

PETROLOGY OF QUATERNARY VOLCANICS OF THE MOUNT GARIBALDI MAP-AREA, SOUTHWESTERN BRITISH COLUMBIA

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ABSTRACT. The petrology of a suite of volcanic rocks having limited age range and areal distribution but wide compositional differences is described. The mineralogy shows remarkably little relationship to bulk composition of the rocks. Cooling histories, particularly as influencing mineral zoning and degree of crystallization, and pressure histories are important in determining what minerals are present and what is the composition of these minerals. Rock classification based on chemical composition is hence more suited for correlation of these rocks than is one based on mineralogic composition.

Petrologic characters and the volumetric distribution of rock types suggests the differentiation of a basaltic magma contaminated by granitic material, followed by gravitative selection during extrusion.

INTRODUCTION

Geologic mapping in the Mount Garibaldi map-area, in the southern Coast Mountains of British Columbia (fig. 1), discloses a varied group of volcanic rocks postdating the last major uplift (Pliocene?). Lavas and pyroclastics of this group range from basalt to dacite, and an associated intrusive consists of rhyodacite glass. No less than 30 distinct volcanic centers exist in the 14 by 25-mile map-area. Information obtained by field mapping permits a more or less reliable estimate of the volume of rock associated with each center.

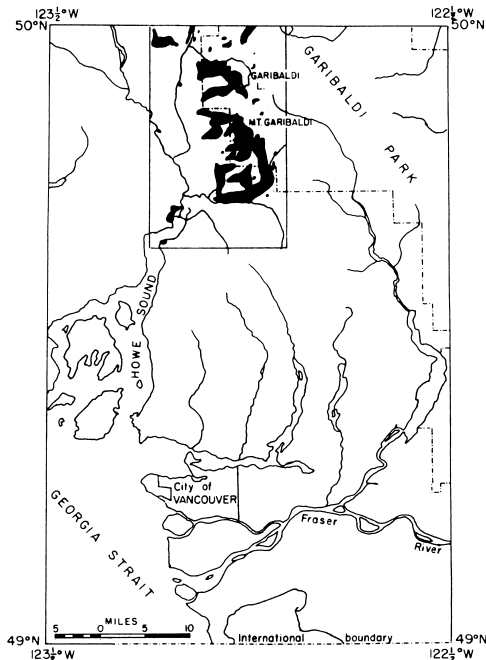


Fig. 1. Index map of the Mount Garibaldi map-area (small rectangle) showing distribution of Quaternary volcanic rocks in black.

Petrologic study of these volcanic rocks has been made to establish

- (1) the range in bulk composition
- (2) the volumes of rock in each of several compositional groups, and
- (3) the relationships between bulk composition and composition of constituent minerals.

Field mapping was carried on during the summers of 1946 and 1947, and petrologic studies were undertaken mainly during the succeeding two winters. Approximately 150 hand specimens were available for study from which 50 thin sections and 16 rock analyses were obtained. Artificial fusions of the chemically analysed rocks displayed a close relationship between refractive index and composition (Mathews, 1951) and this relationship was used to determine the approximate composition of the remainder of the hand specimens. Mineral composition was determined by optical methods as outlined below.

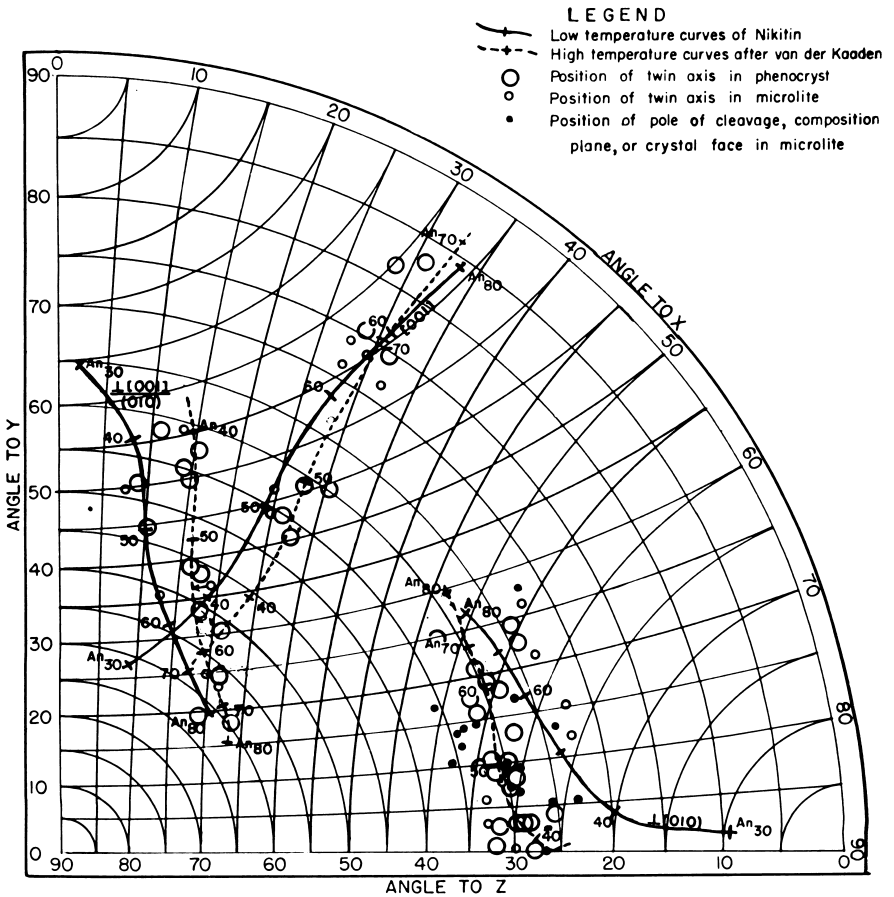


Fig. 2. Optic orientation of twin axes in plagioclases of the Quaternary volcanic rocks.

MINERALOGY

Plagioclases.—Determination of plagioclases in thin section has been carried out as far as possible by the Fedoroff method as outlined by Nikitin (1936) and described in English, with minor modifications, by Turner (1947). In this method the relationship between the optic indicatrix of a twin lamella and the twin axis is determined by universal stage, and the twin axis is identified by its angular relationship to some other composition plane or cleavage in the same crystal. The data are plotted on an appropriate diagram (fig. 2) and compared with the standard curves provided by Nikitin. Under favorable conditions the positions of indicatrix and twin axis can be established within a very few degrees. However, strong zoning in some phenocrysts reduces accuracy, and in microlites the overlapping of twin lamellae or of crystal and adjoining, clouded groundmass limit the possible observations. In many microlites only two optic directions could be measured and these had to be related to the pole of an identifiable cleavage plane, composition plane, or crystal face.

Points plotted on the Nikitin diagram commonly fall to one side of Nikitin's curves. The deviation is much too great, in many cases, to be attributed solely to observational errors which, in any event, should lead to a more or less symmetrical scatter of points. Similar discrepancies have been noted by Larsson (1940) and Turner (1947). Scholler in 1942 showed that "anomalous" orientations of the optic indicatrix can be produced artificially by the heat treatment of feldspars with "normal" optic properties. Köhler (1942) and Oftedahl (1944) distinguish "high temperature" feldspars, with the "anomalous" optic data, from "low temperature" feldspars, and this distinction, since confirmed by x-ray data (Goodyear and Duffin, 1955), is now generally accepted (e.g. Tuttle and Bowen, 1950; Chayes, 1952; Köhler, 1949; and van der Kaaden, 1951). The anomalous Garibaldi feldspars can, with some confidence, be considered high temperature varieties.

Studies of high temperature feldspars have been hampered by the scarcity of determinative data, but van der Kaaden (1951) has compiled the available information and provides the counterparts of Nikitin's curves (fig. 2). These have been used throughout the present work, with the assumption that *all* the plagioclases have high temperature optics.

The compositions of the plagioclases, as thus determined, show no close relationship to the bulk composition of the rocks in which they occur (fig. 3). Phenocrysts, and to a less extent microlites, display a great range in anorthite content in rocks of similar bulk composition, and the ranges for dacite are almost coincident with that for basalt. The plagioclases of many dacites, especially those with a glassy groundmass, are commonly more calcic than those of the basalts, which are generally holocrystalline. Not only is there a wide range of feldspars found in rocks of one composition, but a great variety can be found in a single flow, and indeed in a single specimen or thin section.

Zoning is also common within individual crystals. Those phenocrysts with sodic cores and calcic rims are xenocrysts, judging by the reaction zone commonly marked by a series of glass inclusions, or by the sharp boundary which generally separates the inner and outer parts of the crystal. They may be

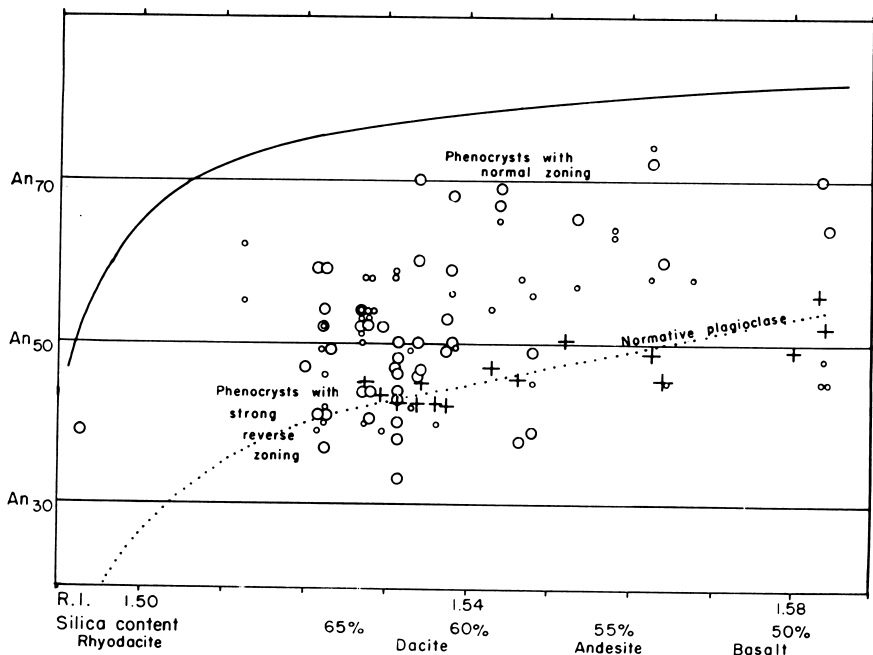


Fig. 3. Relationships in the Quaternary volcanic rocks between plagioclase phenocrysts (large circles), microlites (small circles), normative plagioclase (crosses), and the refractive index of the fused rocks in which they occur. Solid line: composition of first crystals from a melt with the composition of the normative plagioclase.

derived from partly assimilated fragments of quartz diorite, for their composition and dimensions approximate the feldspar grains of the earlier plutonic rocks of the map-area. The phenocrysts with normal zoning or whose cores are similar in composition to their rims probably crystallized from a magma represented by the present volcanic rocks. These are compared with the normative feldspar (calculated from the chemical analyses) (fig. 3), and with the feldspar that would crystallize from a pure plagioclase melt having the composition of this normative plagioclase (Bowen, 1913). The stable phenocrysts prove to be more sodic than would be anticipated from a consideration of the plagioclase cooling curves alone, just as in the San Juan volcanic rocks of Colorado (Larsen et al., 1938).

The outermost shell of all the phenocrysts, irrespective of type of zoning, tends to be uniform in thickness from grain to grain, and to be of approximately the same composition or range of composition as the microlites in the same rock. Even these outermost shells, like the microlites themselves, show some zoning, being in general somewhat more sodic at the outer surface of the crystal than at a point few microns or tens of microns toward the core. They evidently represent the layer crystallized after the lava has been extruded and thus correspond to the crystals of the second generation.

The microlites of only a few of the rocks are more sodic than the normative plagioclase of the same rock; presumably they compensate for pheno-

crysts more calcic than in the norm. Rocks in which both phenocrysts and microlites are more calcic than in the norm are, as a rule, only partly crystalline; the glassy groundmass probably contains the missing albite content. Such a relationship is most common in the dacites.

The frequency of twin laws are listed in table 1, together with the frequencies determined by Larsson (1940) in the Tronador volcanic rocks of Patagonia, by Paliuc (1932) and Wenk (1933) in the extrusive rocks of Siebenbürg (Roumania), by Ghika-Budesti (1939) in the rocks of the Banat area (Roumania), and by Spaenhauer (1933) in artificial plagioclases.

TABLE 1
Frequency of Twin Laws in Plagioclases

Twin Law	Mount Garibaldi			Tronador	Sieben.		Banat	Artif.	
	Phen.	Micr.	Tot.*		%	%			%
Albite	20	8	28	37	24	49½	45	26	28
Mannebach	2	1	3	4	—	5½	7	9½	—
Carlsbad	9	5	14	18	38½	14	17½	26	43
Ala	3	2	5	7	1	—	—	—	—
Acline and/or						1	—	8	—
Pericline	2	—	2	2½	2	24½	13	—	—
Albite-Ala	2	—	2	2½	2	—	—	—	—
Albite-Carls.	10	5	15	20	32½	4	13	22½	29
Baveno	—	—	—	—	—	1½	4½	—	—
Ambiguous	6	1	7	9	—	—	—	8*	—
Total Number									
Determined	<u>54</u>	<u>22</u>	<u>76</u>	<u>—</u>	<u>95</u>	<u>431</u>	<u>149</u>	<u>53</u>	<u>68</u>

* Described as "others"

The determinations of the Mount Garibaldi feldspars indicate that the most common twins are Albite, Albite-Carlsbad, and Carlsbad, in that order, and that there is little difference in the relative frequency of twin laws between phenocrysts and microlites. The results are in accord with those of Paliuc and Wenk who also investigated rocks in which intermediate plagioclases predominated. Larsson (1940, p. 373) indicates that the frequency of twin laws is a function of composition and that in the calcic plagioclases Carlsbad twinning predominates, but no such relationship is recognized in plagioclases from the Mount Garibaldi map-area.

The normative composition of feldspar in the chemically analysed rocks is illustrated diagrammatically in figure 4.

Potash feldspar.—No potash feldspars are known in the volcanic rocks of the map area.

Silica minerals.—Only two silica minerals have been recognized in thin sections of the volcanic rocks: Cristobalite and quartz.

Cristobalite occurs both in cavities and in the groundmass of holocrystalline dacites. It characteristically displays a series of overlapping plates "like tiles on a roof" (MacGregor, 1938) or the surface pattern of a golf ball (Howell Williams, pers. comm.) given it by cleavage and twinning (?). This

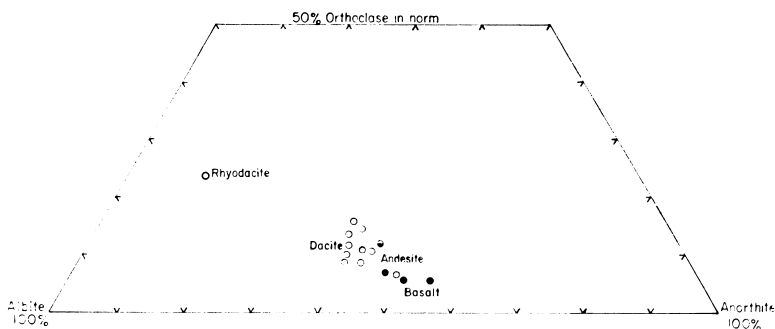


Fig. 4. Normative feldspars in the Quaternary volcanic rocks.

appearance, together with distinct negative relief, low birefringence, and an uniaxial negative interference figure recognizable in some grains, serves to identify the mineral. It is one of the last minerals to crystallize. Though abundant in some of the holocrystalline rocks, it is scarce or absent in merocrystalline rocks of the same composition.

Quartz occurs in a few of the dacites as large, widely-scattered grains, surrounded by coronas of augite. These grains evidently were not in equilibrium with the magma but, surrounded by the continuous shell of augite grains, they may have reacted very slowly with the melt. Strain shadows, visible in a few grains, are attributed to deformation of quartz prior to incorporation in the magma. These quartz xenocrysts may have been derived by partial assimilation of quartz diorite. The presence of accompanying feldspar xenocrysts tends to confirm this suggestion, but inclusions of quartz diorite as such are rare and show no notable signs of assimilation. In partly assimilated inclusions of arkose in one dacite, though the cement has been converted to glass, the aggregate retains its continuity. In a more advanced stage of vitrification, inclusions of both arkose and quartz diorite might have become disintegrated into isolated xenocrysts of quartz and feldspar.

Orthopyroxenes.—Orthopyroxene is the most common of the mafic minerals occurring as phenocrysts in many dacites and a few andesites, and as a groundmass mineral in nearly all dacites. In some rocks it is the only mafic mineral present; in others it is accompanied by amphibole, by augite, or by augite and olivine.

Composition of orthopyroxenes was determined using universal stage measurements of 2V and the optic data of Hess and Phillips (1940). These determinations show the orthopyroxenes to range from En_{60} to En_{94} and to average En_{75} . The magnesia content shows little relationship to the composition of the rock (fig. 5) or to the presence or absence of other mafic minerals. The MgO/FeO ratios are, with one exception, higher than in associated augites, unlike the relationship in Skaergaard pyroxenes (Muir, 1951, p. 709-711). The MgO/FeO ratio tends also to be higher in the orthopyroxenes than in the rock as a whole, even in those rocks containing no other ferromagnesian mineral (fig. 5). In these rocks the ferrous iron may be concentrated in the glassy groundmass.

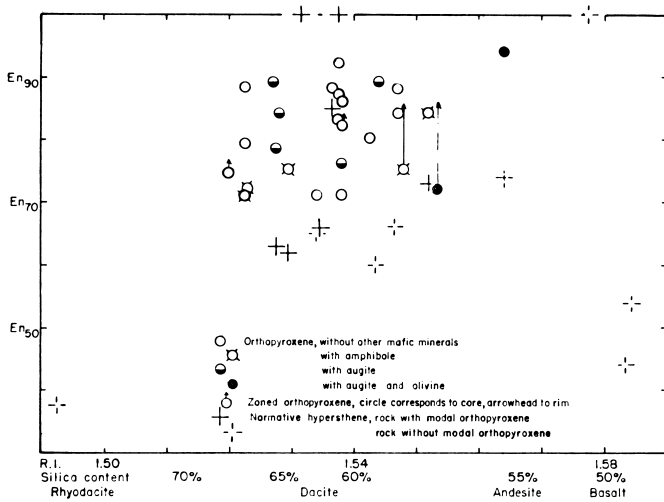


Fig. 5. Relationship between modal and normative composition of orthopyroxenes of the Quaternary volcanic rocks and the refractive index of the rocks in which they occur.

Reverse zoning of orthopyroxene, in which the core is distinctly richer in iron than the rim, has been observed in several sections but most of the orthopyroxenes are nearly uniform in composition throughout. None has been observed which becomes markedly richer in iron from core to rim.

Amphibole.—Both green and brown hornblende are present in many dacites and are generally but not invariably accompanied by orthopyroxene.

Oxyhornblende occurs with normal hornblendes in a few rocks. Resorption rims are common on both hornblende and oxyhornblende and in many rocks the amphibole has become completely converted to a pseudomorph clouded with black opaque dust. In one specimen an aggregate of orthopyroxene, black opaque minerals, and plagioclase forms such a pseudomorph after amphibole. In many sections gradations can be found between black opaque pseudomorphs and a murky pyroxene.

The relationships of green and brown hornblende to one another and to oxyhornblende has been discussed by MacGregor (1938, p. 51-53) who suggests that the green hornblende, the typical form in deep seated magmas, is converted by 'auto-oxidation' to brown hornblende and oxyhornblende by loss of hydrogen (or water) under reduced confining pressure though at elevated temperatures. The black resorption rims and pseudomorphs of oxyhornblende, of brown hornblende, and, less commonly, of green hornblende, he likewise attributes (p. 54-5) to loss of confining pressure at high temperature.

Augite.—Augite is present in all basalts and andesites and in a few dacites but does not occur with amphibole. It generally forms glomeroporphyritic clusters of relatively small, twinned or untwinned grains. An ophitic texture occurs in one basalt flow.

The compositions of augites in the volcanic rocks, indicated diagrammatically in figure 6, are based on observations of refractive index of cleavage

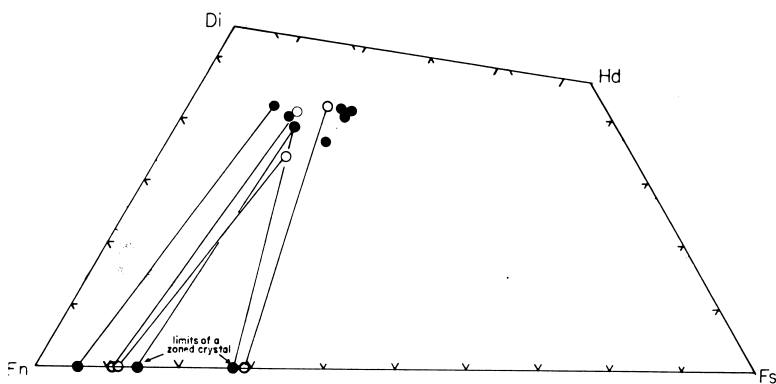


Fig. 6. Composition of augites and accompanying hypersthene of the Quaternary volcanic rocks. Solid circles: with accompanying olivine of composition Fo_{8-18} ; open circles: no accompanying olivine.

flakes together with universal stage measurements of 2V, using the optic data of Wager and Deer (1939). As indicated by Tomita (1934) and affirmed by Wager and Deer, the approximate value of the refractive index γ , used in the optic data, can be obtained by adding 0.004 to the maximum index of a grain resting on a cleavage face. Only a few of the grains in a powdered sample of augite are so oriented and only those showing a second cleavage perpendicular to the slide and inclined extinction can be used for the determination. To further simplify determinations, the angle of rotation necessary to bring the index of the grain into exact coincidence with the index of the immersion oil was measured. The maximum index of the section, γ' , was then evaluated, assuming the range of indices in that section (i.e. $\gamma' - \alpha'$) to be 0.020, the average value obtained by Tomita. A chart prepared by Emmons (1943, pl. 10) can be used to determine this maximum index given the range in indices (i.e. 0.020 in this case), the index of the oil, and the rotation.

Olivine.—Olivine occurs in basalts and andesites as large crystals, originally euhedral but now generally embayed and partly resorbed, it is not known in any dacites. It does not occur as a groundmass mineral in the more basic volcanic rocks. Its composition, as determined from universal stage measurements of 2V and the optic data quoted by Winchell (1933), is between Fo_8 and Fo_{18} .

CHEMICAL COMPOSITION

The chemical compositions of 16 samples from the rocks of the Garibaldi group are given in table 2. Variation diagrams, in which are indicated the relationships of silica content to the content of other oxides (fig. 7) and to normative minerals (fig. 8) are plotted from these analyses. A close relationship between refractive indices of fusion products of these rocks and their chemical analyses (Mathews, 1951) are also indicated (fig. 7). In the two variation diagrams, an almost complete sequence can be recognized between the basalts at one end and the dacites, if not the rhyodacite, at the other. Only a few anomalous analyses stand out, notably nos. 12 and 14 in which lime and magnesia contents are unusually high and alumina contents correspond-

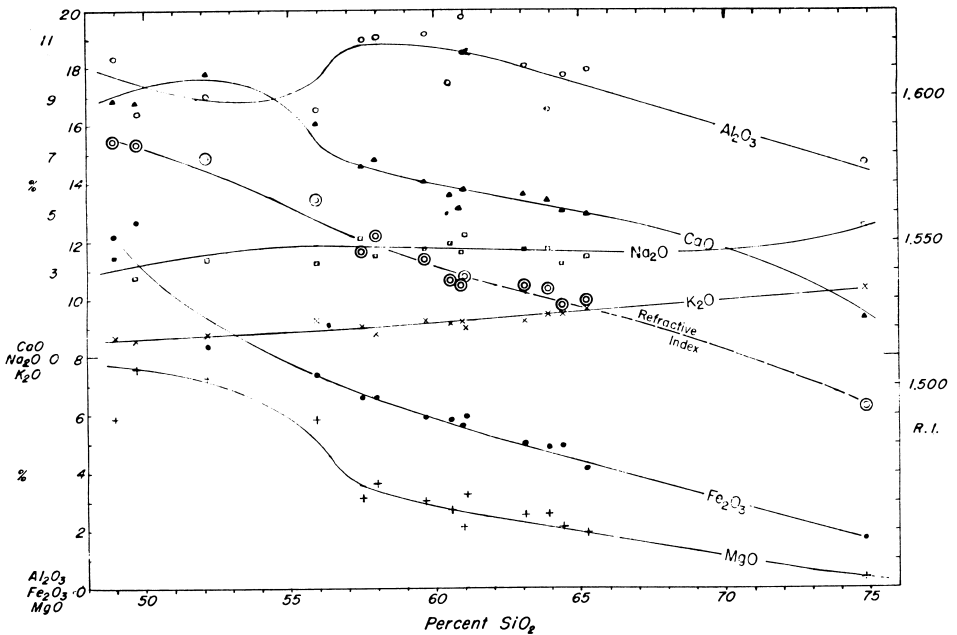


Fig. 7. Variation diagram for the Quaternary volcanic rocks.

ingly low, compared with rocks with similar silica contents. Though such a departure might be produced by accumulation of unusually great amounts of augite in the crystallizing magma and by the resulting displacement of feldspars, the two rocks in question are not exceptionally rich in augite phenocrysts, and if the magma did become overcharged with lime and magnesia by such an accumulation of augite crystals, these must have subsequently become remelted.

The main chemical characteristics of the Quaternary volcanic rocks of the map-area are the low contents of potash and iron and the high content of alumina and lime relative to the average igneous rocks of similar silica contents. The variation diagram for the Garibaldi extrusives shows a much closer correspondence to the diagrams for the volcanic rocks of the High Cascades (Williams, 1932), and of Lassen Peak, than to those for the lavas east of the Cascade Range (Williams, 1935). The high lime and low potash contents are reflected in the unusually high alkali-lime index (Peacock, 1931) of 64.0. In this and in many other respects, the variation curves for the Garibaldi volcanic rocks compare closely with those for the older plutonic rocks of the Mount Garibaldi map-area, the only significant differences being in the slightly higher alumina content and the slightly lower lime content of the later rocks.

ROCK CLASSIFICATION

Nomenclature of the volcanic rocks presents the usual difficulties. Mineralogical composition of the lavas, which is clearly influenced by cooling histories, fails as a reliable basis for classification. Free silica is present as

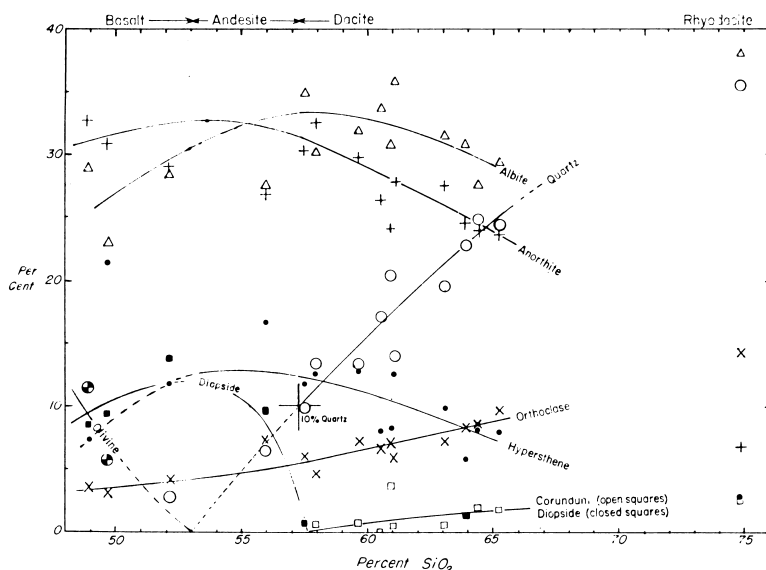


Fig. 8. Variation diagram for normative minerals of the Quaternary volcanic rocks.

crystalite in many of the holocrystalline rocks but hypocrySTALLINE rocks of similar bulk composition may contain no visible silica mineral. The central part of a single flow might, therefore, be classed as dacite on the basis of the cristobalite content, but the margin of the same flow might equally well be classed as andesite by the absence of visible silica mineral.

Plagioclases, both phenocrysts and microlites, show no close relationship to bulk composition. The MgO/FeO ratio of olivine and hypersthene similarly lacks close correlation with rock composition (fig. 5). Olivine crystals in a more or less advanced state of resorption are present in rocks containing normative quartz. Quartz crystals present in still more acid rocks were not in equilibrium with the magma in which they occurred judging from their augite coronas. The slavish use of any system of mineralogical classification would lead to confusion if applied to these rocks.

The normative rather than the modal composition provides a more consistent basis for classification, although here, too, difficulties arise. Oxidation of a basalt, for example, can alter the normative composition of the rock, giving rise to quartz and hematite in place of olivine and hypersthene. Cost limits the number of analyses than can be made. However, the refractive index of the glass formed by fusing rock samples (Mathews, 1951) offers a reasonably reliable, rapid, and inexpensive method of rock determination once the relationship between composition and refractive index has been established for the suite of rocks in question.

The classification of even those volcanic rocks for which chemical analyses are available is, however, not well established. It may be conceded that those rocks of calc-alkaline suites which are undersaturated, as shown by the presence of normative olivine, can be classed as basalts. For those rocks in

which normative olivine has been eliminated by oxidation of the iron, the distinction between basalt and andesite is not so clear, but composition in the unoxidized condition is probably significant. For the rock of the map-area, the boundary between andesite and basalt has been set on the variation curves at the point where the curves for normative quartz and normative olivine have the value zero, that is where silica content is 53 percent and refractive index of the fused rock is 1.575. The boundary between andesite and dacite has similarly been adopted at the point where the curve for normative quartz has a value of 10 percent, that is, where the silica content is 57.2 percent and the refractive index of the fused rock is 1.550. According to this usage, andesite and dacite are the approximate chemical equivalents of the diorite and quartz diorite of the plutonic sequence, in which modal and normative compositions show a fairly close correspondence. It should be noted, however, that many rocks hitherto described as hypersthene andesites would be dacites according to this classification. One of the analysed rocks can be considered a silica-rich rhyodacite, but rocks transitional between dacite and rhyodacite are not known in this suite and the boundary between these two types cannot be precisely defined in terms of silica content or refractive index.

ORIGIN OF THE MAGMAS

Two distinct modes of origin are suggested for the volcanic magmas of the map-area: (1) that they evolved by the differentiation of a single basaltic parent magma, or (2) that they were derived by the refusion of quartz diorites in the presence of a basic intrusive. Following the first hypothesis, the basalts of Daisy Lake (analyses 15 and 16) could represent the parent magma, and the more siliceous andesites, dacites, and rhyodacite could be its differentiates. In accord with this hypothesis is the almost continuous transition in rock types from basalt to dacite in the Garibaldi group as a whole, and the similarities in the basalt and andesite emitted from the Cinder Cone at about the same time (analyses 13 and 16). The anomalous lime and magnesia-rich lavas (analyses 12 and 14) might, as noted above, be explained by a somewhat involved process of concentration and refusion. The rhyodacite, which has an unusually high content of the albite molecule might have to be explained by a similar mechanism. On the other hand, favouring the concept of wholesale remelting of Mesozoic quartz diorites is the very close similarity in compositions between the old plutonic rocks and the dacites, and the widespread occurrence of coarse xenocrysts of quartz and feldspar. The intermediate lavas do not have the high Fe:Mg ratios so striking in fractionation products of some basaltic magmas, notably the Skaergaard intrusion (Tilley, 1950, p. 47-49). Instead, the suite shows the characters of the orogenic volcanic rocks (Tilley, 1950,

p. 49-59): a slight but continuous increase in the ratio $\frac{\text{FeO} + \text{Fe}_2\text{O}_3}{\text{MgO}}$ toward the acid rocks, a marked scatter of points in the variation diagram at the basaltic end, and a relatively high Al_2O_3 content in the basalts themselves. A worthy suggestion is that of Tilley's that the orogenic volcanic series originated by fractionation of a basaltic magma following contamination by silicic material.

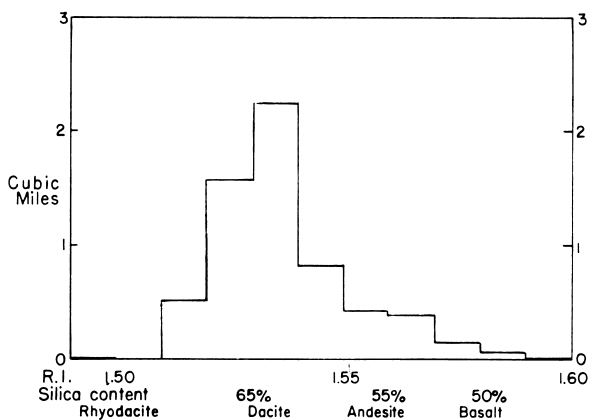


Fig. 9. Frequency diagram of acid to basic rocks of the Quaternary volcanics.

The distribution curve (fig. 9) showing the volumes of volcanic rocks of varying degrees of acidity in the map-area is not one of those which Richardson (1923) has derived on theoretical considerations for a suite formed by differentiation, syntexis, or magmatic mixing, unless a small volume of basic magma and a large volume of acid rocks or acid magma have been involved. The rocks erupted at the surface, however, probably do not provide a representative sample of the magmas developed at depth, for, other things being equal, more acid and less dense magmas would more likely be extruded. The distribution curve, skewed as it is toward the acid end, probably represents, therefore, the result of two or more processes:

- (1) differentiation of a basic magma modified by syntexis,
- and
- (2) selection during extrusion.

TABLE 2
Chemical analyses of Quaternary Volcanic rocks
of the Mount Garibaldi Map-area

	1	2	3	4	5
SiO ₂	74.84	65.24	64.40	63.94	63.08
Al ₂ O ₃	14.66	17.92	17.72	16.48	18.06
Fe ₂ O ₃	.37	1.28	1.61	3.38	1.62
FeO	1.21	2.57	2.99	1.29	3.06
TiO ₂	.12	.40	.60	.46	.58
MnO	.07	Trace	Trace	.23	Trace
CaO	1.36	4.92	5.04	5.38	5.63
MgO	.34	1.94	2.15	2.53	2.59
K ₂ O	2.38	1.65	1.48	1.42	1.22
Na ₂ O	4.49	3.46	3.26	3.64	3.72
H ₂ O, -105°C	Nil	.14	.12	.16	Nil
H ₂ O, +105°C	.25	.63	.24	.98	.08
CO ₂	Nil	Nil	Nil	Nil	Nil
P ₂ O ₅	Trace	.11	.16	.09	.07
	100.09	100.26	99.77	99.98	99.71
	Normative composition				
Quartz	35.38	24.33	24.80	22.67	19.55
Orthoclase	14.06	9.75	8.74	8.39	7.21
Albite	37.97	29.26	27.57	30.78	31.46
Anorthite	6.75	23.69	23.96	24.44	27.48
Corundum	2.22	1.76	1.98	—	.55
Diopside	—	—	—	1.29	—
Hypersthene	2.70	7.83	8.52	5.70	9.77
Olivine	—	—	—	—	—
Magnetite	.54	1.86	2.33	3.58	2.35
Hematite	—	—	—	.91	—
Ilmenite	.23	.76	1.14	.87	1.10
Apatite	Trace	.25	.37	.21	.16
H ₂ O+	.25	.63	.24	.98	.08
H ₂ O-	—	.14	.12	.16	—
Total	100.09	100.26	99.77	99.98	99.71
%An in plag.	14.3	43.4	45.0	42.8	45.0
%MgO in mafics	37.5	67.9	68.8	100.0	71.8
R. I. of fusion	1.4925	1.5295	1.5275	1.5315	1.5345

1. Devitrified rhyodacite, eastern base of Lava Peak

2. Dacite breccia, south face of Columnar Peak

3. Dacite flow, southwest end of Brohm Ridge

4. Dacite debris from glowing avalanche, Diamond Head

5. Dacite flow, Ring Creek lava, from Mamquam River near the terminus of the flow.

Analyses by W. H. Herdsman, Glasgow, Scotland.

TABLE 2 (Continued)
 Chemical analyses of Quaternary Volcanic rocks
 of the Mount Garibaldi Map-area

	6	7	8	9	10	11
SiO ₂	61.07	60.92	60.53	59.65	57.94	57.48
Al ₂ O ₃	18.46	19.74	17.42	19.14	19.07	18.97
Fe ₂ O ₃	1.90	2.32	2.82	1.51	2.58	2.31
FeO	3.63	2.98	2.73	3.97	3.64	3.88
TiO ₂	.56	.66	1.04	.76	.82	.90
MnO	.14	.18	.12	.14	.06	.16
CaO	5.78	5.14	5.60	6.12	6.83	6.62
MgO	3.22	2.13	2.74	3.05	3.66	3.18
K ₂ O	.99	1.20	1.13	1.24	.78	1.04
Na ₂ O	4.23	3.63	3.98	3.77	3.55	4.12
H ₂ O, -105°C	Nil	.24	.48	.03	.14	.12
H ₂ O, +105°C	.07	.83	.92	.56	.66	.76
CO ₂	Nil	Nil	Nil	Nil	Nil	Nil
P ₂ O ₅	.16	.22	.21	.09	.22	.28
	100.21	100.19	99.72	100.03	99.95	99.82
Normative composition						
Quartz	13.95	20.39	17.06	13.30	13.35	9.76
Orthoclase	5.85	7.09	6.68	7.32	4.61	6.14
Albite	35.77	30.70	33.65	31.88	30.02	34.84
Anorthite	27.62	24.06	26.33	29.78	32.44	30.21
Corundum	.31	3.66	—	.68	.50	—
Diopside	—	—	.06	—	—	.65
Hypersthene	12.45	8.10	7.99	12.64	12.42	11.63
Olivine	—	—	—	—	—	—
Magnetite	2.76	3.36	4.09	2.19	3.74	3.35
Hematite	—	—	—	—	—	—
Ilmenite	1.06	1.25	1.97	1.44	1.56	1.71
Apatite	.37	.51	.49	.21	.51	.65
H ₂ O+	.07	.83	.92	.56	.66	.76
H ₂ O-	—	.24	.48	.03	.14	.12
Total	100.21	100.19	99.72	100.03	99.95	99.82
%An in plag.	42.2	42.5	42.5	46.7	50.5	45.0
%MgO in mafics	100.0	71.3	88.3	66.3	78.3	72.1
R. I. of fusion	1.5375	1.5340	1.5365	1.5435	1.5520	1.5465

6. Dacite flow from Clunker Mountain, at The Barrier

7. Dacite dome (?) 0.8 miles northwest of Garibaldi Station

8. Dacite spine (?), The Castle, west of Squamish

9. Dacite flow, near summit of The Black Tusk

10. Dacite dike in breccia, altitude 2,800 feet, southwest slope of Round Mountain

11. Andesitic dacite, The Table.

Analyses by W. H. Herdsman, Glasgow, Scotland.

TABLE 2 (Continued)
 Chemical analyses of Quaternary Volcanic rocks
 of the Mount Garibaldi Map-area

	12	13	14	15	16
SiO ₂	55.97	54.62	52.16	49.68	48.92
Al ₂ O ₃	16.52	19.27	16.92	16.39	18.33
Fe ₂ O ₃	1.60	1.13	7.07	1.83	2.10
FeO	5.18	7.16	1.12	9.77	9.09
TiO ₂	1.02	1.12	.88	1.34	1.88
MnO	.14	.09	.24	.26	.25
CaO	8.06	6.96	9.78	8.84	8.92
MgO	5.82	4.93	7.24	7.62	5.87
K ₂ O	1.24	.64	.73	.54	.64
Na ₂ O	3.25	3.88	3.36	2.72	3.42
H ₂ O, -105°C	.14	.18	.12	.38	.13
H ₂ O, +105°C	.82	.10	.18	.52	.33
CO ₂	Nil	Nil	Nil	Nil	Nil
P ₂ O ₅	.16	.14	.28	.23	.18
	<u>99.92</u>	<u>100.22</u>	<u>100.08</u>	<u>100.12</u>	<u>100.06</u>
Normative composition					
Quartz	6.39	3.04	2.71	—	—
Orthoclase	7.32	3.78	4.31	3.19	3.78
Albite	27.48	32.81	28.41	23.00	28.92
Anorthite	26.84	33.28	28.94	30.92	32.78
Corundum	—	—	—	—	—
Diopside	9.77	.27	13.82	9.38	8.46
Hypersthene	16.53	22.66	11.62	21.38	7.24
Olivine	—	—	—	5.63	11.39
Magnetite	2.32	1.65	1.85	2.65	3.04
Hematite	—	—	5.80	—	—
Ilmenite	1.94	2.13	1.67	2.54	3.57
Apatite	.37	.32	.65	.38	.42
H ₂ O+	.82	.10	.18	.52	.33
H ₂ O-	.14	.18	.12	.38	.13
Total	99.92	100.22	100.08	100.12	100.06
%An in plag.	45.5	48.8	49.0	55.9	51.5
%MgO in mafics	73.8	60.5	100.0	62.9	61.0
R. I. of fusion	1.5640	1.5625	1.5775	1.5835	1.5845

12. Andesite, Eenostuck flow, Skookum Creek

13. Andesite bomb, The Cinder Cone

14. Oxidized 'basalt', altitude 2,600 feet, west slope of Round Mountain (buried valley of Mashiter Creek)

15. Basalt flow, west of Daisy Lake

16. Basalt flow, ½ mile northwest of The Cinder Cone.

Analyses by W. H. Herdsman, Glasgow, Scotland.

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