for the relict plagioclase. Cataclastic effects are not conspicuous but some of the plagioclase crystals have fractured cores and intact rims. The fractures commonly contain sericite.

On the high ridge about 4 miles southeast of here, the contact with the volcanic belt is exposed. The dioritic complex there is similar to here but commonly with patches of spectacular pegmatitic hornblendite. Near the contact the structure is more regular and grades into banded gneiss containing numerous epidote layers. The actual contact with the greenstone of the volcanic belt is not exposed, but except for rare patches of chloritized diorite does not seem to be highly altered.

Zircons from here yielded uncorrected Pb^{207}/Pb^{206} ages of 331 and 294 m.y. on Pb^{207}/Pb^{206}, and a K-Ar determination on hornblende gave 52± 15 m.y.

STOP 12: LANDSLIDE BLOCKS OF PEMBERTON DIORITIC COMPLEX (140.1 miles; 4.7 miles to next stop.)

On the way to this point we passed a light-weathering outcrop on the left. It is a lobe of a fairly clean quartz diorite body which lies mainly west of the highway. It appears to be younger than the Pemberton Complex but may be a cleaner phase of it. The northern contact is against partly dioritized amphibolite and the southern contact is not exposed.

This stop is on the nose of a landslide that has come down from the east side of Green River Valley. The blocks are from an agmatitic[1] phase of Pemberton Complex. Most of the inclusions

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[1] On the Coast Mountains Project the term agmatite is used where inclusions form more than 30% of rock.

are elongate and range from amphibolite to fine-grained diorite. Some are well-defined, others grade into the coarse-grained diorite-quartz diorite matrix. The plutonic rock consists mainly of plagioclase (An^{36}) and hornblende, with considerable magnetite and rare biotite. Epidote forms both vein-filling and scattered discrete crystals. Some of the plagioclase is zoned (normal). No cataclastic effects are visible.

STOP 13: NORTH CONTACT OF ALTA LAKE PENDANT
(144.8 miles; 10.1 miles to next stop.)

Since the last stop we passed across about one mile of hornblende-rich quartz diorite containing numerous rounded amphibolitic inclusions and some amphibolite screens, cut here and there by hornblendic lamprophyre dykes. This was followed by a three-mile-wide belt of diorite and amphibolite that we have mapped as part of the Pemberton Complex. Epidote cored schlieren and screens are common there. South of the complex is a considerably cleaner coarse-grained hornblende-rich quartz diorite which is part of a large body to the southeast. The nature of the contact is not known.

This stop is at the northern contact of the Alta Lake belt of probable Lower Cretaceous metavolcanic and minor metasedimentary rocks. The contact is thought to be a fault but is covered in a small gully. The adjacent pendant is highly fractured and shows several slickensided surfaces. In the diorite about 50 feet above the road is a sharp contact with unaltered andesite. This appears to be a dyke as diorite outcrops south of it also. The first outcrop of the pendant consists of a fairly acid flow, probably a dacite. It is now altered to greenschist facies but in places the original texture is preserved. Subhedral altered plagioclase phenocrysts are commonly packed together. They show faint oscillatory zoning. The matrix is mainly granular plagioclase and quartz. No fresh mafic minerals are preserved, but they may be represented by chlorite and clots of epidote. Mafic minerals do not appear to have been abundant. Epidote also forms abundant veins. Discontinuous sills or dykes are also present. Other rocks in this part of the pendant include quartz-rich meta-greywacke, andesite, and tuff. Most of the rock is in the greenschist facies but locally original texture is well-preserved. Most of the rock is massive, with deformation confined to shear zones, some of which are heavily pyritized.

This projecting arm of the pendant is only about one mile wide whereas the main body is about four miles wide. The southern contact of the projection is marked by a wide shear zone that extends for about 100 meters along the road, and is bordered on the south by a shattered quartz diorite. In thin section the rock is seen through a pervasive haze of sericite. The plagioclase has been pseudomorphically converted to albite and the hornblende to chlorite. Epidote is abundant. Away from the contact the rock shows no distinct cataclastic effects but the alteration is the same.

Our route to the next station brings us near the western contact of the Alta Lake pendant. It is in sharp vertical contact with a quartz diorite pluton about 4 miles wide which separates it from the Callaghan Creek pendant. The pendant rocks in the contact zone are amphibolite at this stop, but elsewhere include biotite schist and stretched pebble conglomerate. Pyrite and epidote are ubiquitous. Several apophyses about 2 feet wide extend from the pluton into the amphibolite. These apophyses contain randomly oriented, angular inclusions of amphibolite. Quartz-plagioclase veins wind sinuously across the foliation in the amphibolite. Thin resistant epidote veins cut the amphibolite with a fairly consistent attitude of 105/65S. The quartz diorite at the contact is cut by thin aplite veins and a 2-to 3-foot-wide pegmatite vein.

STOP 14: CARBONATE BED IN ALTA LAKE PENDANT
(154.9 miles; 17.5 miles to next stop.)

This is the only substantial carbonate bed that has been found in the Alta Lake pendant. The bed is about 250 feet wide. It consists of creamy-white-weathering, fine-grained crystalline limestone, with minor intercalated phyllitic layers and a few quartz lenses. The limestone contains scattered grains of quartz, tremolite and opaques, but about 98% of the rock consists of a mosaic of equant calcite grains.

LUNCH AT WHISTLER

STOP 15: QUARTZ DIORITE IN CHEAKAMUS CANYON
(172.4 miles; 18.5 miles to next stop.)

This stop illustrates structure preserved in the plutonic rock, most of which consists of a light grey weathering, greenish, granitoid augen-gneiss. The texture is markedly cataclastic with large augen of sodic plagioclase and quartz in a granulitic- textured matrix of the same minerals. The matrix consists of two sizes of material -- one an almost medium-grained quartz mosaic, and the other, a very fine-grained quartz-plagioclase-epidote mixture. Staining indicates that the rock contains no K-feldspar. The only mafic mineral is chlorite.

Dark bands, 1/4 to 8 inches (1/2 to 20 cm) wide in the gneiss outline a synclinal structure, part of the base of which is discordant with the foliation of the underlying rock owing to a minor fault on the northern limb. The dark bands are made up of very fine-grained plagioclase and quartz, and somewhat coarser granules of epidote but contain no mafic minerals. The origin of the structure is not known.

The gneiss is cut by plastically deformed quartz veins, and by undeformed basaltic dykes. The basalt consists of a matrix of laboradorite laths and augite granules forming a trachytic texture. A few phenocrysts of augite and rare hornblende are present. There is also a microlitic submatrix that is cloudy to semi-opaque, These dykes are probably related to the Brandywihe flows.

Other dykes, undeformed but apparently older than the above, are also present. They consist of dark greenish-coloured andesite which is made up of saussuritized plagioclase, chlorite, muscovite, and calcite patches. Some clear quartz fills the interstices and appears to be metasomatic. These dykes may be late synplutonic, or entirely post-plutonic but altered by later low-grade metamorphism. Zircons from the relict material at the base of the syncline yield uncorrected Pb^{207}/Pb^{206} ages of 294 and 313 m.y. A K-Ar date from hornblende from slightly deformed quartz diorite at the pass, 0.5 miles (0.8 km) south of here is 158 m.y.

From near this stop one can view in clear weather a late Pleistocene volcanic spire, Mount Fee, elevation 7100 feet (2160 m) to the northwest and to the southwest the rugged Tantalus Range, elevation 6500 feet to 8700 feet (2000 m - 2650 m). The latter was too high to have been overridden by the Pleistocene ice sheet, which here was at the 6000 foot (1800 m) level.

STOP 16: SQUAMISH GRANODIORITE
(190.9 miles; 26.8 miles to next stop.)

At this stop a clean leucocratic granodiorite is exposed in a road cut. It is typical of what were thought to be young Tertiary plutons in the Coast Plutonic Complex, but this impression has not been substantiated; K-Ar age determinations on biotite which yielded a date of 94m.y. are comparable to the 95-99m.y. dates obtained from older-looking quartz diorite at Horseshoe Bay. The granodiorite is more homogeneous and less faulted than the quartz dioritic rocks to the north. The simple wide-spread joint pattern permits the formation of broad imposing cliffs.

The granodiorite consists of about 47% quartz, 30% plagioclase, 20% K-feldspar and 3% biotite, all of which are coarse grained except for the biotite which normally forms smaller crystals. The plagioclase is a sodic oligoclase and about half of the crystals show faint oscillatory zoning (commonly about 12 zones). Quartz forms irregularly shaped crystals, although euhedral faces are developed against K-feldspar. The K-feldspar is irregularly perthitic, shows microcline grid twinning in places, and is poikiloblastic with quartz and plagioclase micro-inclusions. It has replaced plagioclase and quartz by extensive embaying and veining. The biotite forms brown, subhedral crystals that commonly contain one or two apatite crystals. Magnetite is a minor constituent.

Rare dark layers appear in the granodiorite and consist of concentrations of small, commonly euhedral biotite crystals. The crystals show no preferred orientation. Small irregularly-shaped, dark inclusions are visible here and there.

A number of aplite dykes cut the granodiorite. They contain more K-feldspar and much less biotite (chloritized) than the granodiorite, and are quartz monzonite in composition.

The back surface of the west side of the road cut is highly polished by glacial action.

STOP 17: PARTLY FUSED GRANITE INCLUSIONS IN GAMBIER GROUP ANDESITE
(217.7 miles; 11.6 miles to next stop.)

A body of greenish andesite, presumed to be a feeder for the upper volcanic units of the Gambier Group, is exposed in a precipitous cliff on the east side of the road. This body is pipe-shaped, about 1100 feet (350 m) from north to south and half that in width (Vaughan, 1960). A nearly vertical contact with gently dipping Gambier group sediments is exposed a few hundred feet south of the stop. A distinctive feature of the andesite here is the presence of scattered inclusions of granitic rock up to about 3 feet (1 m) across. They display the effects of reheating on incorporation into the andesite: glass or granophyric intergrowths are locally developed, notably along quartz-plagioclase contacts; the mafic minerals have all been altered, plagioclases are in various stages of recrystallization, and quartz is commonly embayed.

STOP 18: UPPER LEVELS HIGHWAY ROADCUT (OPTIONAL STOP)
(229.3 miles; 8 miles to end.)

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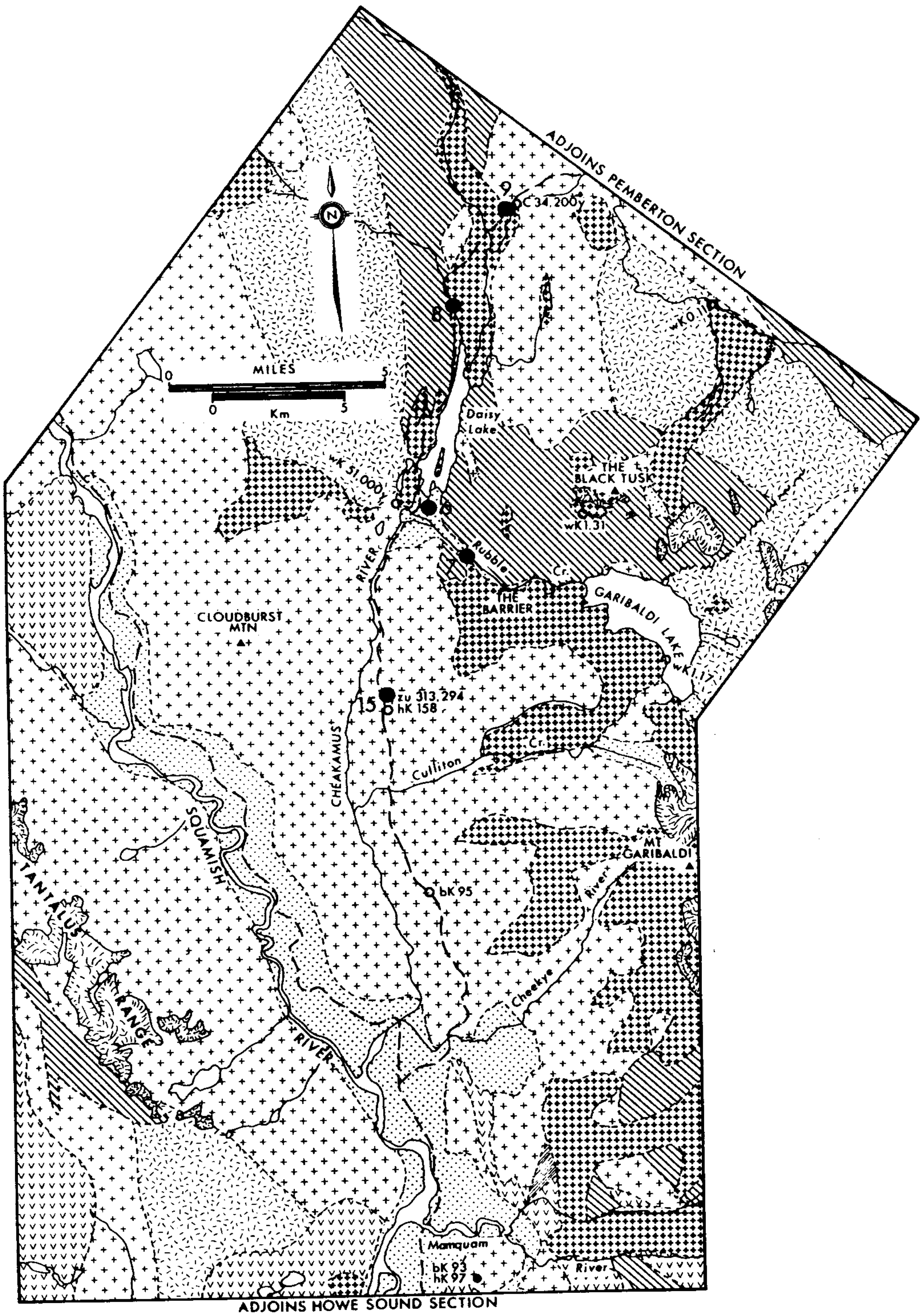

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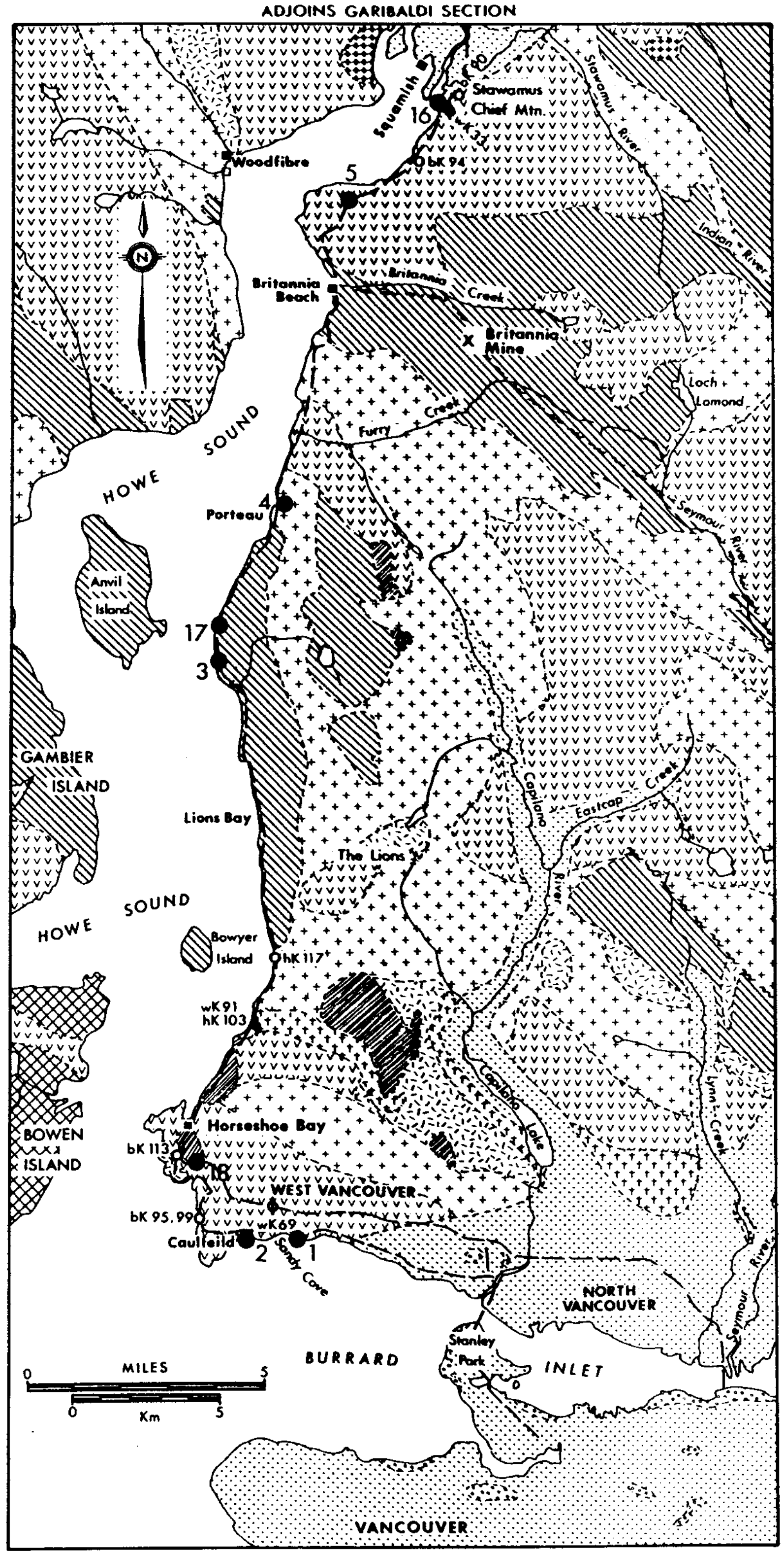

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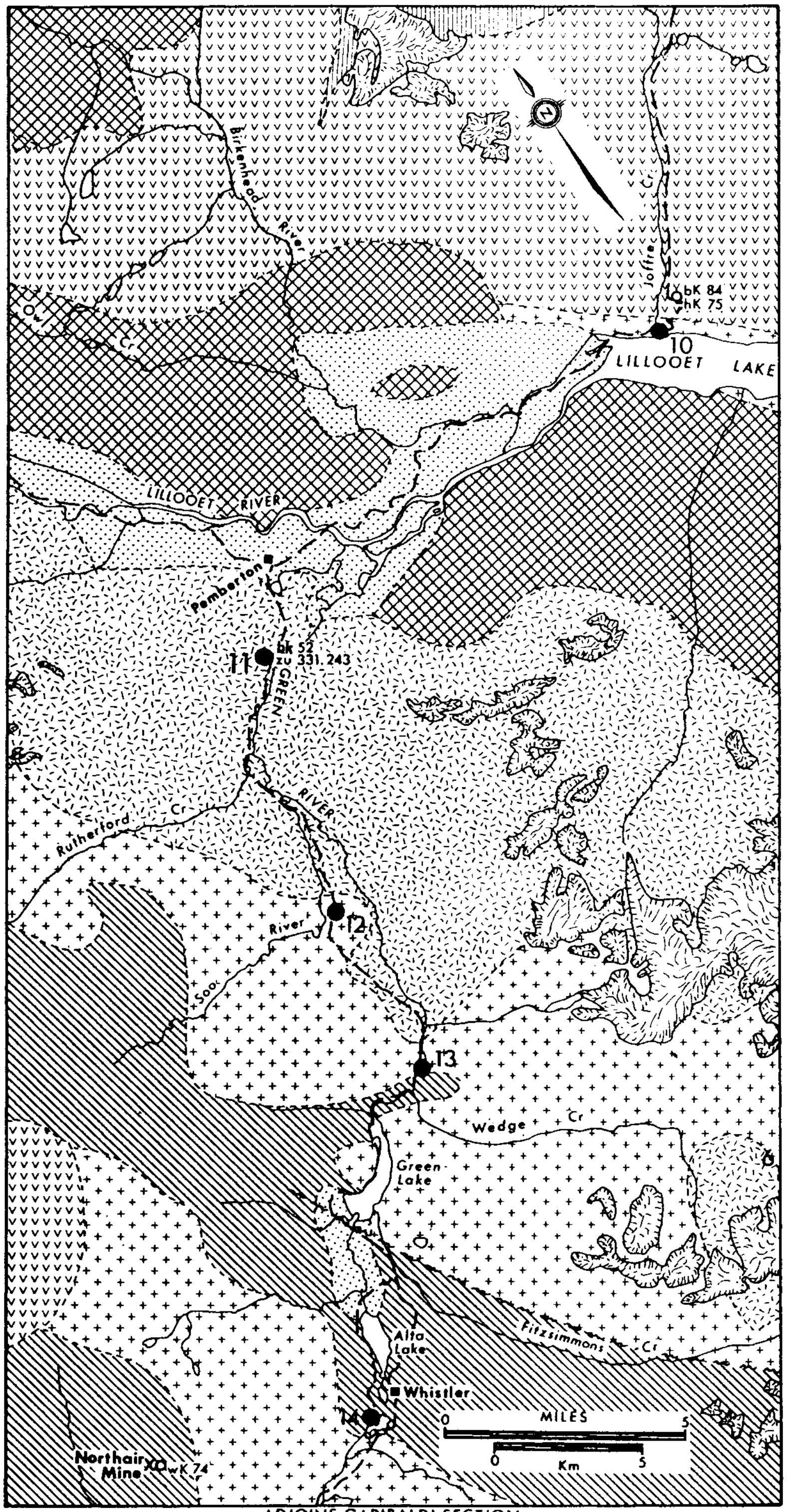

ADJOINS GARIBALDI SECTION

PEMBERTON SECTION

LEGEND

STRATIFIED ROCKS

Recent
Alluvial and glacial deposits

Pliocene to Recent
Garibaldi Group: basalt, andesite, dacite and rhyodacite flows and pyroclastics

Eocene
Sandstone, shale, conglomerate; minor basalt flows or sills

Lower Cretaceous
Gambier Group: tuff, breccia, agglomerate, andesite, argillite, conglomerate; minor crystalline limestone

Lower to Middle Jurassic
Argillite, andesite, greywacke; minor crystalline limestone

Upper Triassic
Bowen Island Group: mainly greenstone; minor chert and breccia
Pemberton Belt: mainly greenstone, breccia; minor argillite and limestone

Pre-Triassic (?)
Amphibolite, schist, migmatite

PLUTONIC ROCKS

Quartz monzonite (granite)

Granodiorite

Quartz diorite

Dioritic complexes; includes diorite, gabbro, and amphibolite

Glacier

Radiometric Ages

SYMBOLS
Single determination.................. O
Multiple determination................. ●
Age determination on dyke........ ϕ ɸ

PREFIXES
Mineral: z-zircon, h-hornblende, b-biotite, w-whole rock

SYSTEM
K-Potassium-Argon, U-Uranium-Lead, C-Carbon

Ages in million years, unless indicated otherwise