SOME FEATURES OF THE GEOLOGY OF

THE NORTH VANCOUVER AREA

by

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ABSTRACT

The Coast Range Batholith north of Vancouver, British Columbia, comprises within the mapped area rocks ranging in composition from granitic pegmatite to gabbro. The most widespread rock is the Capilano quartz-diorite which is markedly heterogeneous, and contains on the average about 3% inclusions. In relative abundance, the quartz-diorite is followed by the Hollyburn granodiorite. More than 80% of the batholithic rock is of these two types. Within the batholith are several roof pendants composed of early Mesozoic volcanics and sediments. One of the most interesting features within the area are the dykes. Although many lie wholly within the batholith, evidence is presented which indicates that they are pre-batholithic. These pre-batholithic dykes are thought to have a significant bearing on the problem of emplacement of the batholithic rock.

The marked heterogeneity of most of the batholithic rock, the distribution and alteration of the inclusions, microscopic textural relationships, and certain other data suggest that much of the exposed batholithic rock occupied its present position by some process of replacement rather than by forceful intrusion. It is recognized, however, that due to the nature of the country, the scope of the work, and to some extent due to the nature of the problem, the evidence is not conclusive.

INTRODUCTION

Although the area dealt with in this report lies adjacent to the largest city in western Canada surprisingly little geological work has been attempted in the vicinity. To some extent this may be attributed to the very rugged and inaccessible nature of the country. More serious, however, is the fact that the area includes the three main water sheds serving the nearby metropolis, and permission to enter is not easily obtained. Yet, standing above either of these reasons has been the general lack of interest in an area which is largely composed of batholithic rocks and which offers little in the way of economic possibilities.

The first report on the area, largely reconnaissance in nature, was made in 1913 by Burwash. The only other work was done in the years 1932-34 by T. C. Phemister, who was at the time on the staff of the University of British Columbia. Phemister's excellent study, which was not published until 1945, served as a very useful guide for the field work.

The present work was done under the auspices of the Canadian Geological Survey. A field party under Dr. J. E. Armstrong began the project in the summer of 1948. The writer joined the party in the following summer. This report includes the more significant results from the work of both seasons and in addition the results of a petrographic study conducted by the writer during the winter of 1949-50.

The writer thankfully acknowledges the kind aid of Dr. Ian Campbell in the investigation of the granitization problem. Sincere thanks go also to Dr. Noble for providing facilities and generous assistance in the making of the whole-section photographs.

In addition thanks are due the field assistants William Heywood (Vancouver), Ralph Venour (Winnipeg), and Surrendra Amin (Bombay) whose aid and cheerful companionship resulted in a very pleasant field season. Robert Christie, the senior assistant during the 1948 season, kindly put his photographs at my disposal. Finally, the writer is deeply indebted to J. E. Armstrong, without whose generous assistance and willing cooperation this report could not have been produced. The writer is particularly thankful for the thin sections and some very good photographs which were provided by Dr. Armstrong.

REGIONAL SETTING

The Coast Range Batholith, of which the 144 square miles covered in this report represents only about .1%, is one of the world's largest plutonic bodies. From a point just south of the Fraser River, it extends 1200 miles northward along the coast of British Columbia, reaching well into Alaska. The maximum width of the batholith, about 125 miles, occurs near its southern end. Throughout its length the average width is approximately 80 miles.

When compared with the area of the Coast Range Batholith, the extent to which it has been geologically investigated is hardly appreciable. Plate 1 shows what work had been done up to 1947. The shoreline has been subjected to reconnaissance mapping, but the only detailed work has been conducted in those few localities which are of economic interest. From time to time, however, geologists have traversed across the batholith, although written reports are rare.

Most of the western border of the batholith lies submerged in the depression between the mainland and the islands off the coast (see Plate 1).

The eastern border coincides roughly with the eastern margin of the Coast Range. Along this boundary the batholith is in contact with an immense series of early Mesozoic volcanic rocks and sediments which comprise a broad belt in central British Columbia. The contact may be very sharp or broadly gradational. In many places the Triassic rocks are undisturbed at the contact. Near latitude 53°N, the writer spent a portion of one summer (1948) mapping the eastern contact. Here the contact is in part a series of vertical slices of country rock alternating with narrow strips of batholithic rock, and in part a simple sharp contact against very gently warped Mesozoic rocks. Unfortunately, the published information concerning the eastern contact of the of the batholith is still insufficient to justify a general statement as to its nature.

LOCAL SETTING

The area mapped comprises the mountainous section of country lying directly north of the city of Vancouver, bounded on the north by latitude 49° 30', and on the east by longitude 123° 00'. The southern and western boundaries are formed by two fjords, Burrard Inlet and Howe Sound, respectively.

Although the region lies near a large city it is not easily accessible. A good road borders the north side of Burrard Inlet servicing several communities. This road ends at the summer resort of Horseshoe Bay which lies at the southern end of Howe Sound. North of Horseshoe Bay the western margin of the area is accessible only by boat. Along this coast, the mountains rise directly from the sea, and the shore is composed of small rocky coves separated from each other by sea cliffs.

Within the last five years the central part of the region has been made accessible by the completion of the road up the valley of the Capilano River. This was built to service a powerline bringing electricity from the Bridge River country in the north to Vancouver. The last road of major usefulness for geological work is that which goes up to the Grouse Mountain Chalet.

Figure 1 -- A view of The Lions from the south

Figure 2 -- Mount Hanover from the west

With the exception of the southern slope, the whole region is rugged. Fig. 1 and 2 show the nature of the high country and Fig. 3 the deep central valley of the Capilano River. The maximum relief is well over 5000 feet in the northern part of the map area. Farther north the relief increases to nearly 9000 feet. At the latitude of Vancouver, the treeline is higher than the mountains in the area. Glaciation, however, has stripped the soil and part of the bedrock from the tops of some of the mountains, so that no trees grow in these spots. Fig. 4 depicts such a surface on Coliseum Mountain. Nevertheless, most of the area is heavily wooded with the typical assemblage of the northwest, namely, pine, Douglas fir, hemlock, cedar, and spruce. Where these woods have not been disturbed the surface is comparatively free of underbrush and travelling is not difficult. In many areas, however, logging operations and forest fires have destroyed the heavy timber. This is replaced by logging slash, windfalls, and almost impenetrable second growth. Serious difficulty in traversing is also presented by the numerous cliffs which occur in the upper elevations. These cliffs may be sheer for several hundred feet and are nearly impossible to traverse. To a person without climbing equipment, however, a face less than 20 feet high proves just as impossible and infinitely more annoying. These latter types of cliffs are very common and absorb many hours of field time.

Figure 3 -- Looking down the Capilano Valley toward Crown Mtn. The Bridge River powerline and road follow the Capilano River

Figure 4 -- Ice-smoothed rock surfaces on the high ridges in the Vancouver area. The bare rock surfaces are strewn with angular boulders, some of which are erratic.

The climate is definitely humid. In the central part of the area the annual rainfall is about 120 inches, most of which falls during the winter months. Toward the south, the precipitation falls off rapidly; Vancouver city receives only about 60 inches annually, and the Fraser River Delta, a few miles farther south, only 30 inches. During the average summer, weather conditions will make about 20 days unsuitable for field work.

GEOLOGY

General Statement

In this report an attempt is made to describe very briefly the principal geologic units. With this as background, special features which seem to bear on the problem of the emplacement of the batholith are treated in some detail.

A general impression of the geology of the North Vancouver sheet can be obtained from the enclosed map (Plate 3). From this it is seen that the area is made up predominantly of batholithic rocks. The former country rock is represented by several roof pendants of early Mesozoic volcanics and sediments.

A short digression is necessary to clarify the meaning of the term "roof pendant" as used in this report. The term was first proposed by Daly[1] in reference to a large patch of

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[1] R. A. Daly - The Okanagan Composite Batholith of the Cascade Mountain System: Geol. Soc. America Bull., vol. 17, p 336, 1906.

Chopaka schist in Similkameen granite, where it carried implications as to shape and mode of origin. The shape was that of a downward directed wegge, or an inverted pyramid. Regarding their origin Daly thought these blocks represented the lower portions of a downward projection of the roof rock into the batholith, the upper portions having been removed by erosion, and the country rock between the pendants by magmatic stoping. The term "pendant" was derived from the somewhat analogous structure in Gothic architecture.

In contrast to pendant is the term "septa", which refers to narrow, approximately vertical screens of pre-batholithic rock which separate plutons of different ages and generally of different composition.

Plate 3 (pocket) shows that the "islands" of country rock fall somewhere between the definitions of "roof pendants" and of "septa". The batholithic rock type differs on opposite sides of two of the "islands", namely, that comprising Mt. Strachan, and that occupying the head of Lynn Creek. In this respect, they resemble "septa". The bodies in question, however, seem too wide and too blunt to warrant the term "septa". In addition, the rocks on the opposite sides of the "islands" are not always different (e.g. the Britannia pendant).

In this report the term "roof pendant" or simply "pendant" is used without connotation as to shape or precise mode of origin, in reference to large bodies of country rock surrounded by plutonic rocks.

The Texada and the Britannia pendants bring out the overall NNW grain of the Coast Range geology. This direction is approximately parallel to the elongation of the Coast Range Batholith. At the southern end of the batholith, however, where it has extensions to the east, the regional trend changes quite sharply from slightly west of north to slightly north of west. This latter trend is reflected in the attitude of the beds in the Lynn and Strachan pendants.

The contacts between batholithic and pendant rocks were located by interpolating between many traverses which crossed them. With respect to the scale of the map they should be quite accurate. This, however, cannot be said for the contacts (dotted) between the different types of batholithic rocks. Only on two occasions were such contacts seen and both involved very acid rocks, the granitic pegmatite and the Sunset granite. Thus, as will be more apparent later, these contacts probably do not exist as lines, yet they serve the purpose of dividing the batholith rocks into units convenient for description. Except for a slight modification in terminology the rocks are classified according to Johannsen's system. It was thought advisable to plot the thin-section determinations on an overlay sheet (Plate 4), to emphasize the non-uniformity of the rock and the dubious character of the dotted contacts. The dotted contacts were first drawn on the basis of traverse notes and the field classification of many hundreds of rock specimens. Then slight adjustments were made to incorporate the results of the microscopic study.

The plotted thin-section data convey some impression of the non-uniformity of the batholithic rock. This impression is felt more strongly in the field. Different specimens taken from even a small outcrop often differ widely in composition. Because of this and also because of the dense lichen growth which usually covers the forest outcrops, it was often difficult to decide whether a representative sample had been taken.

Batholithic Rocks

Although local heterogeneity is confusing and difficult to deal with in this type of country, the broader relations can be distinguished.

The area south and southwest of the Strachan pendant is composed predominantly of a medium-grained sodic granodiorite, with local variations including granite, and granitic pegmatite. Excluding the roof pendant, the zone northeast of the granodiorite is composed principally of granitic rock. This includes the coarse red Sunset granite, the whiter medium-grained Grouse Mountain granite, and probably the granitic element of the Hollyburn complex.

The predominant batholithic rock of the area, the Capilano quartz-diorite, occurs northeast of the Strachan pendant. It is a medium-grained hornblende quartz-diorite. This rock constitutes nearly everything in the Capilano River valley north of its junction with Sisters Creek and has extensions northwest and east of the Capilano valley, from which the rock is named.

Northeast of the Lynn roof pendant a zone of mixed granite and granodiorite separates the northeast side of the pendant from the Capilano quartz-diorite to the north. Actually, the two rocks in this zone are not very different although the orthoclase content varies locally from about 40 to 60% of the rock.

In local areas the Capilano quartz-diorite grades into a hornblende-diorite. These occurrences, however are not mappable except for two rather large bodies. The Crown diorite, as the rock in these bodies was named, comprises most of Crown Mountain and all of The Lions. Some augite-hornblende gabbro is mixed in with the diorite but it could not be mapped separately. Another small body of similar diorite was found in the reentrant angle in the Lynn pendant, but exposures are extremely poor and rare in this area and little is known about it.

North of the Lynn pendant are several small bodies of gabbro, about which practically nothing is known except their presence.

For the most part the age relations between the different types of batholithic rocks could not be determined. Stringers of the Sunset granite were found cutting Hollyburn granodiorite, the rock occupying the southwest portion of the of the area, in a creek bed on the west side of Hollyburn Mtn. In addition, a single inclusion of what appeared to be the Hollyburn granodiorite was found in the granite on the south slope of Grouse Mtn. Thus it is certain that the Sunset granite is later than the Hollyburn granodiorite, and probably the Grouse Mtn. granite is also later. The pegmatitic granite which is most abundant along the shore near Caulfield also cuts the granodiorite. Nothing is known about the pegmatitic granite-Sunset granite relationship. Nor is anything known about the Capilano quartz-diorite - diorite-gabbro relations. The nature of these latter rocks, and the difficulties of terrain make it unlikely that these relations can be settled.

Roof Pendants

The mapped area shows four major roof pendants: the Lynn, Strachan, Britannia and Texada; and two smaller ones: one at Caulfield and the other just north of Horseshoe Bay. The one at Caulfield is very small but because of certain geological features within it, it is more significant than the major pendants.

The elongate body of pre-batholithic country rock which forms the Lynn roof pendant is for the most part composed of metamorphosed andesitic flows and tuffs. The rock is massive and the texture is completely undirected. "Directed" texture is used in this report in reference to any texture having a strike. Interbedded with the volcanic rock are sedimentary beds including limestone (mostly marble), marls and cherts.

The carbonate rock is commonly black and forms rather narrow beds (less than 30 feet) which appear to lens out along their strike within short distances. These beds are partly composed of skarn comprising a great variety of calcium-magnesium silicates. Galena and sphalerite also are present in the skarn and have attracted intermittent economic interest during the last 30 years. Unfortunately those deposits lie in the North Vancouver watershed and consequently the political problems in connection with their development are much more difficult than those of a geological nature.

The very dense chert-like rocks are volumetrically the most important in the sedimentary series and comprise a large portion of the pendant. These rocks may be finely laminated, but usually only broad bands are present. The finely laminated portion contains several types of bands; some have only quartz, others are of epidote and pyroxene, and others chiefly metamorphosed volcanic material.

The beds are normally near vertical and except for minor flexures they strike a few degrees north of west, that is, in conformity with the regional trend of the southern end of the batholith. The main structure is closely folded and parallel to this regional strike, but the rocks have also been affected by minor transverse flexures. The contact between the Lynn pendant and the batholith was rarely seen but appears quite sharp near the ore deposits.

The pendant which occurs on the mainland at Caulfield is much smaller than the pendant just discussed. It measures about 600 by 1200 feet. The rock comprising this inclusion forms the type section for the Caulfield formation. It is composed of fine-grained gneissic rock, the principal member of which is a grey to black rock having alternating feldspar-rich and hornblende-rich layers. These layers are usually a small fraction of a centimeter wide. The nature of the banding and the high feldspar content suggest that these rocks are primarily reconstituted tuffs, although the original texture has been completely destroyed. The gneiss here has the same attitude (slightly north of west) as does the gneiss occurring in the Strachan pendant, in the country rock just north of Horseshoe Bay, and on Bowen Island. The shore exposures at Caulfield are excellent and the rocks here will be further discussed with respect to the pre-batholithic dykes which cut obliquely across the gneiss.

A large portion of the Strachan pendant is also composed of the Caulfield gneiss. Interbedded with the gneiss, however, is a notable amount of volcanic material, presumably metamorphosed flows or sills. They form black or dark grey, fine-grained, massive beds which are completely lacking in directive texture. All the beds in the Strachan pendant are steeply dipping and strike slightly north of west. This direction is parallel to the structure in the Caulfield inclusion, on Bowen Island, and in the Lynn pendant.

Figure 5 -- Exposure of Caulfield gneiss on Strachan Mtn.

Exposures in the northern portion of the Strachan pendant are good, especially on Strachan Mtn. where glaciation has laid the rock bare (see fig. 5). Here again the actual contact was not seen, but since its location can be narrowed down to a few feet it cannot be broadly gradational.

The southern portion of the pendant is densely forested and exposures are rare. This is unfortunate since the contact is more complex here than at the northern end. The typical pendant rocks appear to be separated from the batholith by a zone in which considerable plutonic rock is mixed with the pendant rock. Much of this rock is a rather fine-grained diorite which has a wide variation in the amount of mafic mineral (hornblende mostly) contained. However, there are also patches, zones, and stringers of granite in the diorite. On the basis of general appearance this granite is probably the same as that which crops out on the west coast near Sunset beach. In addition to this, rock of the normal Strachan pendant variety (Caulfield gneiss and volcanics) is also included in the complex zone. As can be seen from the map, the zone is widest on the east side of the pendant and narrow on the west. Outcrops are so rare on the relatively gentle slope rising from Burrard Inlet that the Hollyburn complex, as the rock in this zone was named, could not be examined adequately.

The rocks in the Britannia pendant are composed of a sedimentary series of slates, quartzite and arkose enclosed between two volcanic series of massive blue-grey andesite, flowbreccia, agglomerate and tuff. Of these, the volcanic rocks have the greater thickness. The sediments and the volcanic rocks are apprently conformable. The general attitude of the formation is strike 150° , dip 30° to 50° SW. The attitudes, where evident, are fairly consistent, but the rock types do not apparently persist along the strike from one ridge to another. This implies that there is more faulting or deformation than is apparent. The contact of the Britannia pendant with the batholithic rock is irregular in detail, more so than is indicated by the map.

The country rock in the Texada pendant which forms the cliffs along the west coast north of Bowyer Island is composed mostly of massive greenstone (actually a grey-green andesite). These fine-grained metamorphosed volcanics have no directive texture, yet they are not uniform throughout. Irregular patches and zones of highly contaminated diorite are scattered throughout the body. The diorite grades into the greenstone very gradually, and in many outcrops it is very difficult to distinguish between the two. The Texada greenstone was so-named because of its resemblance to the greenstone member of a series whose type locality is on Texada Island, one of the islands north of Vancouver.

The massive character of most of this pendant obscures its internal structure. The probably general trend is 20° to 40° west of north, as indicated by very local flow structure, and possible horizons of pyroclastic rocks. This block of volcanics disappears under the waters of Howe Sound, so its width is unknown. The eastern contact is sharp in detail but very irregular. It was located by running traverses up the mountain slopes from a series of points along the coast.

The rocks in the Britannia pendant and in the Texada pendant are probably closely related, but in what manner is not clear. The close relation is suggested by the narrowness of the separating quartz diorite body (about 2000 feet). As far as has been determined there is no exposed connection between these two pendants.

Xenoliths

Besides the roof pendants, small xenoliths or inclusions are scattered throughout the granodiorite and quartz-diorite. They make up an estimated 3% of the volume of the exposed batholith. These will be discussed later in the report.

SPECIAL FEATURES

Pre-batholithic dykes

Probably the most unique feature in the North Vancouver area is the pre-batholith dyke. There are many of these dykes in the area yet their pre-batholith age was not recognized until Phemister made his study of the Caulfield area in the early "thirties". These dykes are found throughout the whole area, although the exposures are rather poor, except in the Caulfield area where the more detailed work on the dykes was conducted.

Pl. 2 (after Phemister, op cit, fig.5, p.56)

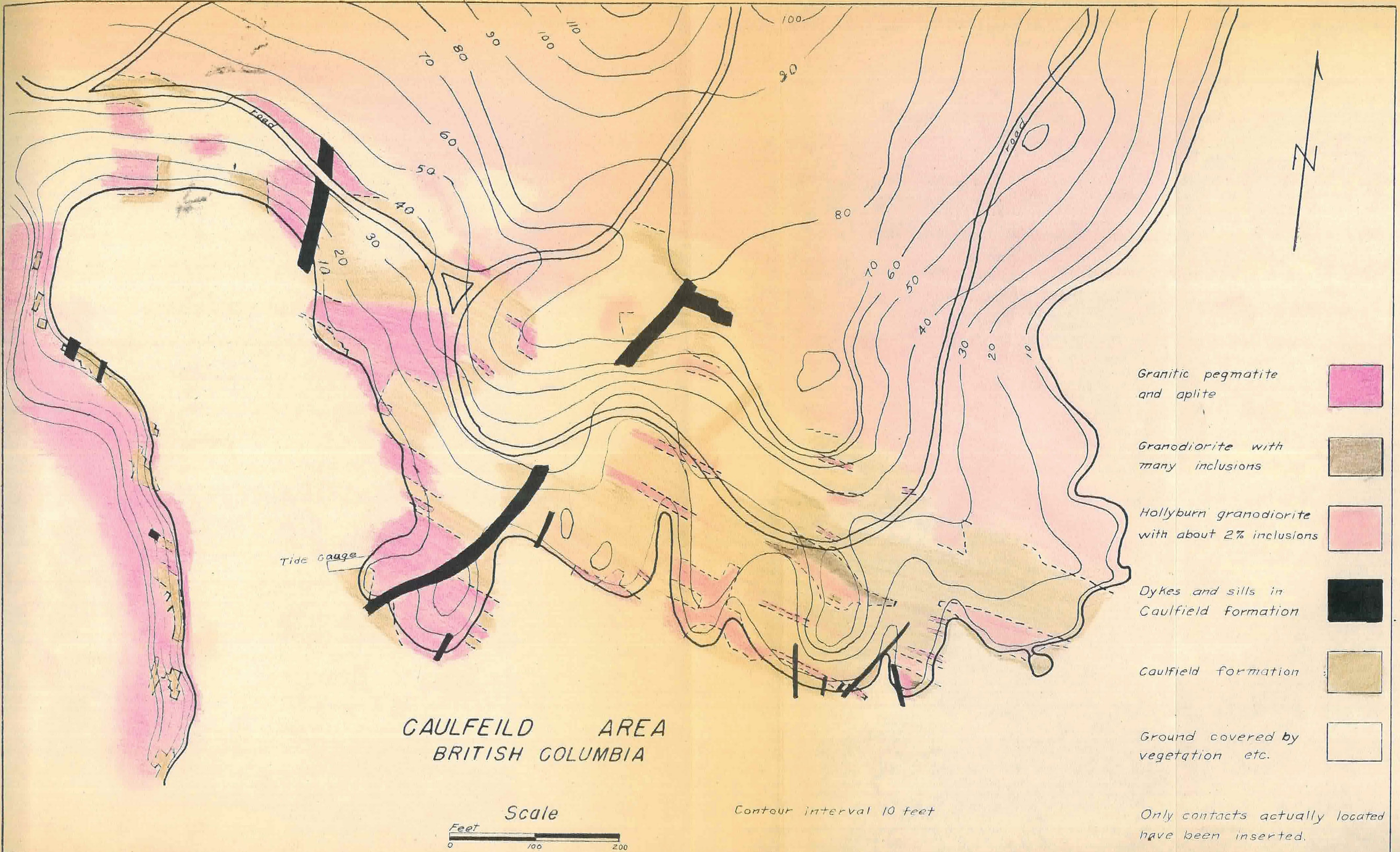

Figure 6 -- A pre-batholith dyke at the water's edge in granitic pegmatite at Caulfield.

Figure 7 -- A closer view of the dyke shown in fig. 6. Notice that the granitic pegmatite cuts the dyke (beneath the hammer)

One of these dykes is shown in fig. 6. At first glance it appears to be a normal dyke cutting the granitic pegmatite. Upon closer inspection, however, the pegmatitic rock is seen to be cutting the dyke (fig. 7). At other localities these dykes are intruded by stringers of granitic pegmatite, which sometimes swell to bulbous forms within the dykes.

The typical pre-batholith dyke rock is very fine-grained, dark green or dark grey, and usually massive. Most of the rock is a microcrystalline aggregate of quartz, andesine, hornblende and biotite, with few or many porphyroblasts of plagioclase. Most of these dykes are a calcic andesite.

The largest pre-batholith dyke found is the one mapped by Phemister near the tide gage at Caulfield (see pl. 2). At the water's edge this dyke cuts obliquely across the Caulfield gneiss. Here and there the chilled edges of the dyke are still preserved. Following the dyke northward from the shore one finds that it passed out of the gneiss inclusion into the granite pegmatite. Except for minor intrusions of the granitic rock, the dyke essentially maintains its shape. For a distance of about 80 feet the dyke is in batholithic rock, then it passes into the main Caulfield inclusion to the north. On the northwest side of the dyke the plutonic rock has displaced considerably more of the Caulfield gneiss than on the southeast side. Thus the dyke was able, apparently, to act as a barrier protecting the gneiss from the granitic rock. This barrier effect is more strikingly shown by the

Figure 8 -- A pre-batholith dyke thought to be intruded by stringers of Hollyburn granodiorite. (The geometric relations shown, however could permit an opposite interpretation).

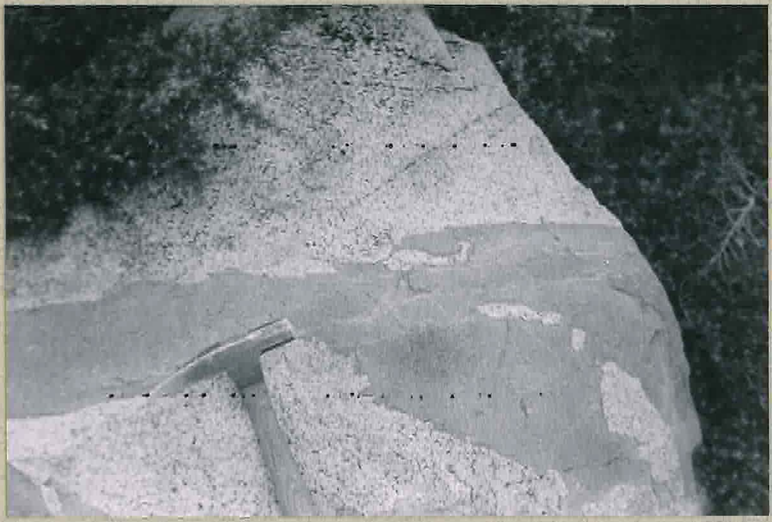

Figure 9 -- Typical contact features of the pre-batholith dykes. The borders seem to have been corroded by the Capilano quartz-diorite.

pre-batholith dyke which occurs on the shore north of the tide gage (pl.2). For almost 100 feet, the dyke separates the gneiss on the east from the granitic pegmatite on the west.

Within the mapped area are many hundreds of these dykes. Most are believed to be pre-batholitic but only a few (roughly 20) can be proved to be so. Stringers of granitic rock within the dykes (fig. 8) suggest that they are pre-batholithic. Considered individually, however, any illustration (such as fig. 8), is inconclusive, since conditions could be imagined by which the age relations would be reversed. Yet the cumulative weight of the very numerous occurrences of stringers of batholithic rock in the dykes has led to the belief that these stringers are fairly reliable evidence of a pre-batholitic age. The same significance is attached to the highly corroded borders exhibited by some of the dykes (see fig. 9).

The pre-batholith dykes have a tendency to be porphyroblastic. This is true especially for the central portions; the chilled edges are generally free of metacrysts. The fine-grained border does not seem to be affected until the very last stage of absorption of the dyke rock. Fig. 10 shows an early stage in which the centre of a dyke has begun to fade away within relatively unaffected borders. A later stage is represented in fig. 11 where the same dyke is shown rapidly becoming a "ghost".

It is rather uncommon, but occasionally a dyke is truncated completely by batholithic rock. One example occurs in

Figure 10 -- A pre-batholithic dyke showing the beginnings of replacement by the Crown diorite. The borders of the dyke have not been affected. (Locality: near The Lions).

Figure 11 -- This is the same dyke as shown in fig. 10, but here the process has advanced to a later stage. (The dyke offset may be the result of original intrusive form, or of pre-batholithic faulting)

Figure 12 -- A pre-batholith dyke almost severed by Capilano quartz-diorite. The light colored band along the contact above the hammer is due to surface discoloration, not due to a chilled edge.

Figure 13 -- A pre-batholith dyke showing the typical blunt nose. Irregular shape may be due to original intrusive form, or to distortion caused by movement of the batholithic rock.

the Caulfield area. More commonly a dyke is almost severed as shown in fig. 12.

Occasionally a pre-batholith dyke may have been deformed during the emplacement of the granitic rock (see fig. 13). There is no evidence of shearing in the dyke. Thus if its present shape is truly the result of deformation (rather than original intrusive form), it must have been made plastic during the emplacement of the granitic rock.

As can be seen in many of the figures (e.g. fig. 10, 12) the jointing in the batholithic rock passes through the dykes. This is true for all the pre-batholith dykes. The "Tertiary" basalt dykes, on the other hand, exhibit their own jointing which stops abruptly at the contacts (shown in fig. 14). Once in a while a pre-batholith dyke will be parallel to one of the joint sets in the batholith. This is, however, fortuitous, and is not the general case.

Significance of pre-batholith dykes

To evaluate the import of the pre-batholith dykes is a difficult task. That these bodies are actually pre-batholithic has been adequately demonstrated and is a fact agreed upon by a number of geologists including both staunch "magmatists" and fervent "granitizationists". With respect to these dykes two main hypotheses have been advanced. Both are admittedly most difficult to comprehend.

The first hypothesis holds that the dykes are stoped out units of country rock. It is possible that the dyke contacts

Figure 14 -- A "Tertiary" dyke showing its distinctive jointing.

may have had joint planes localized along them to facilitate the removal of the country rock. The physical difficulties of such a process are obvious. Most of the pre-batholith dykes occur completely isolated in granodiorite (etc.). Some of these, often less than 18 inches wide, have been traced for several hundred feet (a good example appears on Goat Mtn.). The surrounding batholithic rock commonly contains only about 3% of country rock in the form of small inclusions, consequently the removal of the country rock from around the dyke has been remarkably complete. The theory implies that the granitic batholith was very viscous; otherwise the dykes surely would have been broken up or strongly deformed. If the dykes had been plastic at the time, as well they might have, more deformation (like that shown in fig. 13) would be expected while they floundered in the magma.

The objections to a viscous magma are the same as have been expounded "ad nauseum" in the thousands of granitization debates which have taken place the world over during the last one hundred years. High viscosity would slow up the stoping process to such an extent that the time required for complete separation of the dyke and country rock would be very great, since the process could only be effected either by small differences in rates of sinking, or by differences in direction of movement. The latter could be caused only by currents in the magma which the slender dykes could hardly resist. The same viscous magma would also have to effect the "lit par lit" injections in the Caulfield formation, and the keystone type of "intrusion" yet the be discussed. The room problem on a small scale is exemplified in the latter type of "intrusion".

The second hypothesis maintains that the country rock was changed to batholithic rock by some process of granitization. The dyke rock with its chilled edges, and different composition (though often very slight) is pictured as being more resistant to the granitization agents than the country rock. Admittedly the degree of selectivity required during replacement is at least remarkable. Yet selectivity is certainly more characteristic of replacement processes than of intrusion processes.

In a sense this hypothesis attempts to solve the problem by substituting one mystery for another. The objections other than the extreme selectivity required, are those advanced against the granitization theories in general, and their magnitude is dependent on the viewpoint of the observer.

It is held by some "magmatists" that the room problem is of the same order of magnitude in both the replacement and intrusive mechanisms. According to Barth[1], the lithosphere

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[1]Barth, T.F.W. - The Distribution of Oxygen in the Lithosphere: Jour. Geol., vol. 56, p 41-49, 1948.

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is composed of 90% oxygen by volume. In the granitization process the oxygen framework of the rock can be considered stable and only a small proportion of the cations which make up the remaining 10% of the volume need be displaced to effect the change from country rock to granitic rock. Thus the room problem in comparison with the intrusive theory is negligible.

More important as an objection to having the country rock around the dykes replaced by a granitization process is the extremely high energy requirements of the "emanations" and the lack of a suitable source for them. Also is the peculiar ability of these "emanations" to convert several different rock types into essentially one granitic type.

As is obvious from the relative positions in which I have placed the two theories in this report, I prefer the latter hypothesis. The reason for upholding a hypothesis which is as old as modern geology lies chiefly in the abundant evidence of replacement that is present throughout the whole area, although at any one locality the evidence is only on a small scale.

Post-batholith dykes

The "Tertiary" dykes are composed of black basalt, and are the youngest rocks in the area. Their fresh and unaltered appearance makes these dykes easily identifiable. In rock type they are identical with, and probably related to the small basalt flow of Sentinel Hill. The age of these volcanics is not positively known. However, they rest on the Eocene Burrard formation and are covered by Pleistocene glacial deposits. Their age is probably mid-Miocene, corres-

Figure 15 -- "Probable post-batholithic dykes at Copper Cove, in the Hollyburn granodiorite. Principal criteria: the preservation of the chilled edges, and apparent control by the joint planes in the granodiorite.

ponding to the period of great volcanic activity in the northwest. In comparison with the older dykes, those of the Tertiary are very few (less than 20 were found). The jointing in these dykes is entirely independent of that in the batholithic rocks, as shown in fig. 14. Since the basalt dykes and flows apparently have little bearing on the major problem of the emplacement of the batholithic rocks, they are summarily dismissed in this report.

Quotes have been used in reference to the "Tertiary" dykes because there is another group of dykes which are older, yet may also be of Tertiary age. The identification of these old post-batholith dykes was very difficult and the result seldom certain. In lithology they appear identical with the pre-batholith dykes, although possibly not quite so dense. The following evidence was used to assign these dykes to the "probably post-batholithic" group.

1. The tendency of these dykes to be parallel to one of the prominent joint planes in the batholith rock.
2. Well-defined, and within the limits of the outcrop, unbreached, chilled borders.
3. A tendency to occur in subparallel swarms (as shown at Copper Cave, fig. 15).
4. Some evidence of a joint pattern independent of that of the batholith.
5. Lack of porphyroblastic development.

None of the above criteria, however, is conclusive alone.

For example, if a dyke is parallel to a joint set in the batholith, a post-batholithic age is not demonstrated, since the same relationship could have been produced by a pre-batholith dyke whose presence decided the attitude of the joint planes. Although, if the joint pattern was consistent in the batholith over a broad area, the control over the formation of the joints exercised by the dykes would be negligible. The batholith joint pattern is, however, exceedingly variable, in both direction and spacing. For the local area in which the jointing is consistent, a dyke, or swarm of dykes, may have been an influential factor. This was apparently so in the case of the few pre-batholith dykes which are parallel to the jointing in the granitic rock.

Chilled borders, unless well defined and extensive, also are not conclusive. They are found in the pre-batholith dykes, but usually are breached in many places by the granitic rock. An independent joint pattern in a dyke is believed to be good evidence, but only rarely does it occur.

The lack of porphyroblasts is suggestive of a post-batholithic age. Microscopic examination was made of about 50 thin sections of the older dykes. About 90% of the dykes identified in the field as pre-batholith showed at least some porphyroblastic development in thin section. Of those identified in the field as "probable post-batholith", about 75% showed no porphyroblasts. The discrepancy (10%) in the former may be attributed to the accidental location of the thin

Figure 16 -- An inclusion "dyke" of Caulfield gneiss in Hollyburn granodiorite (at Caulfield)

sections, and in the latter case due to misidentification because of inconclusive field evidence.

Inclusion "dykes"

Occasionally a massive bed in the Caulfield formation or other country rock has been isolated in granitic rock, as shown in fig. 16. When only partially exposed, as is the usual case, these dyke-like slabs are very difficult to distinguish from pre-batholith dykes. Since the original texture in both the pre-batholith dykes and the massive country rock has generally been entirely reconstituted, and the compositions of both appear to be identical, thin sections were of little value in determining whether the rock in question was a dyke or a fragment of country rock. Where the rock contained "lit par lit" injections it was called an inclusion "dyke" because of the similarity of the rock to a slab of Caulfield rock. This feature was, however rare and it is possible that some of the shorter dykes called pre-batholithic should have been listed as inclusion "dykes". The inclusion "dykes" are a confusing feature, but not overly important.

Inclusions

It was noticed during the field investigation that a higher percentage of inclusions was recorded when the exposure was very good. This was caused by the rock discoloration, and lichen covering which obscured the presence of inclusions in the average outcrop and resulted in somewhat low estimates.

So little of the whole area is exposed, that to give even a rough approximation of the inclusion content for the entire mapped area is an act that borders on the naive. T. C. Phemister[1] proffered an estimate of 3% inclusions in the

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1 Phemister, T. C. - The Coast Range Batholith Near Vancouver, British Columbia: Quart. Jour. Geol. Soc. Lon., vol. 101, p 69, 1945.

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batholithic rock (excluding of course the large pendants). Although the writer is in agreement with Phemister's estimate, no proof can be produced. In any single outcrop the actual figure ranges from zero to well over 20%.

In the 5000 feet of vertical section, no apparent concentration of inclusions was noted with respect to elevation. Inclusions occur in the batholithic rock at sea-level and on the mountain tops with no consistent difference in abundance. In their horizontal distribution, however, some slight variation occurs. A broad poorly defined zone exists between Crown Mtn. and The Lions, in which the percentage of inclusions is higher than the average, probably approaching 10%. The mountain mass between Sisters Creek and the Capilano River, which is included in this zone locally contains over 20% inclusions.

As a rule inclusions tend to be rarer in the more acid rocks. They are apparently non-existent in the Sunset granite. In the granitic pegmatite they are locally abundant around Caulfield, but overall they probably average less than one percent. With respect to the more basic plutonic types, diorite and gabbro, inclusions are present, and sometimes abundantly so, but many are in the "ghost" stage in which the outlines are practically indistinguishable.

The rock comprising the less altered inclusions can be matched with that forming the massive andesite of the country rock and of the pre-batholith dykes. At Caulfield, a few gneissic inclusions can be found. The average inclusion is well-rounded and distinctly porphyroblastic (usually with medium andesine metacrysts), generally appearing to be in the process of replacement (see fig. 17 and 18). Every stage exists from a massive, very fine-grained rock, through those flooded with plagioclase metacrysts, to "ghost" inclusions. The last stage is approached in the central inclusions of fig. 19.

Sometimes a group of inclusions will be markedly elongate. The individuals in such a group are within small limits parallel to one another. Such groups usually occur close to a large inclusion or pendant, and when thus located are parallel to the structure in these bodies. Examples are to be found at Caulfield, and north of Nemo Creek.

Some inclusions apparently have been distorted, as shown in fig. 20. At Caulfield some inclusions in which the gneissic structure still remains show up to 30 degrees rotation with respect to the strike of the Caulfield gneiss (fig. 21). It is unlikely that the rotation shown is only an

Figure 17 -- Stringers of Capilano quartz-diorite replacing an inclusion. This is typical of many inclusions in the Capilano quartz-diorite and the Hollyburn granodiorite.

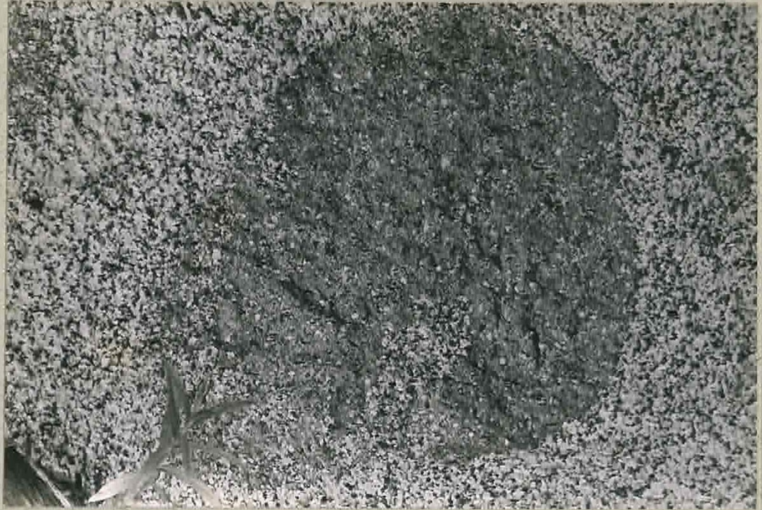

Figure 18 --- Destruction of an inclusion by the development of metacrysts. The granitic rock is the Capilano quartz-diorite between Sisters Ck. and the Capilano River.

Figure 19 -- An illustration of "ghost" inclusions (especially right central portion of the photograph) in the Capilano quartz-diorite.

Figure 20 -- The inclusion (in Capilano quartz-diorite) here has apparently been drawn out and distorted.

Figure 21 -- Inclusions of Caulfield formation in Hollyburn granodiorite. Most are structureless, but the gneissic structure in two of them suggests some rotation. (at Caulfield)

apparent phenomenon due to pre-existing folds because tight minor folds in the gneissic bands of the Caulfield formation are virtually non-existent. Thus the inclusions appear to have been in a batholithic mass that was once somewhat plastic.

On the ridge leading north to Black Mtn., a peculiar inclusion occurs in the Hollyburn granodiorite. It is round, porphyroblastic, and about a foot in diameter. The peculiar feature is a major joint which divides the inclusion vertically into two approximately equal parts. The joint stops abruptly at the border of the inclusion, and the granodiorite immediately surrounding it has no joints. Since this small inclusion is gripped in the batholith by interlocking crystals, and mutual feldspar metacrysts (i.e. metacrysts shared by batholith and the inclusion), it is very unlikely that the joint could have been formed after the emplacement of the batholithic rock -- yet the plutonic rock did not enter the joint plane. This suggests that the emplacement of the batholithic rock was not overly dependent upon open space.

If one assumes the likelihood that the joint passes completely through the inclusion, then an additional conclusion is that the inclusion was not free to fall apart in the batholithic medium.

Banding

Except for the occasional group of inclusions, obvious banding in the batholithic rock is rare within the mapped area. One example, however, does occur in the diorite-gabbro

Figure 22 -- Banding, possibly flow banding in the diorite-gabbro complex of The Lions. The bands are segregations of dark minerals, hornblende and augite.

Figure 23 -- Keystone pattern of "intrusion" typical in the Caulfield formation at Caulfield. Granitic rock is Hollyburn granodiorite.

complex of The Lions. As represented in fig. 22, the structure is produced by banded segregations of hornblende and augite in the gabbro. There is no large body of country rock close enough to this occurrence to permit comparisons of its structure to the banding pictured. Because of the distinctness, straightness, and localization of the banding the writer prefers to interpret it as "ghost" bedding rather than flow structure. Definite proof, however, is lacking and the possibility of primary foliation cannot be dismissed.

In general, oriented structures are rare in the batholithic rocks. Locally, however, in the Capilano quartz-diorite, the rock is slightly foliated, although the trends are inconsistent even within every small areas. On the whole the batholithic rocks are "richtungslos".

Keystone "intrusions"

The Caulfield formation has a prominent joint system which has controlled to a large extent the emplacement of the batholithic rock within it. One set is approximately vertical, and parallel to the bedding. Another set, also vertical, is at about right angles to the bedding, and a third joint set is approximately horizontal. Fig. 23 shows the keystone shape of "intrusion" that often results from the joint system. Similar patterns, occurring where the third dimension is visible suggest that the rectangle of granitic rock in fig. 23 has appreciable depth. That is, the square does not represent a thin "vein" of granitic rock lying in the horizontal joint plane. Other features in the picture include: a lack of distortion of the bedding, several small structureless inclusions, and distinct scallops on the outer edge of the partly free fragment in the upper right hand corner of the block. The first and last points are suggestive of replacement. Close inspection shows that the partly freed fragment of country rock in the upper corner is actually not displaced. It is still solidly connected with the country rock along its upper edge. Removal of the country rock by a stoping mechanism or by upward displacement is fraught with difficulty, especially when it is borne in mind that the pattern in the photograph occurs also on the vertical scale. If the country rock has been faded by a process of replacement and alteration, the sharpness of the boundaries is remarkable. Yet the writer prefers this view, partly because the gap in the knowledge of replacement processes is greater than that in the understanding of intrusion mechanisms.

MICROSCOPIC FEATURES

General Statement

The concept of a batholith as a mass of plutonic rock uniform in texture and composition was refuted at every stage in the investigation of the North Vancouver area. In the preceding pages, an attempt was made to convey some impression of the heteogeneity found in the batholithic rocks. This was evident when traversing in the field, when reviewing the hand specimens in camp, and finally when examining the thin sections under the microscope.

Of the 130 thin sections of plutonic rock examined, only about 20 seemed cleanly crystallized, "normal" igneous rock. In all the remaining sections there was more or less evidence of contamination. The best method for recognizing foreign material in the granitic rock seemed to lie in examining many thin sections in a very short time, commencing with the country rock, then the contact rocks and partially replaced inclusions, and finally the purer granitic rock. This general plan is followed where possible in the following descriptions.

Country Rock

Neither sufficient hours nor sufficient thin sections were available to make a microscopic examination of all the different rock types in the area. There are three types of country rock, however, that form most of the pendants and nearly all of the inclusions. Only these will be described, partly because of their relative abundance, and partly because of some interesting relationships which they show with the batholithic rock.

Type 1

Perhaps the most common type is a fine-grained granulite containing an interlocking mosaic of feldspar (calcic to medium andesine) grains with more or less hornblende. Quartz is present in variable amounts but tends to be quite low.

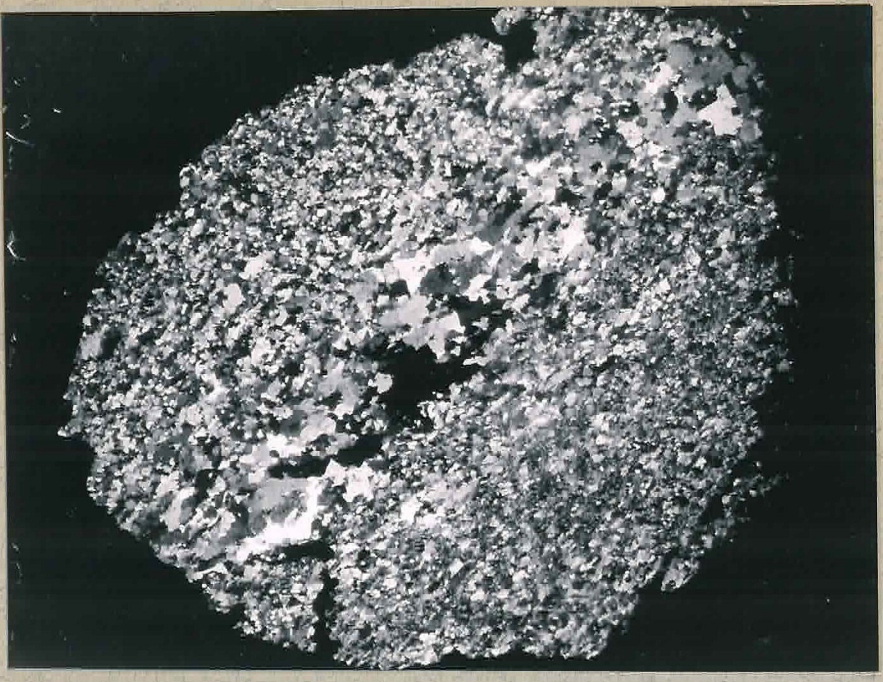

Figure 24A -- Upperleft is Caulfield granulite; lower right is pre-batholith dyke. These are separated by a "lit-par-lit" stringer of granitic pegmatite. The pegmatite is preferentially replacing the granulite. Some replacement of the dyke has also occurred but the dyke contact is still relatively straight, while the contact with the Caulfield granulite is quite irregular in detail. (X5: crossed nicols).

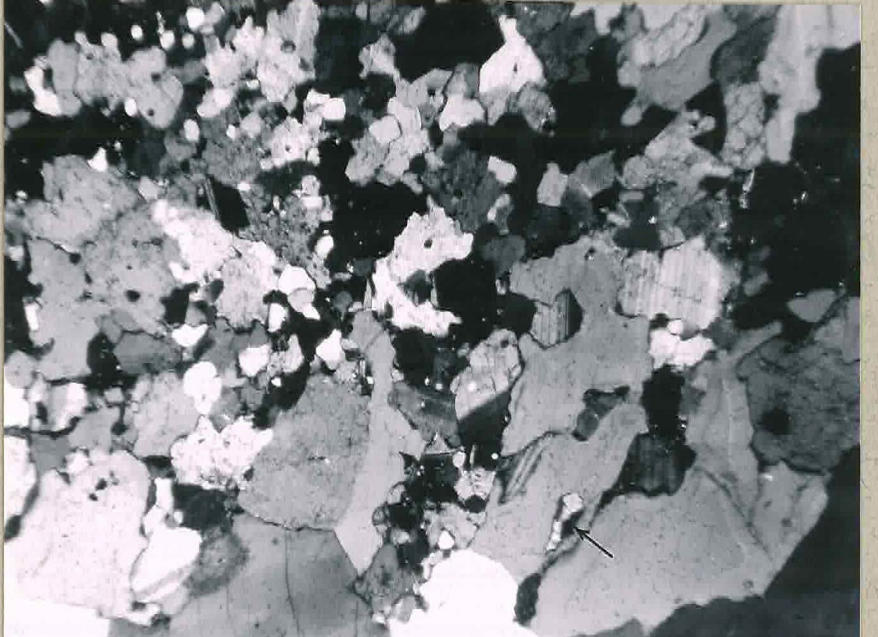

Figure 24B -- Showing the detail of the replacement of granulite by pegmatite.(in fig. 24A). Notice the residuals of granulite jutting downward into the pegmatite and suspended residual (arrow). (X40; crossed nicols)

Minor amounts of magnetite, apatite, and sphene are also present. This rock makes up most of the Caulfield formation. It is completely recrystallized so that no original texture remains. Quite often it is gneissic. The banding (although possibly the result of metamorphism) and the feldspar-rich composition suggest that the rock was originally an andesitic tuff.

Fig. 24A shows a "lit-par-lit" injection of granitic pegmatite along the contact between the large pre-batholith dyke at Caulfield, and the Caulfield formation. On the scale of the thin section the Caulfield rock is the typical fine-grained granulite described above. The pre-batholith dyke differs not in grain size but slightly in composition and texture. It has considerably more hornblende and a directive texture parallel to the contact. The figures show that the emplacement of the granitic pegmatite stringer was not by forceful injection of the rocks but by a process of replacement (notice the suspended structures in fig. 24B). The pegmatite solutions (if solutions they were) presumably were localized along the plane of structural weakness represented by the dyke contact. That an actual fissure existed along the contact is possible although theoretically not necessary since the baked edge of country rock or the chilled edge of the dyke may have possessed a crystal structure that was more susceptible to replacement than the surrounding country rock. After the contact was occupied by the granitic pegmatite the replacement activity showed a distinct preference for the Caulfield rock. It is true that the dyke rock also was subject to replacement but far less so than the Caulfield rock. To some extent this is illustrated in fig. 24A.

If the process envisioned above proceeded until all the Caulfield rock was removed from the dyke, the result would be the typical isolated pre-batholithic dyke seen in the area.

Type 2

Another very common rock type occurring in the roof pendants and to a lesser extent in the small pendant at Caulfield is a fine-grained hypabyssal rock. The principal minerals are medium andesine and hornblende. Quartz may be present to the extent of about 10% but is quite variable. Small amounts of orthoclase, magnetite, and apatite are usually evident. This group of rocks represents a metamorphosed series of slightly basic andesite flows and sills. In overall composition they differ only slightly from their tuffaceous complement in the Caulfield formation. These are the type rocks of the Texada pendant. Although similar in composition to the granulites and gneisses of the Caulfield pendant, this rock type lacks the banding and differs in texture. In spite of the fact that considerable alteration of the plagioclase to a mixture of sericite and clay minerals, and of hornblende to biotite, has taken place, the original orthophyric texture is still discernible, particularly in the euhedral laths of plagioclase. Only partial

Figure 25A -- An irregular growth of granitic elements within a partly orthophyric (not well developed) fine-grained andesite. (X5: crossed nicols)

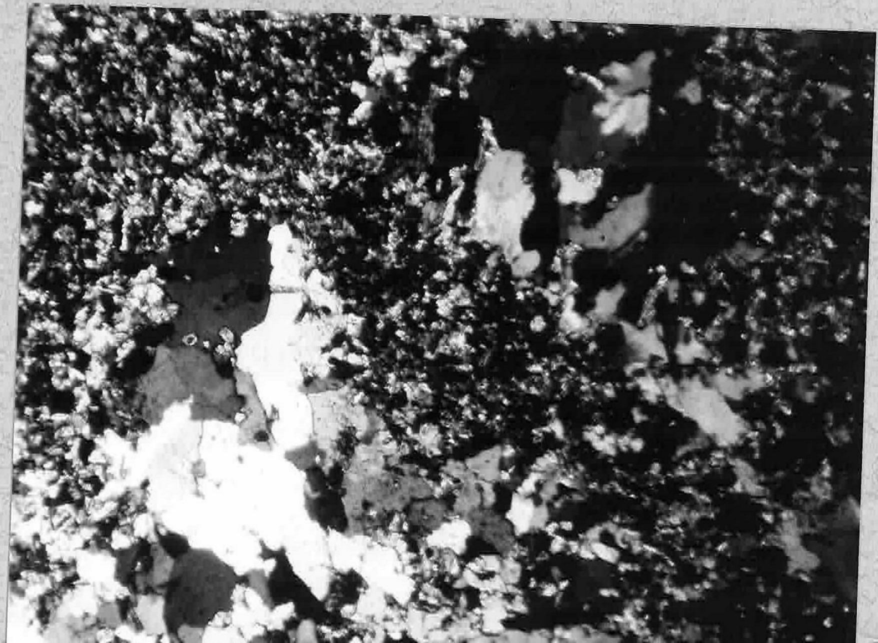

Figure 25B -- An enlargement of a portion of 25A showing the pervasion of andesite by granitic rock. Notice the residuals which are almost invariably left by this replacement process. (X40: crossed nicols) recrystallization has taken place.

Figures 25A and 25B show the partial replacement of this type of rock by the felsic material of the batholith. The location is on the summit of Hollyburn Mtn. where patches and stringers of aplitic material mark an early stage in the replacement of the Strachan pendant. A later stage is represented in the mixed granitic and pendant material comprising the Hollyburn complex which borders the southern part of the Strachan pendant.

It should be noticed in fig. 25B that small residual patches of the country rock are very commonly isolated in a much coarser-grained granitic material. Here they are evidently residual, but when these tiny aggregations of fine-grained material occur in the otherwise pure batholithic rock, where no country rock is available for comparison in the thin section, two interpretations are possible. One holds that they are the result of vagaries in crystallization, and the other, that they are actually residual. These occurrences are very important since they are present in the great majority of the thin sections from specimens that were collected to represent the pure batholithic rock.

The more feldspathic inclusions, and irregular patches in the greenstone of the pendants underwent a marked recrystallization before being changed to batholithic rock. The fine-grained calcic andesite of the greenstone became a fine-grained calcic diorite due to the marked growth of the plagio-

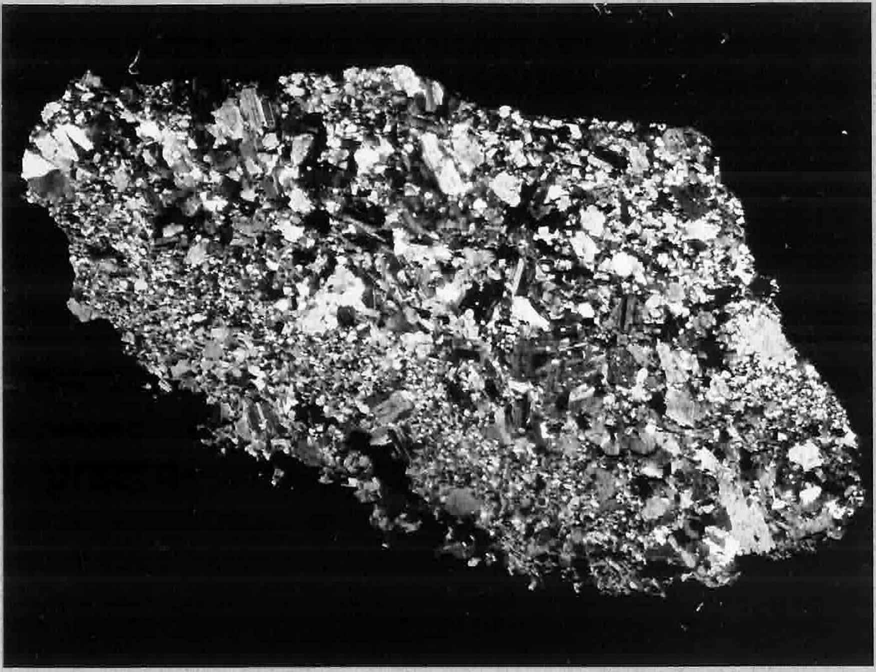

Figure 26 -- Showing the partial change of a somewhat calcic andesite to a rather fine-grained basic diorite. Impurities of the andesitic material within the diorite are evident. The thin section shown came from a large inclusion in the Capilano quartz-diorite; however, identical patches of diorite have formed in the greenstone (especially in the Texada pendant). (X5: crossed nicols)

clase laths. The average grain size increased from about 0.08 mm to about 0.7 mm. That these larger laths are metacrysts is more evident when the process is only about half complete, as shown in fig. 26. The evidence that the larger crystals are actually metacrysts lies principally in the fact that they contain as inclusions small aggregations of the fine-grained andesite. Where the process is nearly complete about the only indication lies in the group of well-developed sericite flakes which are usually clustered around the center of the plagioclase laths, and the fine-grained interstitial material around them.

After the development of this semi-panidioblastic texture which occurs in practically all the smaller feldspathic inclusions, granitic elements begin to replace it. Figures 27A and 27B show this process. The granitic material shows a marked preference for incorporating first the fine-grained interstitial material, then the larger feldspar laths, and finally the hornblende (and other maficsif any). The feldspar of the granitic rock, a calcic oligoclase, is shown in fig. 27B to contain hornblende residuals from the fine-grained interstitial material. This suggests that the large feldspar, a batholithic element, grew in place by incorporating the felsic members of the interstitial material, and the larger andesine laths with suitable additions and subtractions of Na and Ca respectively by the granitizing "agents".

Figure 27A -- Showing the contact between a calcic fine-grained diorite inclusion and the Hollyburn granodiorite. Note the relative sharpness of the contact, and the presence of a granitic patch within the diorite. (X5: crossed nicols)

Figure 27B -- An enlargement of a portion of the right side of the granitic patch within the diorite in fig. 27A. Notice the presence of very fine-grained residuals of diorite within the granodiorite, specially in the large plagioclase crystal on the right (arrow). The residuals are hornblende (light colored) and magnetite. (X40: crossed nicols)

Figure 28A -- This depicts the random pervasion of calcic diorite inclusion by Hollyburn granodiorite. The granodiorite metacrysts contain inclusions of all the minerals comprising the diorite. Hornblende, however, is the most abundant residual (most of the diorite feldspar having been absorbed in the formation of the granitic metacrysts). (X5: crossed nicol nicols

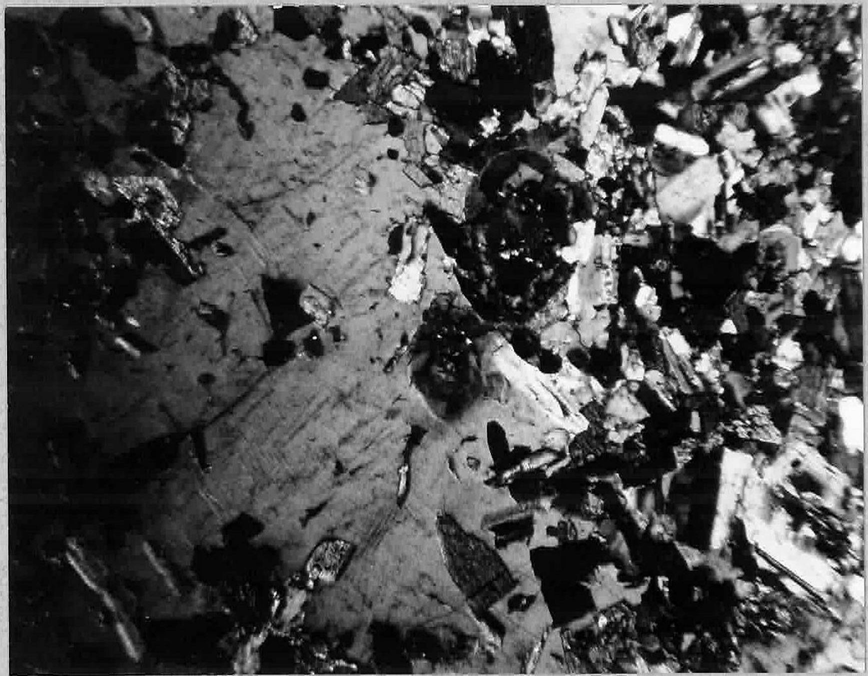

Figure 28B -- An enlargement of a part of fig. 28A showing residuals of hornblende, biotite and magnetite in the orthoclase of the granodiorite. Residual plagioclase also occurs but not within the field. (X40: crossed nicols)

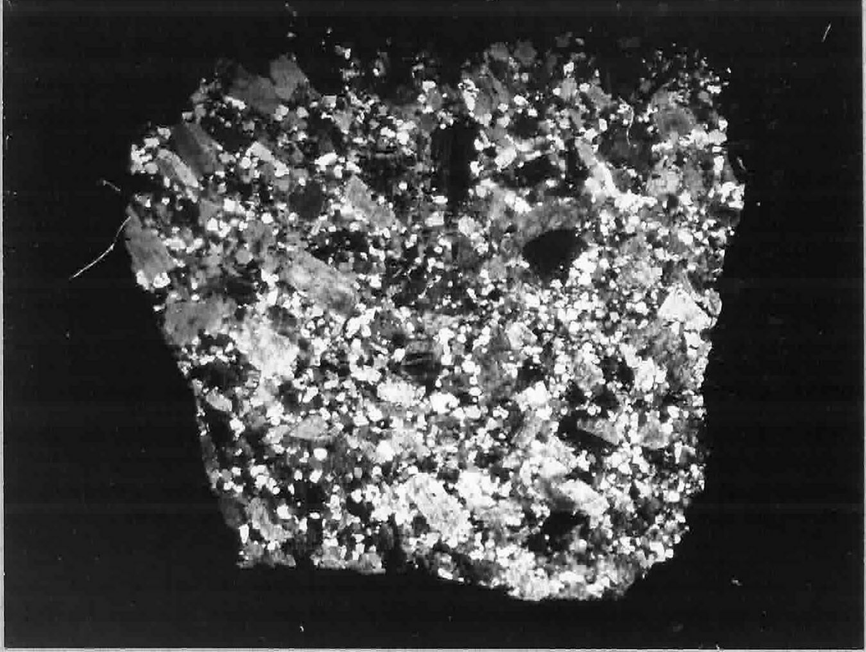

Figure 29 -- Aporphyroblastic granulite. The metacrysts represent elements of the Capilano quartz-diorite in a rock which was dubiously identified as an inclusion because no borders could be seen. Close inspection reveals granulite material including quartz, feldspar, and hornblende within the metacrysts. (X5: crossed nicols)

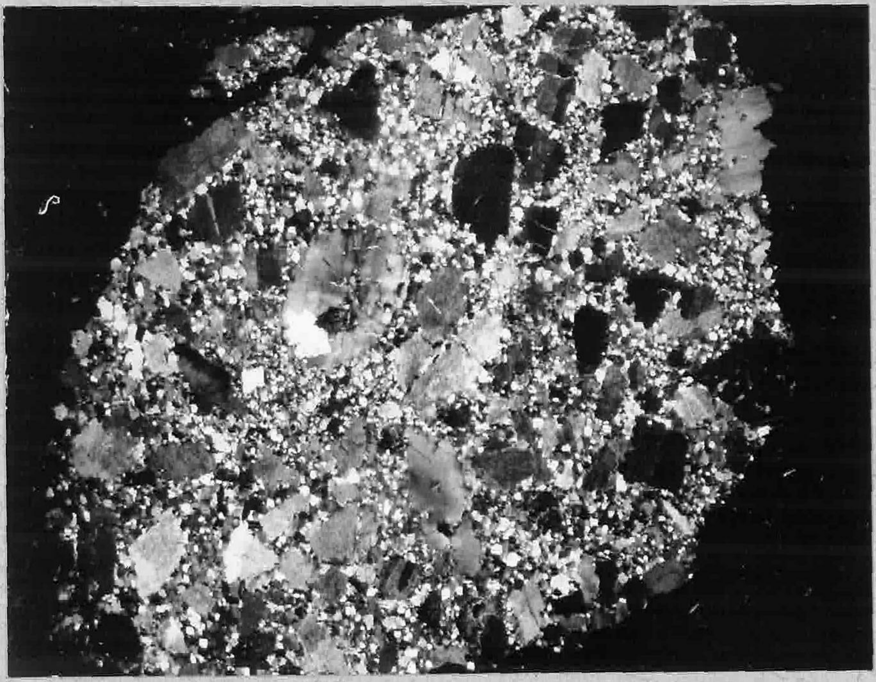

Figure 30 A -- Microscopic examination has shown that this is not a typical specimen of Capilano diorite, although the specimen was collected as such. It is a porphyroblastic granulite like that in fig. 29. Notice the superficial resemblance to mortar texture. (X5: crossed nicols)

Figure 30B -- An enlargement of the quartz metacryst in the upper right corner of fig. 30A (arrow). A residual aggregate of granulite occurs within the metacryst (right side) indicating that the granulite is not a result of post-batholithic cataclastism. (see text). (X40: crossed nicols)

Much the same phenomenon is shown in figs. 28A and 28B. Here, however, the pervasion of the granitic elements (referring to crystals) is less orderly, and their growth is taking place at several points within the section. The enlargement of a portion of figs. 28A and 28B depicts the orthoclase replacing the calcic diorite. Characteristically, it leaves a few plagioclase laths, and most of the hornblende is poikiloblastic suspension.

Type 3

A far less common type of country rock is a quartz-feldspar granulite that is fine grained but coarser than the first two types described. This rock like most of the Caulfield formation has been completely recrystallized. The relatively high quartz content (more than 60%) suggests that the original rock was sedimentary. This rock presumably because of its composition and texture favored the development of abundant feldspar, and some quartz metacrysts. This is shown in fig. 29, of a section of a large inclusion in the Capilano quartz-diorite on the northeast side of Grouse Mtn.

Within a mile of the above locality a specimen of apparently uncontaminated Capilano quartz diorite was collected. It is shown in fig. 30A and 30B. It differs under the microscope very little from that shown in fig. 29. The slightly larger and more numerous metacrysts in fig. 30A have obliterated the megascopic indications that the rock was a highly altered inclusion rather than a "normal" plutonic rock.

Figure 31 A -- A rather pure specimen of Hollyburn granodiorite near Caulfield. (X5: crossed nicols)

Figure 31B -- An enlargement of the left side of fig. 31A showing residual(?) plagioclase being replaced by orthoclase). (X40: crossed nicols)

Some mention should be made here of the startling resemblance of the texture of these porphyroblastic granulites to cataclastic textures. The fine-grained granulite resembles interstitially mortared fragments of the larger crystals. That this is not the case, however, is shown by the rather common inclusion of small aggregates of granulite within the metacrysts. In the normal cataclastic process, the small crystals are formed by the breaking off and recrystallization of fragments of the larger crystals at the points of greatest stress; these points occur at the boundaries of the larger crystals, not within them. A good example of the small crystals within a metacryst is shown by the large quartz metacryst occurring on the right side of fig. 30B.

Batholithic rock

When thin sections of what appeared in the field to be "normal" batholithic rock were examined many of the features in the partially granitized inclusions were found to exist here also. In some sections the evidence of contamination by country rock was not abundant. In about 10% of the sections of plutonic rock examined there was apparently no contamination. In the majority of the rest, however, the evidence was considerable. Figures 31A, 31B, 31, and 32 show some of this evidence.

Figure 31A is a fairly typical example of the Hollyburn granodiorite near Caulfield. Notice in this figure that there are two textures present. One is a medium-grained granitoid texture consisting of subhedral to anhedral crystals of quartz and feldspar. The other consists of scattered fine-grained, and usually euhedral plagioclase crystals. On the left side of the figure these crystals are contained in the orthoclase (actually a microperthite). With them is a thin scattering of fine-grained impurities, chiefly sericite and hornblende. Figure 31B shows more clearly the orthoclase replacing the plagioclase.

It might be argued that in normal crystallization from a magma orthoclase crystallized last and corrosion of the earlier plagioclase crystals by it would be expected. The overall weight of the following evidence suggests that this is not so:

1. These plagioclase crystals are distinctly smaller, and more euhedral, than those of similar composition in the granitic rock.
2. Often these residual crystals will be full of sericite crystals, while the larger plagioclase crystals of the plutonic rock are clear.
3. They appear identical in form and composition (medium to calcic andesine) to the isolated feldspars in the partly altered inclusions.

Another feature, characteristic of much of the plutonic rock in the North Vancouver map-area, is the tendency for the mafic minerals, chiefly hornblende, to occupy an interstitial position with respect to the quartz and feldspar. Where

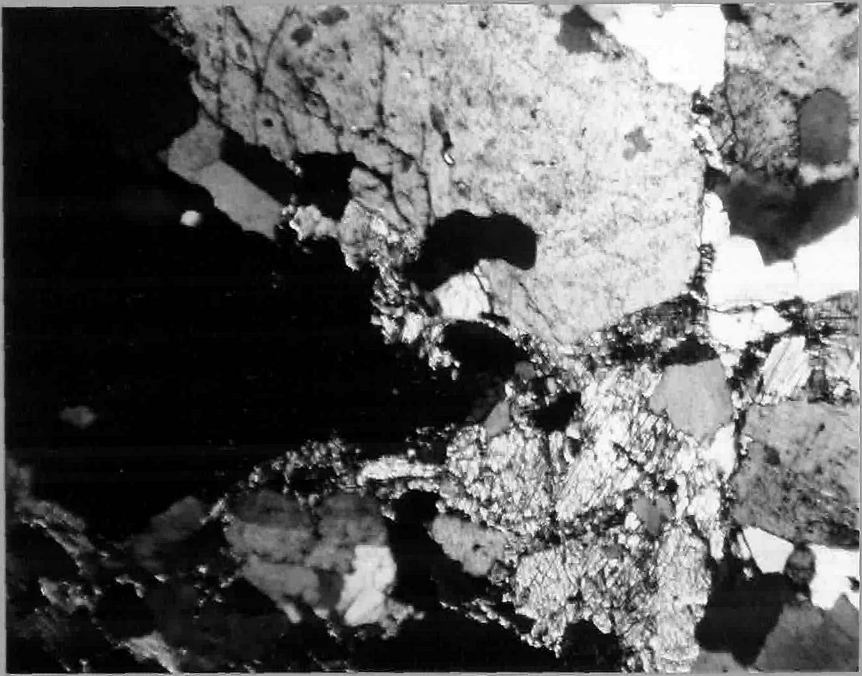

Figure 32A -- A photograph depicting the rather common tendency for the mafic to occupy a interstitial position. The mafic mineral is hornblende in the Capilano quartz-diorite (X40; crossed nicols).

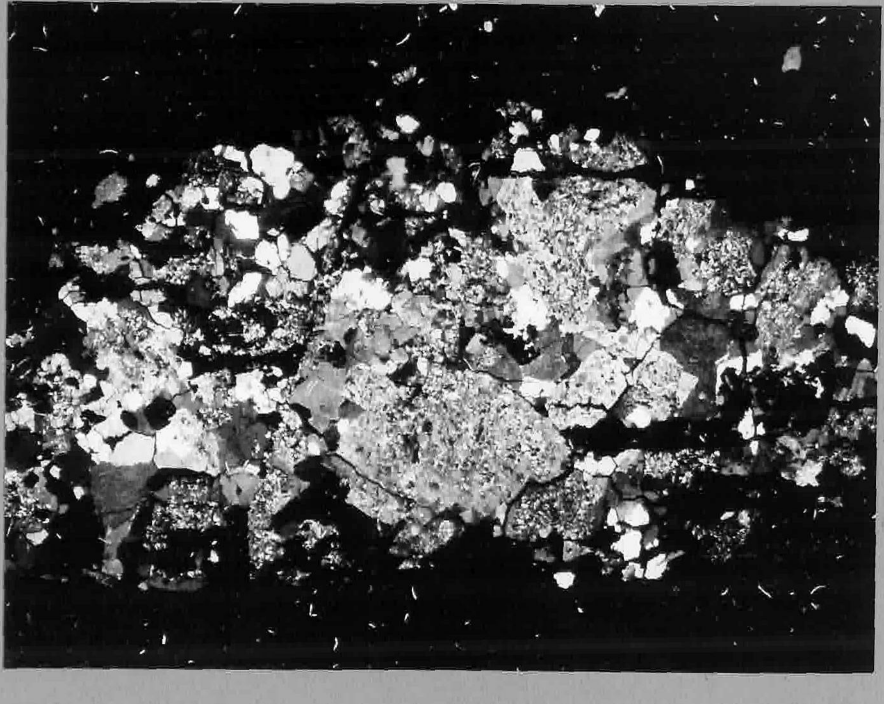

Figure 33 -- A specimen of Grouse Mtn. granite with numerous inclusions, chiefly well crystallized epidote with some hornblende and magnetite. The inclusions are residual(?) (see text). (X5: crossed nicols)

these hornblende crystals are small, they are probably residual from the country rock. This is the general case. Occasionally, however, the interstitial hornblende has apparently recrystallized and coalesced to form relatively large anhedral crystals, as shown in fig. 32. The interstitial position and anhedral shape serve to distinguish this hornblende from the euhedral (or nearly so) hornblende resulting from normal crystallization.

Figure 33 shows a specimen of Grouse Mtn. granite flooded with inclusions. Most are small crystals of epidote, with some hornblende and magnetite. Also a few slightly larger plagioclase crystals are held in a poikiloblastic manner by the feldspars of the granite. These inclusions probably do not represent the alteration of the batholithic feldspar for the following reasons:

1. They are very well crystallized. It is unlikely that conditions could be such that the alteration products of the feldspar would form, and recrystallize, while in a neighboring feldspar of idential composition alteration products have not yet even formed.
2. The alteration of the feldspar could not yield the tiny hornblende and magnetite crystals which comprise some of the included matter.
3. Similar aggregations occur in quartz and commonly interstitially among the crystals of the granitic rock.

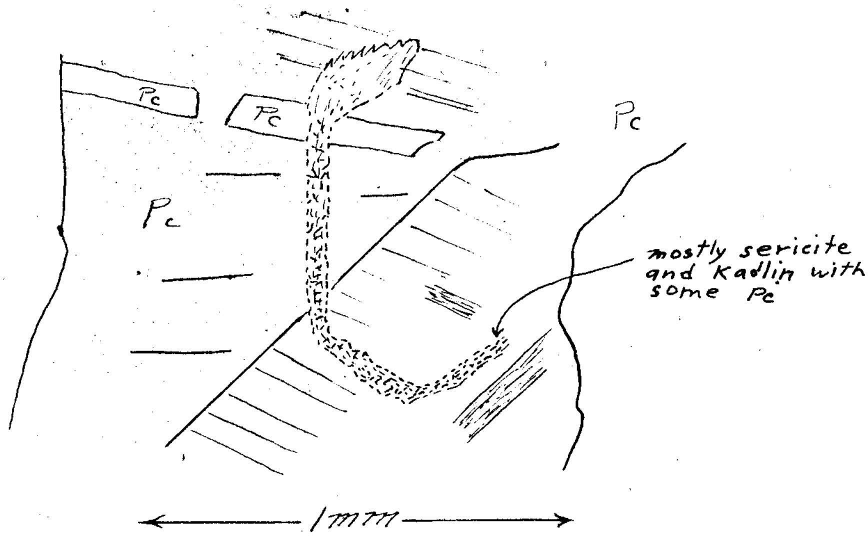

PLATE 5

This illustration depicts the rather regular-shaped trail of alteration products. Enough unaltered plagioclase remains within it to cause the entire trail to have a simultaneous extinction. It apparently bears no relation to the plagioclase crystals which now contain it. The shape suggests that the trail represents a portion of the outer(?) ring of a zoned plagioclase crystal, the rest of which has been recrystallized or replaced.

Figure 34 -- Sutured boundaries of quartz crystals in a specimen of Capilano quartz-diorite from the west base of Crown Mtn. It is, perhaps, suggestive of post-batholithic recrystallization. (X40: crossed nicols).

4. Although the tendency is not well shown in fig. 33, the inclusions are commonly clustered near the central part of unzoned plagioclase crystals.

It appears to the writer that these inclusions represent contamination by the country rock.

Post-batholithic recrystallization

Along the north shore of Burrard Inlet continental Eocene sediments rest on the weathered surface of the batholith. These rocks are undisturbed and indicate a lack of post-batholithic dynamic metamorphism. Yet a few of the sections of the Capilano quartz-diorite showed some evidence that local recrystallization has taken place in the plutonic rock. This is suggested by some quartz crystals which possess highly sutured boundaries, as shown in fig. 34 and also by the phenomenon of albite twinning being superimposed on a faintly zoned plagioclase (this latter feature may be a coincident development). This disappearance of zoning and general recrystallization was also indicated by a curious pattern of some semi-opaque and opaque debris (see plate 5). A narrow trail of this debris may have a polygon shape as if it once existed around the edge, or between the zones of a well-zoned large plagioclase crystal. The zoned crystal is no longer present; instead, usually, is a well-twinned specimen. Occasionally the debris polygon may pass over the crystal boundaries of several twinned plagioclase crystals, indicating major yet quiescent reconstitution of the rock. This post-batholithic period of recrystallization may be related to the mid-Tertiary vulcanism that took place within the region, but the whole matter is very nebulous.

GEOLOGIC HISTORY

The geologic history of the area may be summarized briefly thus:

During the early Mesozoic, the volcanic activity that dominated the central portion of the province produced great thicknesses of volcanic flows and pyroclastics. Before the period ended, the formations thus produced extended westward over the present site of the Coast Ranges, and included most of the islands off the coast. Fluctuations in the Triassic seas produced a few limestone beds along the coast which were intercalated with the volcanic series.

Before the coming of the batholith, in the Vancouver area at least, several events took place. The volcanic series was strongly folded and portions of it (represented by the Caulfield formation) were rendered gneissose at this time. When this activity was over, the country rock was intruded by a series of calcic andesite dykes. The similarity in lithology between the country rock and these dykes suggests that the dykes were related to the dying phases of the volcanic period.

During a long period which extended from Lower Jurassic to Upper Cretaceous the various plutons of the Coast Range Batholith were emplaced. The mechanism by which this took place must remain a matter of speculation. Both intrusion and replacement have occurred. In my estimate the evidence of replacement in the area mapped is much stronger than the evidence of intrusion. This may be related to the fact that the portion of the batholith exposed in this southern area represents only the uppermost part. Perhaps this is analogous to the Pellisier granite of the Northern Inyo Range[1]

[1] Anderson, G.A. - Granitization, Albitization and Related Phenomena in the North Inyo Range Region: Geol. Soc. America Bull., vol. 48, pp 1-74, 1937.

while the more purely intrusive granite, represented by the Boundary Peak granite in the Inyos, underlies the area but is not yet exposed.

In the Vancouver area the record of the Tertiary is poor. However, the batholith was exposed and deeply weathered before the deposition of the Eocene shales and sandstones. Some time in the middle Tertiary, basalt dykes cut these rocks, and a small flow occurred at Sentinel Hill.

The Pleistocene brought the fjord-forming glaciers. Alpine glaciation continued long after the retreat of the large valley glaciers, probably into historical time.

SUMMARY

In this report no attempt was made to present the detailed geology. Only a sketch of those factors which seemed significant in the method of emplacement of the batholith was given.

The field evidence suggestive of replacement includes:

1. Marked heterogeneity in composition and texture of practically all the batholithic rock except the Sunset granite.
2. Inclusions -- the abundance at all elevations and their areal distribution (none in the Sunset granite). They show all gradations from relatively unaltered country rock through those that are highly porphyroblastic, to "ghost" inclusions and finally batholithic rock.
3. Pre-batholith dykes.
4. The keystone pattern of "intrusion".

The microscopic evidence for replacement includes:

1. Abundance of contamination.
2. The "lit-par-lit" injections are apparently a result of localized replacement.
3. Textural relationships
   a. Interstitial position of the mafic minerals
   b. Pseudocataclastic textures
   c. Abundant metacrysts
   d. Growth of granitic textures within the dykes and the country rock.

CONCLUSION

The similarity between the thin sections examined and those described from the Pellisier granite of the Inyos by Anderson was very striking.

There is some evidence that with the probable exception of the Sunset granite a large proportion of the exposed batholithic rocks could have been formed by a replacement process. During the process local areas became slightly plastic permitting some limited movement and intrusion. The lack of inclusions in the Sunset granite suggests that this rock was actually in a homogeneous magmatic state before it began to crystallize. Its uniformity in composition and texture is in marked contrast with most of the batholithic rock in the area.

Below the heterogeneous batholithic rock, and possibly exposed within the area, the magmatic type of granitic rock probably exists. The Sunset granite is possibly a member of the underlying magmatic rock.

The writer has found it very difficult to transfer the general impressions gained from innumerable small scale features in the field to the body of the thesis. In a sense the evidence indicating a replacement process has a feature, which is almost inherent, of being on a small scale, while that for intrusion is more often on a large scale. This fact tends to guide geologists to the conclusion that the bathoolithic rock formed by granitization itself is a small scale feature in relation to that formed by crystallization of a magma -- and perhaps this is so. It has been the impression of the writer, however, that granitization processes are more important than is suggested by the scale of the supporting evidence. If the writer has presented a case which is somewhat unconvincing he has at least accurately portrayed his unsettled state of mind on this most profound geologic problem.

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