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BULLETIN 126

FELDSPAR AND QUARTZ PHENOCRYSTS IN THE SHINGLE CREEK PORPHYRY, BRITISH COLUMBIA

H. H. Bostock

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PREFACE

The study of an interesting complex of sanidine-plagioclase-quartz porphyries was undertaken by the author as a doctorate thesis problem for the University of Wisconsin. The thesis is the basis for this report.

The author presents some tentative conclusions on the nature and origin of the phenocrysts and, in the light of these conclusions, discusses the origin of the rocks themselves.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, December 3, 1963

BULLETIN 126 — Feldspat- und Quarz-Einsprenglinge im Porphyr von Shingle Creek in Britisch-Kolumbien.

Von H. H. Bostock

Dieser Bericht bringt einige vorläufige Schlüsse über das Wesen und den Ursprung der Einsprenglinge und behandelt den Ursprung der Gesteine selbst.

БЮЛЛЕТЕНЬ 126 — Вкрапленники полевого шпата и кварца в порфире Шингль Крик, в Британской Колумбии.

Г. Г. Босток

В работе предложены некоторые предварительные выводы о природе и происхождении вкрапленников, а также рассматривается происхождение самих горных пород.

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Abstract

The Shingle Creek porphyry is exposed within an area of some 4½ by 1½ miles immediately southwest of Penticton, British Columbia. It is intruded into a basement complex composed chiefly of andesine-rich granodiorite, and is bordered on the south by tuff and agglomerate that may form remnants of a volcanic cone. These rocks are in part overlapped by basic volcanic rocks of the Marron Formation.

The porphyry is coarsely porphyritic with sanidine, plagioclase, quartz, and minor mafic phenocrysts in a fine-grained matrix. It is differentiated into an earlier albite-bearing phase followed by an oligoclase-bearing phase. Plagioclase in the range An_8 to An_{19} is largely missing. The two plagioclase phases are essentially similar, except that the mean lime content is slightly higher in the oligoclase phase.

Petrographic and mineralogical features of the broad eastern part of the intrusion, herein called the 'neck', are compared with those of dykes to the north and west. Rock forming the dykes is chemically similar to that forming the neck. Regions of low phenocryst concentration are found in the albite phase of the neck and in the oligoclase phase of part of the dykes adjacent to the neck. Albite from the neck shows higher negative optic angles than albite from the dykes. No difference between optic angles of oligoclase from the two regions was demonstrated. Alpha refractive index measurements suggest that the range in plagioclase composition is much the same in both the dykes and the neck.

Large sanidine phenocrysts show oscillatory zoning with compositions chiefly in the range Or_{60} to Or_{80}. Oscillation photographs indicate that some crystals are unmixed and that crystals not unmixed have average optic angles less than 30 degrees. A thin-section fragment of a zoned sanidine heated for 20 minutes at 800°C retained its zoned texture; however, cryptoperthitic unmixing was homogenized by similar treatment. The lowest optic angles in sanidine are found in the neck.

Quartz phenocrysts show rounded to embayed outlines and are commonly surrounded by haloes of matrix quartz or chalcedony (?).

Résumé

Le porphyre de Shingle Creek qui affleure dans une aire mesurant 4½ sur 1½ mille se trouve juste au sud-ouest de Penticton (C.-B.). Il est injecté dans un complexe de base composé surtout de granodiorite riche en andésine, et sa bordure Sud est formée de tuf et d'agglomérat qui sont peut-être des vestiges d'un cône volcanique. Ces roches sont recouvertes en partie par des roches ignées basiques de la formation Marron.

Le porphyre est à grain grossier; il contient de la sanidine, du plagioclase, du quartz et un peu de phénocristaux de minéraux ferromagnésiens dans une gangue microgrenue. On le classe en deux faciès, le premier en date étant à

albite et le second, à oligoclase. Il n'y a guère de plagioclase dont la composition chimique varie de 8 à 19 p. 100 en anorthite. Les deux faciès à plagioclase sont presque identiques, mais la teneur moyenne en chaux du faciès à oligoclase est un peu supérieure.

L'auteur compare les caractères des roches et des minéraux du grand secteur Est de l'intrusion, qu'il appelle «neck», avec ceux des dykes situés au nord et à l'ouest. Il y a une ressemblance chimique entre la roche des dykes et celle du «neck». Il y a des secteurs contenant peu de phénocristaux dans le faciès à albite du «neck» et, près de ce dernier, dans le faciès à oligoclase d'une partie des dykes. L'albite présente dans le «neck» montre des angles optiques négatifs plus ouverts que ceux de l'albite des dykes. On n'a pas prouvé que les angles optiques de l'oligoclase des deux endroits diffèrent. Des mesures de l'indice de réfraction alpha portent à croire que la composition du plagioclase varie à peu près dans la même proportion dans les dykes comme dans le «neck».

De gros phénocristaux de sanidine montrent une structure zonaire oscillante et se composent le plus souvent de 60 à 80 p. 100 en orthose. D'après des photos prises par oscillation, certains cristaux sont purs (non mélangés) et leur angle optique moyen est inférieur à 30. Une partie d'une coupe mince de sanidine zonaire, chauffée pendant 20 minutes à 800°C, a conservé sa structure; cependant, on a homogénéisé de la même façon l'enchevêtrement de cryptoperthite. C'est dans le «neck» qu'on a trouvé les angles optiques les plus fermés dans la sanidine.

Les phénocristaux de quartz, dont les contours sont tantôt creux, sont le plus souvent entourés de halos de quartz ou de calcédoine (?) dans la gangue.

INTRODUCTION

Location and Accessibility

The Shingle Creek porphyry lies in the valley of Shingle Creek on the Penticton Indian Reserve, roughly 3 miles southwest of the Canadian Pacific Railway station at Penticton. It is exposed across an area of about 4½ miles (east to west) by 1½ miles (north to south); volcanic debris associated with it is exposed to the south and west. General disposition of the porphyry relative to the surrounding countryside and geological formations is shown on the map by H. S. Bostock (1941).

The area can be reached either by the north branch of Shingle Creek road from Penticton or by the south branch from Skaha wharf. These two branches join near the northeast corner of the intrusion and continue westward along the intrusion, up the bottom of Shingle Creek valley to Shatford Creek. The part of the porphyry south of Shingle Creek may be seen along a poor road that winds up onto the silt terraces west of the highway near Skaha wharf.

General Nature and Terminology

Though dyke-like in general outline, the porphyry is broadest within Okanagan Valley and tapers rather abruptly westward where it penetrates the west wall of the valley. The structure is further complicated by two closely similar petrological phases, each of which is present on both sides of the constriction. These phases are distinguished only by the presence of albite in the earlier and oligoclase in the later. Tuff, bearing the same minerals as the porphyry, and intercalated agglomerate are exposed in a belt to the south and west and may be remnants of an irregular volcanic cone.

For convenience, parts of the intrusion are named:

(1) *The north dyke*: the large dyke that extends westward along the north slopes above Shingle Creek and crosses to the south side of the valley at its western end.

(2) *The neck*: the broad part of the porphyry that extends from the east limit of outcrop westward to the promontory that restricts Shingle Creek valley where it passes into Okanagan Valley, but excluding the small dykes cutting lower Shingle Creek valley (*see* Inset, Map 1169A, *in pocket*). The remainder of the porphyry is referred to as *the dykes.*

(3) *Southeast contact canyon*: the sinuous canyon that follows the southeast contact of the intrusion (southwest contact of the neck).

Previous Geological Work

The areas of Tertiary rocks in southern British Columbia, of which the Shingle Creek porphyry is part, were first delineated by G. M. Dawson (1877). In 1928, H. S. Bostock (1941) mapped the area including the porphyry at a scale of 1 inch to 1 mile. R. F. Flint (1935), W. H. Mathews (1944), and others have published accounts of the Pleistocene and Recent deposits, and of the geomorphic features of Okanagan Valley. In his study of the etch reactions of alpha and beta quartz, V. Ben Meen (1934) used quartz phenocrysts from the "Quartz Porphyry at Penticton, B.C."

The study of the Shingle Creek area was suggested to the author by H. S. Bostock. A section across the north dyke and an area along southeast contact canyon were investigated as a Master's thesis problem for the University of British Columbia (H. H. Bostock, 1956).

Field Work

Field work was carried out during the summer of 1957 for the Geological Survey of Canada. Mapping was done by plane-table using a triangulated control and a datum level of 1,109 feet for the waterline at Skaha wharf. A base line of 9,700 feet was measured along the Canadian Pacific Railway bed in Okanagan Valley.

Physiography

Shingle Creek lies at the southeast end of the Interior Plateau, which forms part of the Interior System of British Columbia. The porphyry is contained entirely within Shingle Creek valley, one of many tributary valleys that deeply dissect the southern end of the Plateau. Relief within the area reaches a maximum of 3,400 feet, with the ridges north and south of Shingle Creek attaining an altitude of slightly more than 4,500 feet above sea-level.

Physiographically the area may be divided into (1) the mountain slopes; (2) the silt and gravel terraces; and (3) the Shingle Creek flood plain.

Mountain Slopes

From the ridge summits down to about 3,500 feet the mountain slopes are relatively gentle, but from that level down to about 2,000 feet, they are steeper. In this interval, talus is abundant, and numerous gullies dissect the glacial till. Below the 2,000-foot contour, bedrock is extensively covered with alluvium, silt, and till. Most of the larger gullies on the mountain slopes diminish in size or vanish entirely between the 1,800- and 2,000-foot levels.

Silt and Gravel Terraces

These deposits consist principally of fresh feldspathic rock flour, cream white to pale buff, with interbedded clay laminae near the bottom and some sand and gravel near the top, particularly along the course of Shingle Creek (Flint, 1935).

The author has observed gravel and till lying beneath some of the silt deposits in the lower valley of Shingle Creek. In the steeper parts of the valley, talus deposits may also underlie the silt. Fine laminations and crossbedding are common along the vertical silt bluffs in Okanagan Valley above and below the mouth of Shingle Creek. Silt and gravel benches are also well developed in the valley at the junction of Shatford and Shingle Creeks.

Shingle Creek Flood Plain

At their junction, Shatford and Shingle Creeks are sluggish streams meandering across a nearly flat flood plain 200 to 300 yards wide. Below the junction, the valley grade steepens and Shingle Creek flows between silt bluffs and fans in a gully 50 to 100 yards wide. At an elevation of about 1,350 feet, a mile west of Okanagan Valley, the creek is confined to a rock-walled gorge about 30 yards wide and reaches its maximum grade of about 1 in 10. Below this the grade diminishes and the flood plain gradually widens to its junction with Okanagan Valley.

Acknowledgments

The author wishes to express his appreciation to Professors R. M. Gates and S. W. Bailey of the University of Wisconsin for guidance and helpful suggestions; to members of the Geological Survey of Canada; and to Dr. John Moore of Carleton University, Ottawa, who critically read the manuscript.

Indians of the Penticton Reserve kindly permitted work on their land; and John C. Lamont of Chemainus, British Columbia, gave excellent assistance in the field.

GENERAL GEOLOGY

Consolidated rocks of the Shingle Creek area, which range from post-Triassic to early Tertiary, may be broadly divided into an older plutonic group and a younger essentially volcanic group. The plutonic group includes diorite, quartz diorite, granodiorite, and fine porphyritic to medium-grained granite. The volcanic group includes the Shingle Creek porphyry, a shallow intensely porphyritic intrusion of granitic composition; the Springbrook Formation, which, at Shingle Creek, is largely composed of tuff and agglomerate; and the Marron basic volcanic rocks.

Table of Formations

Era	Period	Formation	Lithology
Cenozoic	Pleistocene to Recent		Glacial till, silt, alluvium, talus
	Unconformity		
	Pre-late Eocene	Marron	Andesite, trachyandesite, basalt, agglomerate, tuff
		Springbrook	Tuff, agglomerate, breccia mudstone
		Shingle Creek porphyry	Granite porphyry
Intrusive contact			
Mesozoic	Post-Triassic		Fine porphyritic to medium-grained granite Granodiorite Diorite, quartz diorite

Post-Triassic Plutonic Rocks

Diorite

The diorite at Shingle Creek is a melanocratic, equigranular, medium-grained rock that is in contact with the Shingle Creek porphyry at its western extremity. Exposures are commonly iron stained, unlike those of the granodiorite and granitic rocks. Age relations between the diorite and other plutonic rocks in the area are not clear, except that diorite outcrops are cut by fine-grained granite dykes.

The proportions of minerals in the diorite vary considerably, and some specimens might better be classified as quartz diorites. The rock is, however, typically rich in plagioclase (An_{40} to An_{50}) and hornblende, with various amounts of biotite and chlorite, and minor epidote and quartz. Magnetite, apatite, and sphene are accessory minerals. Zoning in plagioclase, though present, tends to be fuzzy in contrast to that in the plagioclase of the granodiorite. Analyses and norms of two specimens are given in Table IX.

On the slopes north of Shingle Creek diorite and granodiorite are lithologically distinct, but south of the creek the two rocks are separated by a hybrid zone in which potash feldspar and quartz occur. Minor pyroxene, largely altered to blue-green amphibole, was observed in one specimen from this zone.

Granodiorite

The granodiorite is a leucocratic to mesocratic, slightly porphyritic, medium- to coarse-grained rock that forms the host rock for most of the Shingle Creek porphyry. Most outcrops weather to a coarse sugary surface and may be white or buff, in contrast to the diorite. The granodiorite is intruded locally by fine-grained granitic dykes.

The granodiorite is typically a plagioclase-rich (An_{20} to An_{40}) rock with a moderate quartz and microcline content, and minor but variable amounts of hornblende, biotite, and chlorite. Magnetite, sphene, apatite, and zircon are accessory minerals. Many plagioclase crystals are strongly zoned, the zones becoming more sodic in one or two major steps towards the crystal rim. A background of delicate oscillations is present between each step.

Variations in the granodiorite resemble those in the diorite, in so far as the granodorite is also more uniform north of Shingle Creek than it is to the south. On the lower slopes south of the creek immediately east of the hybrid zone, the granodiorite contains prominent log-like hornblende crystals and is somewhat more mafic than the rock north of the creek. This variation can be seen by comparing analyses 3 and 4, Table IX.

Fine-Grained Granite

South of Shingle Creek, both diorite and granodiorite have been intruded by fine-grained to slightly porphyritic pinkish granitic dykes. Fine- to medium-grained granite occurs along the south-central edge of the area mapped and also within the hybrid zone. The crosscutting relations shown by the granitic dykes indicate that these granitic rocks are the youngest phase of the plutonic group at Shingle Creek. Similar fine-grained granite in fragments and cobbles in the lower exposures of the volcanic debris associated with the Shingle Creek porphyry suggests that the granitic rocks are older than the Shingle Creek porphyry.

The granitic rocks consist essentially of microcline, quartz, and plagioclase (An_{19} to An_{23}), with minor magnetite and muscovite. Zircon and apatite were identified in thin section.

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The Hybrid Zone

This zone lies between the diorite and granodiorite south of Shingle Creek. Granitic dykes and patches of granitic rock are common within the zone; granitic dykes appear to be more abundant in its vicinity. The rocks of the hybrid zone vary from quartz diorite to granite, variations in texture and mafic content being particularly noticeable. Inclusions rich in biotite are present in some outcrops, and irregular biotite schlieren were observed in others. The wide variation in composition suggests that all three phases, diorite, granodiorite, and fine-grained granite, may have been involved in the formation of this zone.

The Shingle Creek Porphyry

From known exposures, the Shingle Creek porphyry intrusion is 1.5 miles wide at its broadest and some 4 miles long, with a subsidiary dyke extending about half a mile west of the main body. Further small bodies of porphyry may possibly exist in regions of rocks older than the porphyry that are not covered by the present map. Extensions of the Shingle Creek porphyry may occur beneath the Marron Formation to the south, but no evidence of such has been found.

The porphyry is roughly crescent-shaped, concave to the south, and contracts laterally towards the western tip. A roughly semicircular group of porphyry hills at the broad east end of the intrusion, in conjunction with the mountain side to the southwest, defines a prominent depression (*see* Pl. I) of unknown origin. Its south margin comprises, essentially, granodiorite in the west and porphyry in the east, both overlain by tuff and agglomerate of the Springbrook Formation. The lower parts of the intrusion in the east are thickly covered with silt, which conceals most

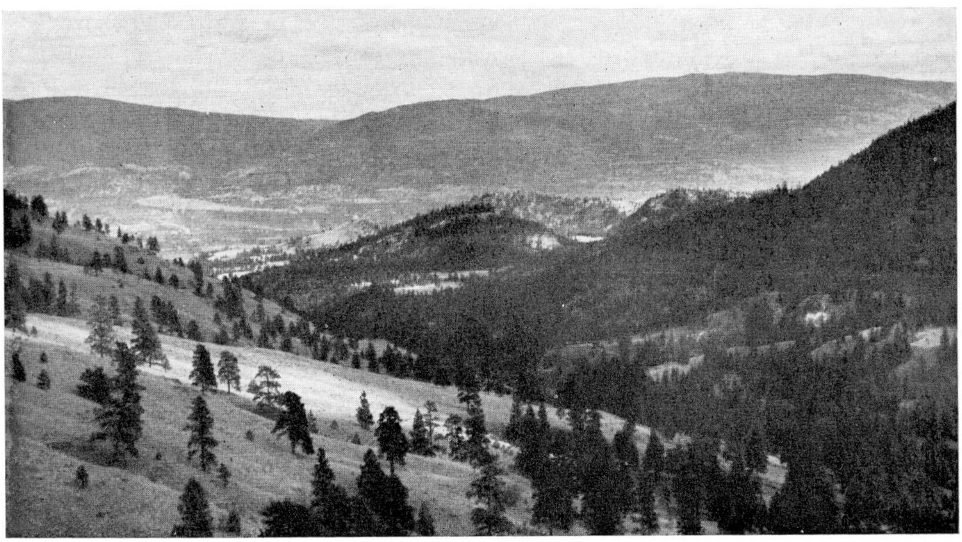

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PLATE I. Eastward from the north slopes above Shingle Creek towards the neck. The view shows the prominent semicircular group of hills (centre-right) with tuff and agglomerate forming the upper hillside on the right.

of the structural detail. To the west, the porphyry tapers, apparently splits into two main branches of dyke-like form, and penetrates the massive granodiorite along the west wall of Okanagan Valley.

The porphyry intrudes diorite and granodiorite of the post-Triassic plutonic complex. It cuts parts of the tuff and agglomerate deposits that border the neck and form part of the Springbrook Formation. This and the presence of fragments of large pink sanidine phenocrysts and embayed quartz crystals in parts of the Springbrook Formation, for which the only possible known source is the porphyry or its parent magma, suggest that the porphyry and the Springbrook Formation at Shingle Creek are essentially contemporaneous. However, if porphyritic rocks closely resembling the Shingle Creek porphyry but of different age are buried beneath the Marron Formation, the Shingle Creek porphyry may be younger than the Springbrook Formation. If so, the Shingle Creek porphyry must have been emplaced between deposition of the Springbrook Formation and the extrusion of the Marron basic volcanic rocks as dykes similar to the latter cut the porphyry. As the White Lake Formation, which overlies the Marron Formation some 5 miles south of the porphyry, contains plant fossils of probable Eocene age (H. S. Bostock, 1941), and the Springbrook Formation is considered Paleocene or Eocene, the Shingle Creek porphyry is also considered to be Paleocene or Eocene.

The porphyry is granitic, and contains euhedral sanidine phenocrysts up to 4 inches long in variable abundance. Also present are white to orange albite (An_1 to An_8) or oligoclase (An_{19} to An_{25}) phenocrysts up to half an inch long, grey rounded quartz bipyramids some as much as three quarters of an inch long, and a few smaller biotite, chlorite, and magnetite crystals. These are set in a red, pink, buff, grey, or greenish aphanitic matrix. Accessory minerals include zircon and sphene. Calcite is commonly found in tiny lenses and veins, and fluorite was identified in a single specimen from the east end of the isolated body of porphyry south of southeast contact canyon. Chalcedony was tentatively identified in fine-grained haloes about some quartz phenocrysts. An average analysis of porphyry specimens and the norm calculated from it are given in Table IX.

The Springbrook Formation

Associated with the Shingle Creek intrusion are tuff and agglomerate bodies that border the east end of the neck and extend southwestward as a belt of outcrops around the plutonic rocks into which the Shingle Creek dykes were intruded. These deposits form part of the Springbrook Formation (H. S. Bostock, 1941), an extensive assemblage of mixed sediments and volcanic rocks that lies here and there on the pre-Tertiary surface beneath the Marron volcanic rocks.

The Springbrook Formation is considered to be early Tertiary, perhaps Paleocene, on the basis of plant fossils found in Olalla map-area west of Shingle Creek (H. S. Bostock, 1941). Little (1961) included this formation and similar rocks to the east in the Paleocene or Eocene and reported that, although several plant collections have been made from these rocks, a definite age has not been established. An imprint of a segmented stem resembling that of a horsetail, *Equisitum,* was found in a specimen of tuff from southeast contact canyon, but it was not diagnostic.

The tuffaceous facies comprises the greater part of the Springbrook Formation at Shingle Creek. It is typically a sandy, grey-white, green, or buff rock consisting of fragments of quartz, plagioclase, and potash feldspar crystals set in a powdery to thoroughly coherent matrix. Some quartz fragments with embayed surfaces typical of quartz phenocrysts from the Shingle Creek porphyry were noted. Angular fragments of grey porphyry occur locally, and a few rounded pebbles or cobbles of plutonic rock may be found. Some specimens show shard-like structures. In thin section the matrix of non-bedded tuff is seen to be very finely crystalline, similar to the finer grained matrices in the porphyry itself. Some specimens show small patches of matrix with slightly coarser grain size surrounded by indistinct finer grained borders in which birefringence appears low. Quartz or feldspar phenocrysts or fragments are commonly partly or completely included within such patches. In addition, discrete fragments of porphyry made evident by darker colour may be present. Other specimens show fresh continuous matrices. Quartz fragments are chiefly angular and commonly delicately so. Sector-like fragments with one rounded edge, or complete rounded crystals also occur. Feldspar crystals appear to have been less severely fractured than quartz. The greater part of the tuffaceous facies is unbedded, but up to 200 feet of bedded silty to sandy, grey-green tuff is present directly below the Marron flows south of the southeast contact canyon. Bedded tuff and pebbly lenses, in which the pebbles are chiefly of plutonic rocks, occur locally south of the western dykes.

The agglomerate facies of the Springbrook Formation is composed of varying mixtures of pebbles, cobbles, boulders, and angular blocks, chiefly of plutonic lithology (*see* Pl. II). This material is embedded in an olive-brown, green, or grey sandy or fine-grained siliceous matrix that varies widely both in abundance and in coherence. In some exposures cobbles are so abundant that they touch one another; in others, they are separated by various amounts of matrix. Agglomerate exposures rarely show bedding but locally contain pebbly or silty lenses. A lens of bedded sand and silt 9 feet thick occurs in the agglomerate remnant at the lower end of southeast contact canyon.

In the bluffs at the southwest margin of the tuff and agglomerate deposits (outside the area mapped) plastically distorted fragments of plutonic rock were observed beside rounded but sound cobbles. Fractures in the rock encircle the cobbles but pass through the distorted fragments.

Structural Features

The tuff and agglomerate of the Springbrook Formation overlap the older plutonic rocks south of Shingle Creek and are overlain by the Marron flows. In part they apparently lie on an earlier phase of the Shingle Creek porphyry, but they are also intruded by porphyry dykes. In general they dip away from prominent porphyry exposures, but in detail their structural relations are diverse.

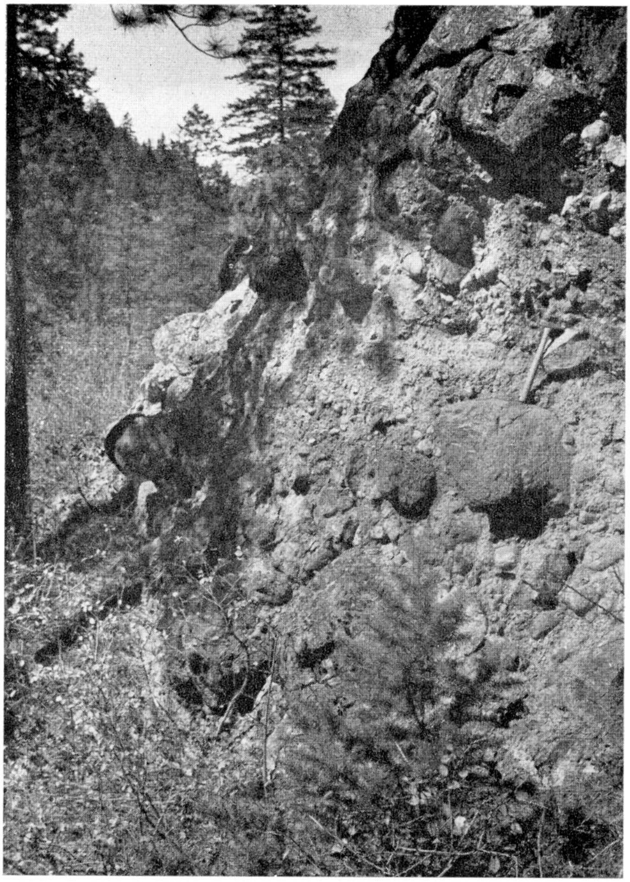

PLATE II. Agglomerate facies of Springbrook Formation along southeast contact canyon. Cobbles and boulders are rounded and vary greatly in size.

GSC 1-5-1957

Within the map-area, agglomerate is most prominent in the lower exposures overlooking Okanagan Valley, in the lower walls of southeast contact canyon, and along the unconformity between the granodiorite and the Springbrook Formation. Tuff is most prominent in higher exposures, except that tuff and pebbly agglomerate are predominant in the outlier low on the eastern margin of the porphyry. Immediately beneath the Marron flows, bedded tuff on the upper slopes interfingers downward and eastward with agglomerate. Graded bedding is well developed in the interfingered zone. Along the lower walls of southeast contact canyon, small bodies of agglomerate lie on and against the Shingle Creek porphyry, and at one place along the north wall an agglomerate body is engulfed in the porphyry. Near the head of the canyon, agglomerate along the north wall lies on a tuff surface that dips southward and eastward into the canyon at 40 to 50 degrees. At the upper rim along the south wall, small remnants of agglomerate lie on a tuff surface that dips northward into the canyon. West of the canyon, agglomerate appears in a poorly exposed belt probably less than 100 feet thick that lies on the granodiorite at the base of a tuff section some hundreds of feet thick.

Tuff and agglomerate are well exposed on the west- and southwest-facing slopes east of Shatford Creek. There bluffs several hundred feet high are composed of agglomerate with a prominent tuff bed that dips westward away from the porphyry at 25 degrees. This agglomerate is peculiar in that it contains distorted fragments of older rocks intermixed with granodiorite and some granite cobbles. Slightly farther to the southeast massive and bedded tuffs are present, the latter dipping from 25° to 35°SW. Locally bedding is interrupted by irregular masses of agglomerate.

Discussion

The mode of origin of the Springbrook Formation is of particular interest in considering the conditions of emplacement of the Shingle Creek porphyry. It is, therefore, unfortunate that a complete detailed examination of this formation at Shingle Creek was not possible, and that the author was unable to visit the more distant exposures to the south and west.

H. S. Bostock (1941) described the Springbrook Formation as follows:

> It is composed of soils, alluvium, talus, stream and lake deposits and tuffaceous materials that accumulated in the valleys before and during the earlier intrusions of the Marron volcanic rocks. Where the Springbrook Formation is thick, the basal beds are of conglomerate containing large angular boulders. These beds grade upward into conglomerates composed of smaller, more rounded and better sorted materials. Uppermost strata include beds of polished pebbles, tuffaceous sandstones and silts. In the adjoining Olalla map-area these beds contain plants of early Tertiary, perhaps Paleocene age.

However with regards to the Shingle Creek area he stated:

> Pink granite porphyry containing large well-formed pink crystals of orthoclase feldspar in a fine-grained porphyritic groundmass, forms a number of dykes along Shingle Creek valley. To the southeast are outcrops of white or greenish rocks containing similar, large orthoclase crystals but showing in places structures typical of flow rocks. A body of such rock is exposed in cliffs lying between conglomerate beds of the Springbrook Formation. A few miles farther west white tuffaceous material of similar appearance to the flows and containing large fragments of feldspar is stratified with this formation. Fine white tuff that occurs in places in the upper part of the Springbrook Formation is thought also to have its source in a volcanic centre located near the east end of the granite porphyry area.

There is, therefore, some suggestion that tuffaceous materials are most extensively exposed at Shingle Creek and are present in the more remote areas, chiefly towards the tops of the more complete sections, as sandstones and silts.

The tuff at Shingle Creek is composed largely of minerals similar in composition to those of the Shingle Creek porphyry. Large mineral fragments correspond to the porphyry phenocrysts, and the matrix seen in thin section, though very fine grained, appears similar to that of the porphyry. The presence of vermicular embayments in some quartz fragments relates them unequivocally to acid porphyry rocks. Furthermore, angular fragments of porphyry similar (especially in content of unusually large potash feldspar crystals) to the Shingle Creek porphyry may be found in the tuff. There is, therefore, little doubt that the tuff at Shingle Creek was derived largely from an acid porphyry body, either the Shingle Creek porphyry itself or some very similar body not very far distant but now covered by the Marron volcanic rocks. Such a body would probably represent a southward continuation of the Shingle Creek porphyry or a distinct older body.

The delicately angular condition of many quartz fragments, the fragmental to euhedral or slightly rounded texture of other crystals, and, the common presence of small porphyry fragments in a matrix similar to that of the porphyry strongly support the conclusion that the rocks in which they occur are tuffs. To this may be added some argument from the limited structural data. The upper bedded tuff directly beneath the Marron flows in the area mapped strikes nearly east-west and dips at 30° to 40°S. Thence westward the Springbrook Formation extends as a band of outcrops between the older plutonic rocks to the north and the Marron flows to the south as far as Shatford Creek where it dips 25° to 35°SW and bends northward. Though some faulting may have occurred in this area since the Mesozoic, it is unlikely that the dips found at these two localities and implied in the rocks between them could have been reversed. Derivation of the Springbrook Formation by normal processes of erosion and deposition from porphyry rocks to the south therefore seems unlikely.

Crosscutting relations show that the Shingle Creek porphyry is, at least in part, younger than the tuff which, under a simple hypothesis of erosion and deposition, would imply that the porphyry reached the early Tertiary surface and formed an extensive exposure able to supply large quantities of detritus during its active life. However, the absence of porphyry talus, as opposed to isolated fragments, in the tuff close to the intrusion argues against the existence of any extensive porphyry promontory during the active life of the intrusion but would be consistent with a vent origin of the tuff. At the same time the presence of a bedded sand-silt lens in the agglomerate and pebble lenses in which the pebbles are predominantly of older plutonic rocks in the tuff, suggests that processes of sedimentation have also contributed to the development of the Springbrook Formation at Shingle Creek.

Though the origin of the tuff as volcanic ash may be considered established, it is impossible to deny that a major part of the tuff may have been derived from vents, associated either with southward extensions of the Shingle Creek porphyry or with a distinct older porphyry body, the sites of which lie concealed beneath the Marron Formation. Nevertheless, it should be pointed out that there is no positive evidence of porphyry bodies immediately south of those mapped, and that there is some evidence suggesting that the Shingle Creek porphyry did penetrate the early Tertiary surface (*see* section on *Depth of Burial*). Further examination of structures within the Springbrook Formation may be necessary to unequivocally settle this question.

From existing evidence and assuming the source of the tuff to be in a vent associated with present exposures of the Shingle Creek porphyry, a hypothetical set of conditions governing the development of the tuff and agglomerate at Shingle Creek may be suggested. It has been noted that the known beds in the Springbrook Formation, where it is more remote from porphyry contacts, dip southward in the east and southwestward in the west at angles approximating the maximum angle of repose in unconsolidated materials. Hence, because of the predominantly tuffaceous origin of the rocks concerned, it is suggested that the Springbrook Formation at

Shingle Creek represents the remnants of an irregular volcanic cone. The general slope of the plutonic rock surface about Shingle Creek is southward and, if the same slope was present in the early Tertiary, it is likely that tuff deposits north of Shingle Creek were thinner and have been entirely eroded. The same feature would suggest that rock detritus from the mountains to the north and west of the Shingle Creek intrusion may have been transported southward during the early Tertiary. It therefore seems possible that considerable quantities of diorite and granodiorite boulders rounded by stream erosion could have been brought into the area above and immediately north of the Shingle Creek vent. Such boulders may have been conducted in part along gullies at the margins of the cone or, if volcanic disturbance is considered to have caused slumping of northern sections of the cone into the vent, they may have been contributed directly into the mouth of the vent. Accumulation of boulders in the vent might result, during subsequent eruptions, in an intimate intermixture of effervescent lava, pebbles, cobbles, boulders, and blocks of plutonic rocks, and plasticized fragments of plutonic rock torn from the walls of the volcanic conduit at depth. At times such masses may have been erupted as glowing avalanches (Williams, 1941). The abrasive character of such avalanches may account in part for the highly rounded surfaces of boulders in some parts of the agglomerate. At times pebbles, cobbles, and boulders may have been blown out of the vent with ash eruptions or simply spilled out of the vent into gullies following fissures in the sides of the cone. The inward dips at the basal surfaces of the rather poorly consolidated agglomerate remnants along the southeast contact canyon suggest such an origin.

The Marron Formation

The basic flows and pyroclastic rocks of the Marron Formation overlie the Springbrook Formation at Shingle Creek, and extend as a blanket over the country to the south and west of the map-area (*see* Pl. III). They have been described by H. S. Bostock (1941) as follows:

> The volcanic rocks of the Marron Formation were extruded over hills of pre-Tertiary rocks and into valleys partly filled by the Springbrook Formation. They filled these valleys and accumulated to a thickness of over 4,000 feet and are believed to have covered all parts of the map-area. The formation consists mainly of lava flows 10 to 200 feet thick, but in places there are large masses of agglomerate. In the northeastern part of the map-area the lower flows are highly feldspathic. To the northwest some fine-grained acid types were observed. In places, notably northwest of White Lake, there are thin interbeds of conglomerate, sandstone and soil.

Though no fossils have been reported in the Marron Formation, its age is fairly well known from plant fossils found in the underlying Springbrook Formation and in the overlying White Lake Formation, which is exposed some 5 miles south of the Shingle Creek porphyry. As the former is Paleocene or Eocene (Little, 1961) and the latter probably Eocene (H. S. Bostock, 1941), the Marron Formation at Shingle Creek is probably Paleocene or Eocene.

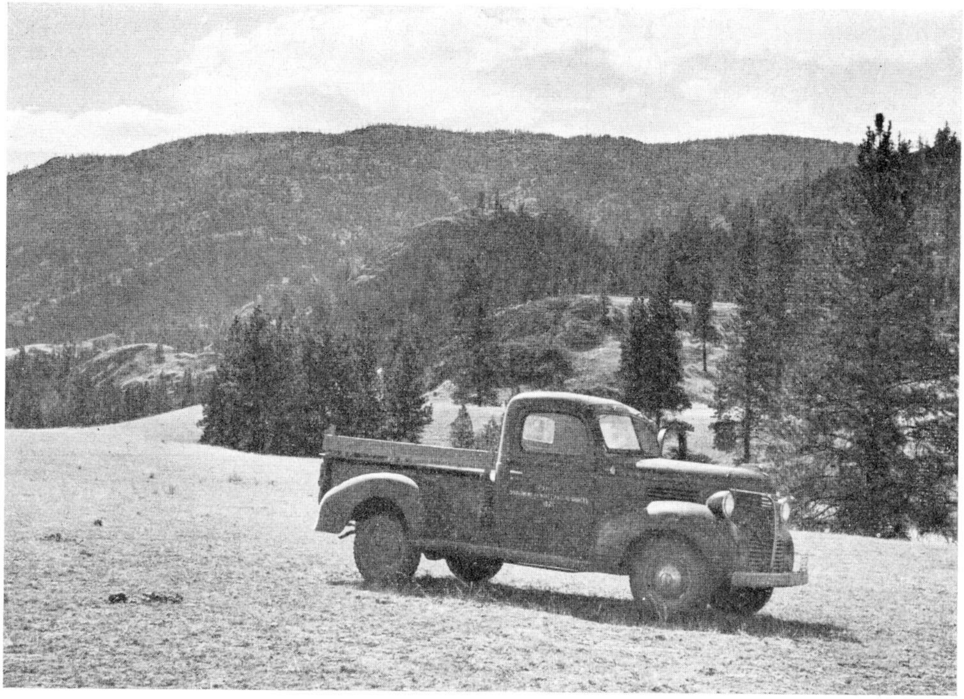

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PLATE III. Southward from the silt flats at the southeast edge of the porphyry. Agglomerate forms a prominent rounded nose in foreground. Directly behind this, a dark andesite knob overlies trachyandesite. Marron flows higher in the section are visible in the background.

The Trachyandesite Flows

At Shingle Creek the uppermost bedded rhyolitic tuffs of the Springbrook Formation are overlain in places by a pink and green mottled feldspathic tuff, which is in turn overlain by extensive but perhaps discontinuous feldspathic flows. These flows contain phenocrysts of feldspar as much as 3 cm long that vary in abundance up to about 20 per cent of the rock. Augite phenocrysts up to 1 cm long, in variable but lesser amounts, are present and locally a distinctive deep orange-brown biotite is abundant. Grey-brown apatite euhedra and some magnetite may also be identified in hand specimens. The phenocrysts occur in a reddish grey to greenish brown, fine-grained matrix, which may be microlitic or equant but is distinctly feldspathic. In many outcrops this rock can be recognized by its vesicular or amygdaloidal texture, some vesicles reaching several centimetres in diameter. The chemical composition and norm of a single specimen are given in Table IX.

The feldspar phenocrysts of the feldspathic flows commonly show a pinkish alteration and in some specimens can be seen partly altered to analcite. Crystals seen in thin section showed no polysynthetic twinning. As suggested by a partial analysis for potassium using the X-ray fluorescence method, the orthoclase content is approximately 20 per cent, and the feldspar is considered to be anorthoclase.

Zeolites are common in amygdules and as linings on the walls of vesicles. Analcite, thomsonite, and heulandite have been identified. Calcite and epidote are common.

The Andesite Flows

Above the trachyandesite is a series of andesitic flows and agglomerate beds, probably more than 3,000 feet thick, in the bluffs overlooking Skaha Lake. These flows and beds vary in colour from black or dark blue-grey to greenish grey or olive-green. They differ in colour from the trachyandesite and generally contain smaller phenocrysts. Vesicles are not as common; biotite is rare.

In thin section plagioclase is seen to reach a calcic maximum about An_{50} and is commonly zoned to sodic andesine or calcic oligoclase. Plagioclase in the matrix is commonly microlitic. Augite phenocrysts are present in most specimens.

Three specimens of andesite from the flows immediately southeast of the porphyry have been analyzed by the rapid methods. The results together with the calculated norms are given in Table IX.

Basic Dykes

Aphanitic to porphyritic buff, red-brown, dark olive, and blue-grey dykes cut the porphyry and the Springbrook Formation. Within the area mapped, these dykes do not stray far into the older plutonic rocks. In the Marron Formation itself they are difficult to recognize but are most apparent cutting agglomerate beds.

The darker dykes are similar in appearance to many of the Marron flows but the red and buff coloured dykes have no counterparts. For the most part the red and buff dykes are thoroughly weathered, but a fresh specimen, obtained from a buff dyke cutting the west end of the north dyke, shows andesine (An_{40-44}) phenocrysts up to 1.5 mm long in an aphanitic feldspathic matrix.

THE SHINGLE CREEK PORPHYRY

Laboratory Methods

Optical Procedures

The minerals described herein were determined chiefly by Becke line refractive index methods. Variations in plagioclase composition were estimated from alpha refractive indices obtained by the double variation method (Emmons, 1943) wherever the state of alteration of the crystals would permit. Individual measurements are believed to have an accuracy of ± 0.0005. On altered plagioclase crystals Becke line observations were made in white light to distinguish albite and oligoclase. Such measurements were used to complete the map of the porphyry but not in statistical comparison of plagioclase compositions.

Optic angles of feldspar (2V alpha) from the Shingle Creek porphyry were determined in thin section using the five axis universal stage. Optic angle measurements on plagioclase were corrected to the nearest degree using the correction curves of Tröger (1952), and individual measurements are considered accurate to ± 2 degrees. Optic angles of sanidine were measured in special thin sections ground to approximately 0.1 mm thickness. This procedure increased the definition of zone patterns and extinction positions. For each sanidine crystal the average optic angle was estimated from the broader more even areas between zone maxima and minima (*see* Pl. VI) in fields at the core and rim of the crystal. Individual measurements are reproducible to ± 2 degrees. No corrections were made, as both axes could be reached with rotations less than 25 degrees.

X-Ray Procedures

Powder diffraction records of the $\bar{2}01$ peak were recorded for sanidine using a 1 degree slit and a scanning speed of $\frac{1}{8}$ degree per minute. Single crystal *b*-axis oscillation photographs were taken of sanidine cleavage fragments with cleavages oriented parallel with the X-ray beam at the centre of a 15-degree oscillation arc. The desired cleavage fragments were broken from the uncovered oriented thin sections after immersing the desired area in a drop of acetone to prevent the ejection and loss of the fragment.

Chemical Analyses

Analyses were made in the laboratories of the Geological Survey. The country rock analyses and fifteen of the sixteen analyses of rocks from the Shingle Creek porphyry were made by the rapid methods, the remaining one was made by the classical wet chemical method. No greater accuracy can be assigned to the latter method, however, because of the sampling error to which it is subject. Approximate limits of error arising from the rapid method analyses of the specimens from the porphyry are believed to be:

SiO_2	± 0.5
Al_2O_3	± 0.5
Fe_2O_3	± 0.1
FeO	± 0.05
CaO	± 0.2
MgO	± 0.2
Na_2O	± 0.1
K_2O	± 0.1
TiO_2	± 0.05
MnO	± 0.02
P_2O_5	± 0.02

(NOTE: Uncertainty values vary with concentration except for SiO_2 and Al_2O_3)

Because of the large size of sanidine phenocrysts and the limited size of rock specimens (3 to 12 cubic inches), it was considered that analyses would be more comparable if all sanidine phenocrysts larger than the quartz and plagioclase phenocrysts were excluded. The specimens were, therefore, crushed and the large sanidine crystals excluded manually. The shortcomings of this procedure were not at first fully appreciated; however, an attempt has been made to allow for these in the conclusions drawn.

Samples from four of the least altered sanidine crystals from the oligoclase phase in the dykes were analyzed for Ba, Sr, Rb, and Ca. Na and K were also determined in one crystal. Biotite and chlorite inclusions in each sample were removed prior to analysis by passing the powdered specimens through a Franz isodynamic separator.

Modal Analyses

Modal analyses to determine the proportions of the smaller phenocrysts and matrix in specimens from the Shingle Creek porphyry were made on slabs cut in such a way that the two sides yielded a combined flat surface of about 40 sq cm. These surfaces were etched with hydrofluoric acid and stained with sodium cobaltinitrate to sharpen the contrast between feldspar phenocrysts and matrix. A quarter centimetre grid was laid out on each surface and counts made of the matrix and main phenocrysts. The latter were divided into four groups: quartz, plagioclase, mafic minerals, and sanidine (maximum intercept counted less than 1 cm). Intercepts on plagioclase crystals seen were all less than 1 cm, but several quartz crystals showed maximum intercepts of this order. Specimens were cut so that sanidine crystals more than 1 cm across would be few and those that were encountered were omitted from the counts. A minimum of 700 points were counted for each specimen.

Petrography

Definition and Structural Relations of Rock Variations

The megascopic petrography of the Shingle Creek porphyry is broadly uniform except that the rock colour and the abundance of large sanidine phenocrysts vary. Neither of these features proved to be a successful basis for field mapping, but their general distribution is described in this section. Variations in size of quartz and plagioclase phenocrysts are generally small compared with those of sanidine. However, a small area of porphyry in which all phenocrysts are unusually small is present on the southwest face of the small hill north of the depression in the neck. More detailed data on plagioclase phenocrysts suggest that the porphyry may be divided fundamentally into an earlier albite-bearing phase and a later oligoclase-bearing phase. These are not generally recognizable in the field but can be differentiated in the laboratory. The similarity of the two phases in the field has made mapping somewhat interpretative, particularly at the west end of the north dyke where the phases are interspersed. The disposition of the two phases is shown on the main map.

Albite and Oligoclase Porphyry

The contacts between the albite and oligoclase phases of the porphyry were not identified in the field, except where they appeared to coincide with changes in the abundance of large sanidine crystals. Jointing or alteration of the rock in the immediate vicinity of such internal contacts does not seem to have occurred and the present topography shows no apparent relation to them. These phenomena suggest that the two phases were very closely associated in time. However, two features suggest that the albite phase slightly preceded the oligoclase phase:

(1) The albite phenocrysts are in general more altered than the oligoclase phenocrysts, and altered albite cores were identified in one specimen from the oligoclase phase in the neck area.

(2) The disposition of the oligoclase and albite phases with respect to one another and the presence of granodiorite inclusions only in the albite-bearing rocks at the east end of the north dyke are consistent with this hypothesis. At this locality the albite phase occurs along the edges of the dyke, and it is hard to conceive how the albite phase could have plucked large granodiorite inclusions from the walls without apparently penetrating the oligoclase phase if the latter were the earlier.

The oligoclase phase is preponderant in the dykes and is most extensively exposed at their eastern end. In the north dyke it occupies the conduit set up by the albite phase, bodies of which persist as remnants along the walls, as truncated offshoots, or as inclusions in the oligoclase phase. To the east, the oligoclase phase intrudes the albite-bearing neck as a dyke-like body that curls sharply to the south and west, and eventually terminates against agglomerate and albite porphyry on the northeast wall of the upper southeast contact canyon. About 3,000 feet farther to the southwest, oligoclase porphyry is exposed within the tuffaceous member of the volcanic cone. There, oligoclase porphyry outcrops form part of a poorly exposed belt that stretches along the hillside to the west and may represent an oligoclase porphyry flow. However, no structures to confirm this hypothesis could be found. Fluorite was identified in a specimen from the east end of this belt.

Distribution of Large Sanidine Phenocrysts

The distribution of large sanidine phenocrysts within the intrusion is not uniform and their concentration ranges from below 1 per cent to a maximum of between 15 and 20 per cent. The latter estimate is based on a point count made from a photograph of an ice-polished surface considered to contain one of the greatest concentrations of these crystals.

Large sanidine crystals are most plentiful in the albite phase along the margins of the north dyke in its east and central regions. There the concentration approaches 15 to 20 per cent. The albite phase in this part of the north dyke is in marked contrast with the oligoclase phase in which more than two or three large crystals are rarely seen in one outcrop. At the west end of the north dyke the abundance of large crystals is intermediate and the distinction between the two phases could not be made on this basis. Large sanidine phenocrysts are abundant in the oligoclase dykes south of Shingle Creek, in parts of the oligoclase neck, and in the albite phase in the western and south-central parts of the neck, but they appear to be relatively scarce in the greater part of the albite-bearing neck, including the bluffs above Penticton. Very few large sanidine crystals were found in the southeast corner of the intrusion except in the lowest and most eastern outcrops where the abundance may be intermediate.

Distribution of Matrix Colours

Rocks of the albite phase are mostly red to pink but a green variation exists along parts of southeast contact canyon. Only rarely are grey matrices found in the albite phase. South of Shingle Creek, rocks of the oligoclase phase are chiefly grey, but in the north dyke they are red to pink, and in the neck they vary from grey through pink to red.

Statistical Comparisons of Rock Variations

An attempt is made here to compare the albite and oligoclase phases on the basis of chemical composition and of differences in abundance of phenocrysts. The data are also broken down to compare the environment of the neck with that of the dykes. For each parameter the mean value for each group has been calculated and the results compared using Student's "t" test (Moroney, 1956).

The chemical results tend to confirm the similarity of the albite and oligoclase phases with respect to most of the oxides reported, but suggest statistically that the oligoclase-bearing magma contained slightly more lime than the albite-bearing magma. Modal analyses for thirteen specimens suggest that the proportion by volume of phenocrysts in the albite and oligoclase phases is similar, but indicate a higher proportion of phenocrysts in the dykes than in the neck. Since large sanidine phenocrysts were excluded from these analyses, differences in modal analyses may result largely from the greater abundance of large sanidine phenocrysts in the dykes than in the neck.

The data suggest that the volumetric proportion of sanidine phenocrysts to other phenocrysts is greatest where field observations indicate that large sanidine phenocrysts are most abundant. The volumetric proportion of quartz to plagioclase phenocrysts, however, remains roughly constant in eleven of thirteen specimens examined.

Chemical Composition

Analyses of sixteen specimens from the Shingle Creek porphyry are presented in Table I. The sample locations are shown on Figure 1.

In order to estimate the effect of excluding the large sanidine crystals on the proportions of the remaining oxides, the effect of subtracting 20 per cent by weight of ideal sanidine, Or_{75}-Ab_{25}, has been calculated for specimen 11. This specimen is from an outcrop with very few large sanidine crystals and none was removed from the specimen before analysis. The data represent the maximum effects to be expected.

An approximate comparison between analyses of rocks containing abundant large sanidine phenocrysts with those containing very few was attempted by adding the equivalent of 10 per cent of sanidine (Or_{65}-Ab_{35}) to each analysis of the former group, except number 15 from which no large crystals were removed, and recalculating to 100 per cent. Ten per cent of large sanidine crystals was considered the best estimate here possible for the samples concerned. None of the major oxides, however, showed differences significant at the 5 per cent level.

The analyses have been grouped to compare the major oxides of analyses of the neck with those from the dykes, and also of the albite phase and of the oligoclase phase. In each case sufficient lime has been subtracted from the analyses to combine with the CO_2 to form calcite. The data are presented in Tables X and XI to show the means and standard deviations for each group together with an estimate of the statistical significance of the difference in the means.

Comparison of the neck and dyke specimens fails to reveal any significant difference in composition between these two parts of the porphyry. Comparison of the albite and oligoclase phases, however, indicates that the lime content of the latter may average 0.5 per cent higher than that of the former. Calculation indicates that this difference approaches the 2 per cent probability level.

From Table XI it will be noted that the means for all the basic oxides are slightly higher in the oligoclase phase than in the albite phase, though the significance for all but that of calcium was well below the 5 per cent level. As more sanidine may have been removed from the oligoclase phase than from the albite phase these differences should be disregarded. However, as the percentage error introduced by sanidine exclusion is the same for each of the basic oxides, the very distinctly higher value for that of calcium in the oligoclase phase is considered significant. The data therefore suggest that the formation of oligoclase rather than of albite in the oligoclase phase resulted from there being a slightly higher lime content.

Table I

Analyses of the Shingle Creek Porphyry[1]

	Albite Phase							Oligoclase Phase								
	Neck				Dykes			Neck				Dykes			Mixed Rocks	
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
SiO_2	72.0	70.8	72.4	71.0	73.7	71.00	70.5	71.2	72.0	72.1	68.7	68.3	70.6	71.7	69.3	70.5
Al_2O_3	13.9	14.9	14.9	14.8	14.4	14.55	15.3	14.7	15.3	14.8	15.3	14.6	15.0	15.0	14.4	14.5
Fe_2O_3	1.3	0.9	1.1	1.0	1.1	0.75	1.2	1.1	1.1	1.1	1.3	1.3	1.1	1.1	1.2	1.4
FeO	0.37	0.61	0.58	0.65	0.47	0.65	0.43	0.43	0.50	0.50	0.86	0.79	0.58	0.56	0.76	0.58
CaO	1.2	1.6	0.9	0.8	0.5	1.84	1.2	1.6	1.0	0.9	1.6	2.9	1.8	1.7	1.6	2.2
MgO	0.8	0.6	0.6	0.8	0.7	0.35	0.8	0.4	1.3	1.1	1.3	1.3	0.6	0.5	0.9	0.5
Na_2O	4.7	3.8	4.9	4.0	3.4	4.02	3.7	4.2	4.2	3.9	4.1	3.8	4.2	4.6	3.3	3.7
K_2O	4.1	4.4	3.9	4.6	4.6	3.84	4.7	4.4	4.3	4.2	4.9	4.1	3.7	3.7	4.2	4.1
H_2O^+						1.02	0.65				1.00	0.82	0.65	0.35		
H_2O^-	1.00	0.80	0.91	1.00	1.30	0.26		1.30	1.05	0.80					1.60	1.40
TiO_2	0.4	0.3	0.3	0.4	0.3	0.34	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.4	0.4	0.3
P_2O_5	0.1	0.1	0.1	0.1	0.1	0.14	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MnO	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
CO_2	0.42	0.34	0.50	0.25	0.31	1.12	0.16	0.05	0.01	0.03	0.07	1.48	0.38	0.19	0.92	1.16
Total	100.3	99.2	101.1	99.4	100.9	99.90	99.0	99.8	101.3	99.8	99.6	99.8	99.1	99.9	98.7	100.4

[1]All analyses except number 15, which was done by the classic long method, were done by the rapid methods. Sanidine phenocrysts larger than 1 cm, except in number 15, were removed prior to analysis. Rock analyses by the rapid method were made by G. Mensah and S. Malone of the Geological Survey. The single analysis by the classic long method was made by S. Courville of the Survey.

Large sanidine crystals were estimated to be scarce in specimens 11, 17, 20, and 25; of intermediate abundance in specimens 12, 14, 16, 18, 19, and 24; and plentiful (maximum 15-20 per cent by volume) in specimens 13, 15, 21, 22 and 23. Specimen 20 represents a local unusually fine-grained variant.

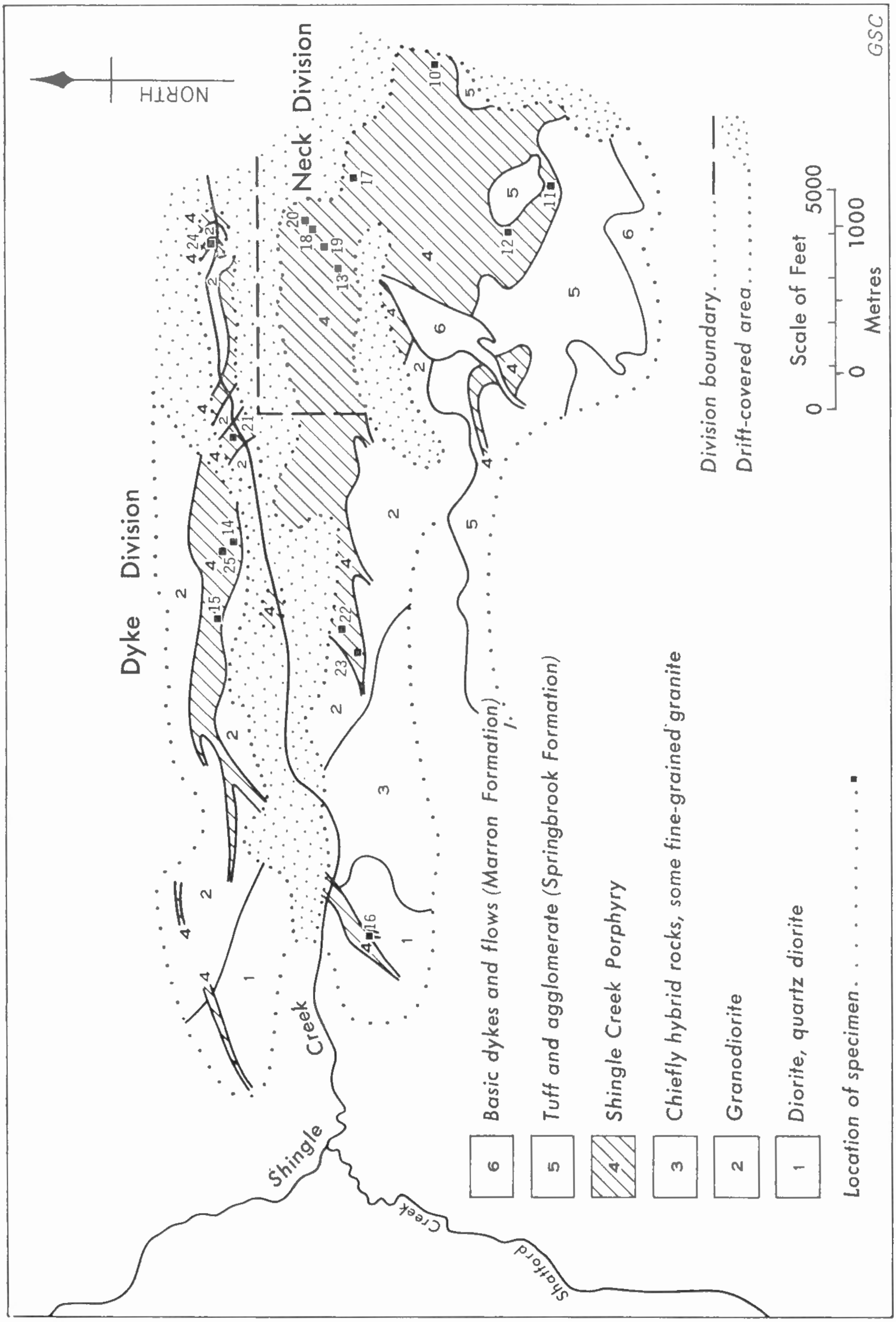

FIGURE 1. Locations of chemically analyzed rock specimens.

Table II

The Effect of Removing 20 per cent by Weight of Sanidine from Analysis 11

		20 gm. Sanidine	Recalculated	Variation
SiO_2	70.8	−13.1	72.1	+1.3
Al_2O_3	14.9	−3.7	14.0	−0.9
Fe_2O_3	0.9		1.1	+0.2
FeO	0.61		0.76	+0.15
CaO	1.6		2.0	+0.4
MgO	0.6		0.8	+0.2
Na_2O	3.8	−0.6	4.0	+0.2
K_2O	4.4	−2.6	2.3	−2.1
Remainder	1.6		2.0	+0.4
Total	99.2		99.1	

Modal Analyses

The results of point counts for thirteen hand specimens representing the neck and dykes and the albite and oligoclase phases are given in Table III. The locations of the outcrops from which the specimens were taken are shown in Figure 2.

Table III

Volumetric Modal Analyses of Phenocrysts[1]

	Albite Phase						Oligoclase Phase						
	Neck			Dykes			Neck			Dykes			
	a	b	c	d	e	f	g	h	i	j	k	l	m
Quartz	7.8	8.4	5.9	12.0	11.0	7.0	7.6	13.6	9.8	11.6	9.4	11.5	5.7
Small sanidine	2.3	4.5	2.5	1.9	2.8	8.6	0.9	4.1	2.5	3.3	2.3	9.0	5.6
Plagioclase	20.9	23.1	17.1	30.6	30.0	22.7	24.5	24.2	27.9	30.9	25.2	20.8	18.4
Mafic minerals	2.0	0.9	1.8	2.9	2.1	3.3	2.5	1.2	1.5	2.4	2.2	2.8	2.3
Matrix	67.0	63.1	72.7	52.6	54.1	58.4	64.5	56.9	58.3	51.8	60.9	55.9	68.0

[1]Large sanidine phenocrysts (maximum intercept greater than 1 cm) not included in these counts. Such crystals were estimated to be essentially absent for specimens b and m; of low to intermediate abundance in specimens a, c, d, f, g, h, and i; and of great abundance (maximum approximately 20 per cent by volume) in specimens e, j, and k.

In considering total changes in proportion of phenocrysts and matrix in the intrusion, the effect of ignoring the large sanidine crystals will be particularly marked. Table IV shows the data for specimen e recalculated to include 20 per cent of large sanidine crystals and represents the maximum effects to be expected. The table suggests that crystallization of large sanidine crystals at the expense of the

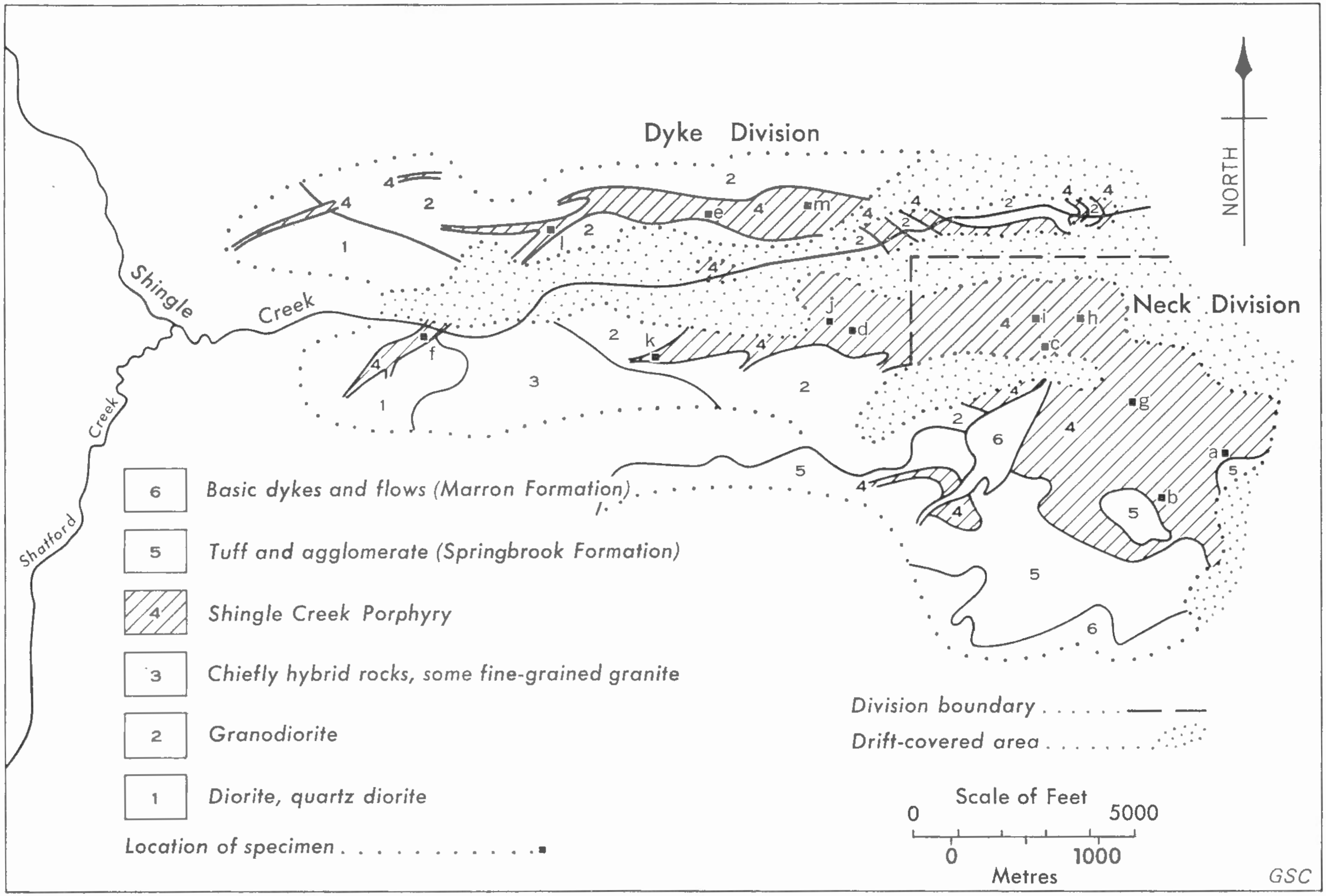

FIGURE 2. Locations of specimens on which modal analyses were made.

matrix would significantly alter the proportions of matrix to small phenocrysts. However, distinct differences in the proportions of matrix to phenocrysts exclusive of large sanidine crystals would probably represent differences in the total amount of phenocrysts formed prior to the crystallization of the matrix.

Table IV

Specimen e Recalculated to Include 20 per cent by Volume of Large Sanidine Phenocrysts

	e measured	difference	e calculated
Quartz	11.0	2.2	8.8
Sanidine	2.8	0.6	2.2
Plagioclase	30.0	6.0	24.0
Mafic minerals	2.1	0.4	1.7
Matrix	54.1	10.8	43.3
Large sanidine phenocrysts			20.0

In Table V porphyry with abundant large sanidine phenocrysts (column 1) is compared with that containing very few (column 2). The data show that the proportion of sanidine with respect to other phenocrysts is considerably greater where large sanidine crystals are abundant. The table further suggests that increased growth of quartz and plagioclase has accompanied growth of the large sanidine crystals. The growth of quartz and plagioclase, however, is considerably less than proportionate to that of the large sanidine crystals.

Table V

A Comparison of Modal Analyses of Porphyry with Abundant and Rare Large Sanidine Phenocrysts

	Abundant Large Sanidine Crystals (1)	Large Sanidine Crystals Absent (2)
Large sanidine	15.0	0.0
Small sanidine	2.4	5.1
Quartz	9.1	7.1
Plagioclase	24.3	20.7
Mafic minerals	1.9	1.6
Matrix	47.3	65.5
Total	100.0	100.0

Column (1) represents an average of modal analyses e, j, and k recalculated to include 15 per cent of large sanidine phenocrysts (the best estimate of average large sanidine content for these specimens). Column (2) represents the average of specimens b and m in which large sanidine phenocrysts were virtually absent.

In Figure 3 the modal analyses of Table III are plotted in order of increasing per cent of plagioclase as abscissae and per cent of other phenocrysts as ordinates. The figure shows that quartz phenocrysts tend to increase in per cent by volume in a manner parallel with plagioclase though two specimens (h and l) with high quartz contents depart from the trend.

Data from rocks of the two phases and two structural divisions (*see* Table III) were examined for significant differences. The means and standard deviations together with an estimate of the significance of differences in the means are given in Tables XII and XIII. The data for specimen m have been excluded because the matrix per cent is distinctly higher than in any of the other specimens from the dykes. This feature and its point of derivation at the east end of the north dyke (i.e., adjacent to the neck) suggest that specimen m may represent a transgression of the neck environment into the east end of the north dyke. Its omission from the calculations seems justified on this basis.

Comparison of the albite and oligoclase phases shows no significant difference, but comparison of the neck and dyke specimens (excluding specimen m) suggests (at the 5 per cent level) that mafic mineral counts are higher and matrix counts lower in the dykes than in the neck. The proportion of large crystals excluded in the modal analyses is considered to be similar for specimens from the oligoclase and albite phases but somewhat greater for specimens from the dykes than from the neck. The validity of the conclusion that matrix per cents are lower in the dykes than in the neck is therefore enhanced, whereas the suggestion that the mafic phenocrysts may be more abundant in the dykes is depreciated (compare Tables III and V).

Mineralogy

The minerals determined from the Shingle Creek porphyry are given in the section *General Geology*; estimations of variation in abundance of the major minerals are presented under *Petrography*. In this section some of the optical, textural, and chemical features of the large phenocrysts are described. These features are used as a basis for comparing the neck with the dykes, and the albite phase with the oligoclase phase.

Sanidine

Megascopic Features

Large sanidine phenocrysts are typically euhedral and vary in size up to about 4 inches. Simple crystals, elongated parallel with the *a*-axis, and showing faces (001), (010), (110), and a second order prism prominently developed are most abundant (*see* Pl. IV, left). Carlsbad twins are common and generally show greatest elongation parallel with *c* (*see* Pl. IV, right). However, a few twins may be found in which two forms typical of the simple crystals (elongate parallel *a*) are related by the Carlsbad law. Twins of intermediate form are also present (*see* Pl. IV, centre).

Some single crystals, in hand specimen, show a rim up to a few millimetres thick of more altered appearance than the main part of the crystal. These rims

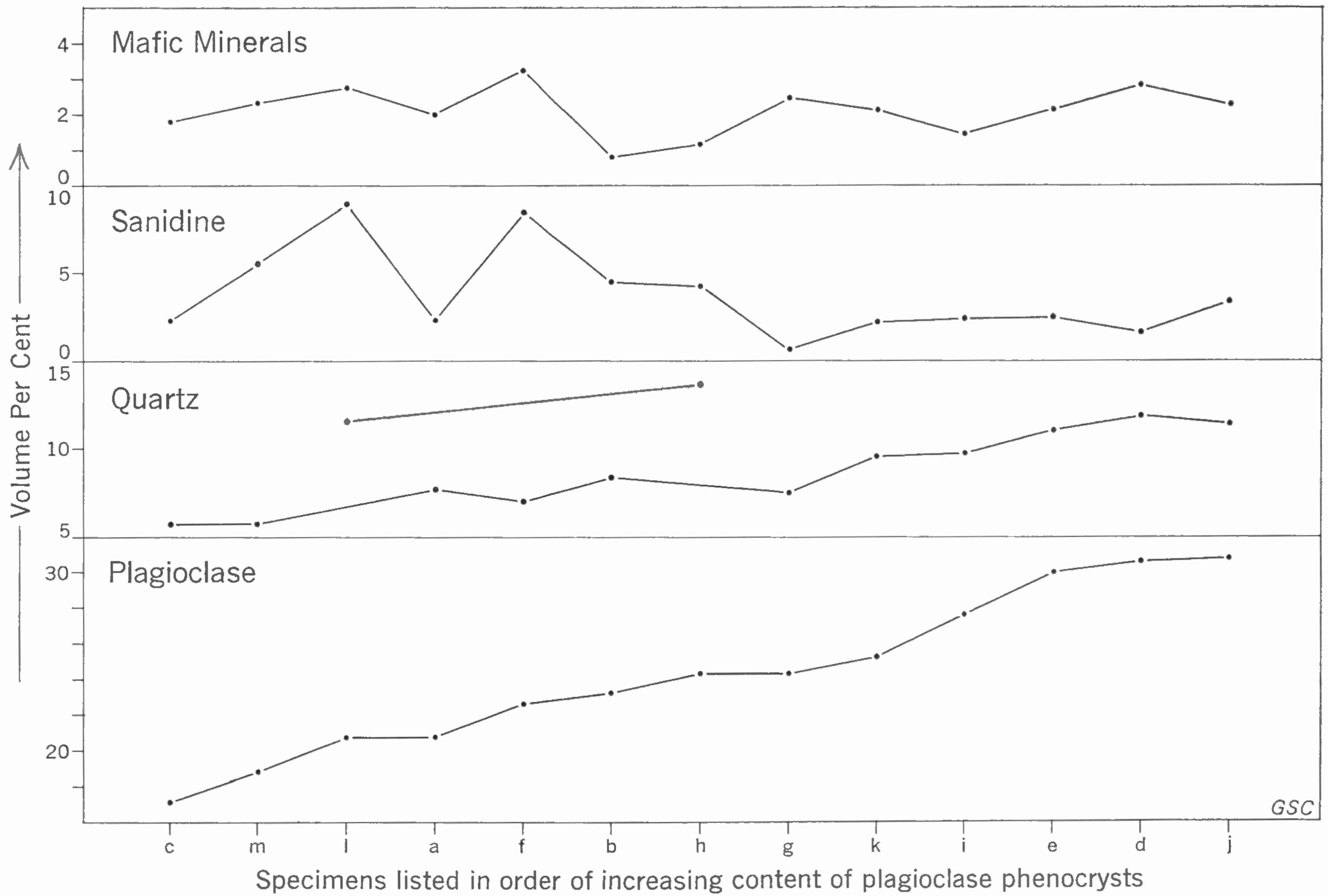

FIGURE 3. Graphs showing the variations in volume per cent of quartz, small sanidine, and mafic phenocrysts with increasing volume per cent of plagioclase phenocrysts.

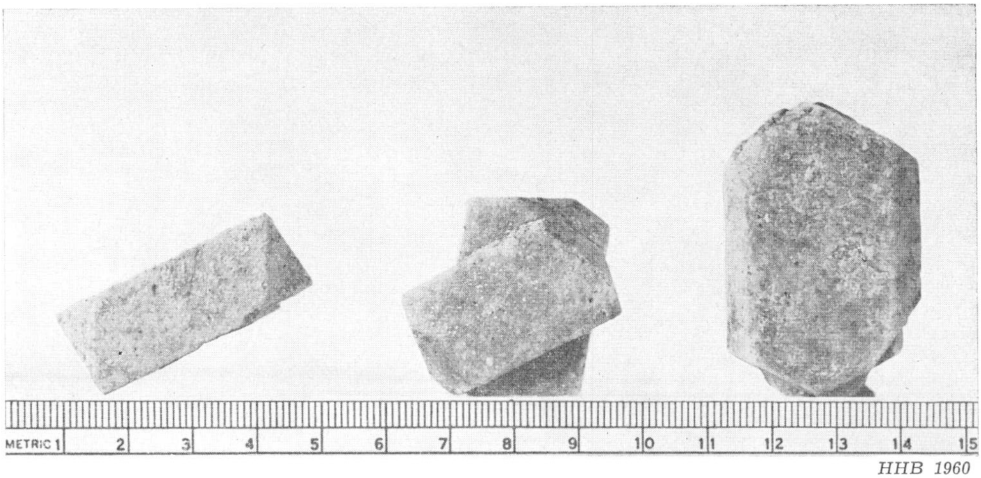

PLATE IV. Simple and twinned sanidine crystals. (1) left—a simple sanidine crystal with habit typical of sanidine in the Shingle Creek porphyry; (2) centre—a Carlsbad twin with components showing slight tendency towards preferential growth parallel to the c-axis (rare at Shingle Creek); (3) right—a Carlsbad twin with marked preferential growth parallel to the axis and typical of Carlsbad twinning in sanidine at Shingle Creek.

generally contain an abundance of small crystals oriented parallel with the surface of the host crystal. Broken crystals commonly show one or more surfaces concentric with the outer surface marked by a fracture or slight change in alteration.

Sanidine crystals at Shingle Creek vary regionally in degree of alteration. Unaltered crystals, common in the dykes, are generally flesh coloured to translucent grey, whereas the more altered crystals, common in the neck, are various shades of pink or white. The most intensely altered crystals are found in the albite phase along southeast contact canyon and the least altered crystals in the oligoclase phase in the central region of the dykes along Shingle Creek.

Microscopic Features

The sanidine crystals in thin section are euhedral but may show rounded corners. Internal fractures concentric with the outer surface, also seen in hand specimen, are evident in thin section (*see* Pl. V A). Such fractures commonly show slightly rounded corners and are thought to represent periods during which growth of the crystal was interrupted by slight resorption. Small plagioclase phenocrysts are the principal inclusions in the large sanidine crystals. Such inclusions become more numerous toward the margins of the host crystal and are abundant in the altered rims present on some sanidine phenocrysts. Plagioclase inclusions do not appear to expand toward the margins of the sanidine hosts. Biotite or chlorite inclusions are present sparingly in most large sanidine crystals but do not appear to be concentrated toward the margins. Quartz inclusions in sanidine are less common. Overgrowths of sanidine on plagioclase were observed in several specimens from the dykes but this texture is not common (*see* Pl. V B). Small sanidine crystals (i.e., those less than 1 cm long) examined in standard thin section show textures similar to those of the large crystals.

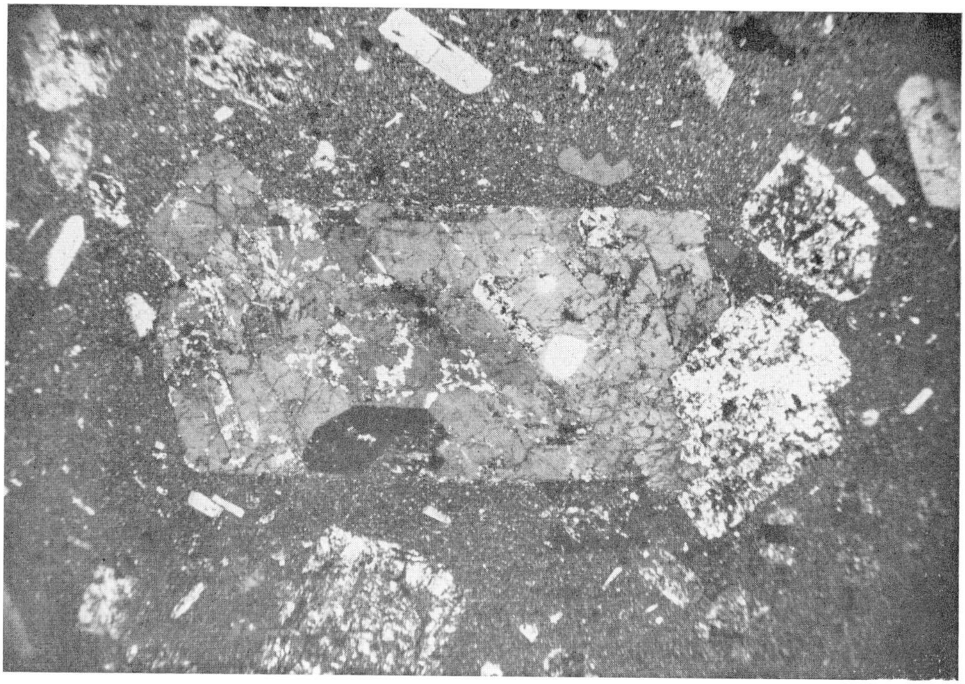

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PLATE V A. Photomicrograph (x10) showing a small sanidine phenocryst with an internal fracture (bottom left) interpreted as a surface of corrosion. Quartz, plagioclase, sanidine, and biotite crystals are included.

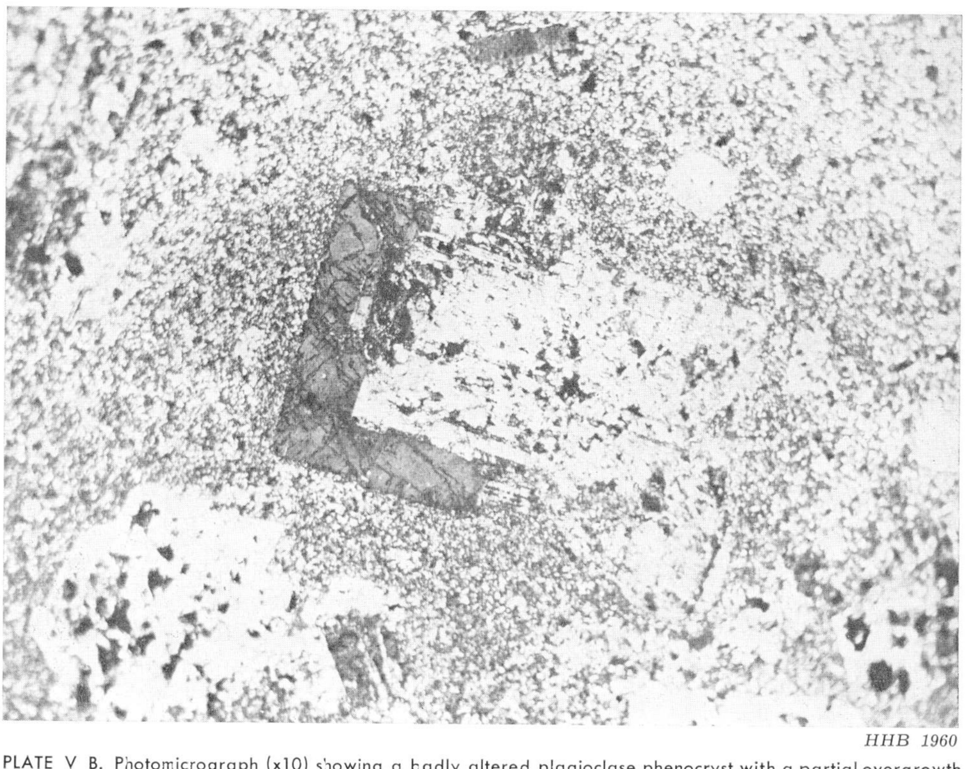

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PLATE V B. Photomicrograph (x10) showing a badly altered plagioclase phenocryst with a partial overgrowth of sanidine.

Zoning

Examination of thin sections cut perpendicular to the optic axis, X, of the large sanidine crystals suggests that, in all, some oscillatory zoning is present. Zones commonly occur in pairs (*see* Pl. VI) with maximum thickness reaching about one third millimetre. The inner member of each pair shows a relatively higher optic angle that decreases gradationally to a minimum at the outer edge of the outer member. The definition of the zones is commonly better toward the outer margin of the crystals where distinct zones of high optic angle are visible in some crystals.

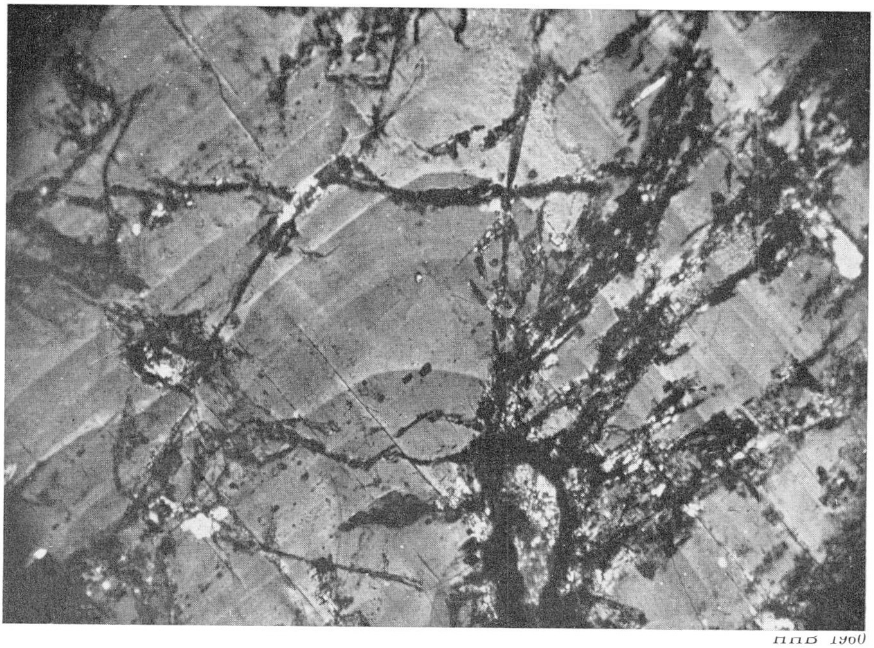

PLATE VI. Photomicrograph (x30) showing zoning in a thin section of a large sanidine phenocryst cut perpendicular to the *X*-axis and about 0.1 mm thick.

Thicknesses of zones were measured in seven of the less fractured and altered thin sections with diameters close to 3 cm. In each section a pencil mark was made at 5 mm and another at 10 mm from the centre of the section along the maximum diameter and thicknesses of two to four distinct zone pairs averaged in the immediate vicinity of the marks. The measurements suggest average zone thickness is 0.22 mm (standard deviation 0.034 mm) at the inner levels and 0.17 mm (standard deviation 0.053 mm) at the outer levels. If the rate of growth (total volume per unit of time) were constant for these crystals, the thickness of zones might be expected to decrease approximately as the square of the zone distance from the centre of the crystal, provided each zone represents the same length of time. Though the measurements are only approximate, both because the position of the section taken varied along the *a*-axis and because the definition of the inner zones is commonly not so clear as the outer, it is nevertheless apparent that zoning at the outer level is not four times thinner than that at the inner level. It is therefore considered that, between these two levels, either the time interval represented by zone pairs increased as the crystal grew or the rate of addition of material to the crystal surfaces increased as crystallization progressed.

Thin sections cut perpendicular to "X" show that all zones reach extinction together, their presence being shown by differences in partial birefringence only. This is to be expected if sanidine is optically monoclinic and "X" lies in the symmetry plane. A section cut perpendicular to "Z" shows that the optic indicatrix for different zones is rotated slightly (approximately 1 degree) about the symmetry axis.

In testing for a possible relationship between zoning and unmixing a zoned fragment from a thin section was heated to 800°C for 20 minutes; zones were found to be unaltered. This suggests that more is involved than the distribution of alkali metal cations alone, as such treatment should be more than sufficient to homogenize unmixed specimens of high albite-sanidine cryptoperthite (*see* Bowen and Tuttle, 1950).

As the strength of the bonds of Al and Si to O are much greater than those of Na and K the stability of zones might be connected with Al-Si substitution. The structure of sanidine (Taylor, 1933) contains sixteen Si-Al positions per unit cell, and charge balance in Na-K feldspar requires that the ratio of Si to Al be 3 to 1. However, the positions occupied by the four Al and twelve Si atoms in each unit cell are not fixed by this consideration. The four Al atoms might be arranged in an identical orderly fashion or some degree of disorder might obtain in each unit cell. Such limited substitution of Al for Si as briefly described is known as Al-Si ordering. The high stability of zoning might result from a variation in the degree of ordering of Al-Si in different zones.

Hewlett (1959) has discussed the theoretical effects of ordering of Al-Si on the optical properties of alkali feldspar and suggests that b- (gamma minus alpha) might be used as an index to the degree of Al-Si order obtained. He pointed out that, whereas gamma and beta vary with Al-Si ordering, unmixing, and composition, alpha varies chiefly with composition. The subtraction of alpha from gamma would thus yield a parameter dependent chiefly on ordering and unmixing.

To test the possibility that the stability of zoning in the sanidine crystals results from variations in Al-Si ordering between different zones, grains showing a maximum difference in partial birefringence were obtained from a crystal showing a minimum of unmixing as suggested by single crystal oscillation and powder diffraction. Alpha and gamma were determined for each grain and the results of the measurements are shown in Table VI.

Possible error in the total birefringence measurements is considered to be ±0.0006. The measurements suggest that the zone of high partial birefringence may have a slightly lower orthoclase content than its counterpart, but the accuracy of the total birefringence measurements is not sufficient to establish a significant difference in Al-Si ordering. However, the total birefringence is significantly higher in both grains than in many of Hewlett's specimens.

Table VI

Variation in Total Birefringence between Zones (specimen 204)

	gamma	alpha	gamma minus alpha
Zone of high partial birefringence (gamma-beta)...	1.5273	1.5218	0.0055
Zone of low partial birefringence (gamma-beta)....	1.5268	1.5209	0.0059

Optic Angle Variation

Estimates of the average optic angle at the core and rim of some forty-three large sanidine phenocrysts are given in Table XIV. The locations from which the specimens were taken are shown in Figure 13.

A comparison of the data from the cores and rims of the crystals is made in Figure 4, which shows the frequency distribution of differences. The figure suggests that no significant consistent difference in the optic angle between cores and rims of the crystals is present. There may, however, be a slight tendency toward higher optic angles at the crystal cores. Comparison of the size differences between rims and cores suggests the possibility that the crystals from the albite phase may show greater variations than those of the oligoclase phase in this respect.

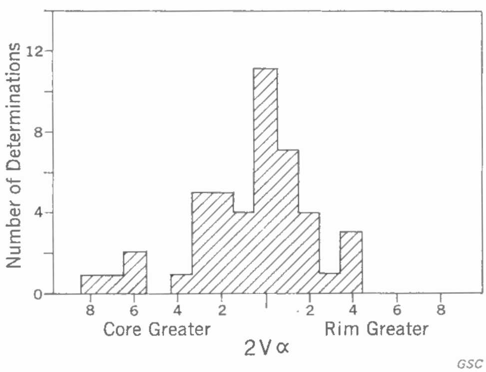

FIGURE 4. Histogram showing the frequency distribution of differences between the optic angle estimated for the cores and rims of the large sanidine phenocrysts.

For further comparisons within the intrusion, core and rim values were combined to obtain an average estimate for each crystal. The dyke and neck divisions of the porphyry were considered on the basis of variations in average optic angle in sanidine phenocrysts. Unfortunately only one crystal from the eastern half of the neck proved sufficiently unaltered to yield a reliable measurement. Optic angles of crystals from the western border of the neck are comparable to those of crystals in the dykes, whereas crystals from the central west half of the neck have low to intermediate optic angles and the single crystal from the east half has a very low optic angle. Insufficient specimens prevent making a reliable statistical comparison of the neck and dyke divisions but it does appear as if the lowest optic angles are found in the neck division (*see* Table XIV). A statistical comparison of optic angles in sanidine phenocrysts from the albite and oligoclase phases suggests that variations in the two phases are similar.

Since the single crystal measurements suggested a correlation between unmixing and the average optic angle estimated for the large sanidine crystals (*see* Table VII), it was thought that the chilling effect of the wall-rocks might have been sufficient to retard unmixing and thus lower the optic angle in crystals closer to the contacts. Similarly, an oligoclase phase dyke penetrating a body of recently injected albite phase magma might have been sufficient to extend the period of unmixing and thus increase the optic angles of sanidine phenocrysts in the albite-bearing wall-rocks. To test these hypotheses a series of twelve crystals taken along a gully that crosses the north dyke just west of its broadest section was examined and the estimated average optic angles plotted (*see* Fig. 5) according to their position in the dyke. The figure suggests that the dyke may be divided into two parts: the southern two thirds, which is characterized by optic angles between 35 and 40 degrees and contains relatively small granodiorite inclusions in its south half only; and the northern one third, which shows variations in optic angles from 25 to 43 degrees and contains large granodiorite inclusions throughout. It is apparent that the crystals taken within a few feet of the north border of the dyke (the south border is not exposed) have close to average optic angles rather than unusually low ones, and that specimen 011 with the lowest optic angle was taken from albite porphyry within a few feet of the oligoclase-bearing core of the dyke. The data thus show that neither the proximity of the dyke walls nor the intrusion of the oligoclase-bearing core into the albite-bearing rocks has been the dominating factor in controlling the size of 2V (alpha) at this level of exposure. The variability of the inclusion-choked northern third of the dyke may result from a selection of different channels by slightly different phases of the magma.

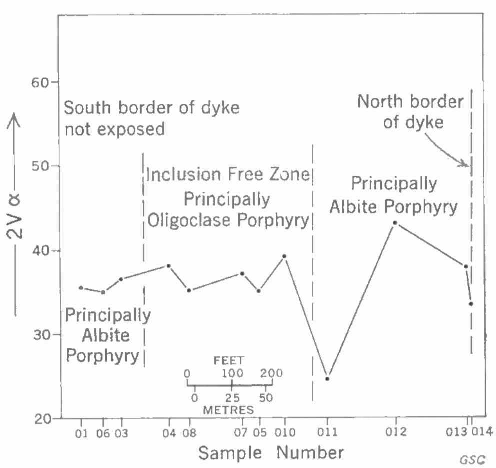

FIGURE 5. Graph showing the variation in 2V (alpha) of sanidine phenocrysts taken along a gully crossing the north dyke just west of its broadest section.

A general consideration of the distribution of high and low values of optic angle in the large sanidine phenocrysts from the dyke division suggests the possibility that lower optic angles may be concentrated in the narrower parts of the dykes. However, the limited extent of exposure in critical areas has not permitted an objective grouping of specimens suitable for statistical comparison.

X-ray Diffraction

Single Crystal Oscillation

Smith and MacKenzie (1955) have suggested that unmixing in alkali feldspars might be studied through the use of 15-degree, *b*-axis oscillation photographs taken with (010) and (001) cleavages oriented parallel with the X-ray beam at the centre of the oscillation arc. In the present study cleavage fragments from thin sections of eight crystals were studied in this manner. All fragments were selected to include a minimum of zoning within their limits. A zone of unusually high birefringence was selected from one crystal (204) but the remaining fragments represent zones of average birefringence. From specimen 08 two fragments were selected to represent the core and rim of the crystal. Parts of six of the photographs obtained are reproduced in Plate VII to illustrate unmixing effects.

The investigation suggests that the crystals may be divided into two groups: one in which the 242 and 442 reflections, discussed by Smith and MacKenzie (1955), as well as others at higher theta values are distinctly doubled along the layer lines; and one in which these reflections are not clearly doubled. For the group with doubled reflections, the reflection with the lower theta angle is always considerably more intense than its companion. Both groups show varying degrees of fuzziness extending to slightly lower and higher theta angles than the main reflection.

Since soda feldspar has a shorter *a*-axis length than potash feldspar, it will give (hkl) reflections (h large) at higher theta values than the equivalent potash feldspar reflections. The doubling of the reflections in the first group thus suggests the unmixing of a soda phase from the potash host. The diffuse streaks between the two principal spots of the doubled reflections have been attributed by Hewlett (1959) to very small regions of unmixed soda feldspar that are not of great enough extent to produce discrete spots by X-ray diffraction. Hewlett recorded diffuse streaks at smaller theta values than the main reflections but these were not so distinct as some of those observed in the present study. He suggested that the interpretation of these streaks, though uncertain, could be due to very small regions of potash feldspar having less soda in solid solution than the bulk of the sample, or to imperfections in the potash feldspar structure, such as small triclinic areas twinned by the pericline law. In the crystals studied here diffuseness at lower theta angles may be due to slight gradational zoning in the fragments used.

The fragment from the centre of specimen 08, after heating for 20 minutes at 800°C, showed only one set of reflections; however, a strongly zoned fragment from specimen 204 after similar treatment showed no visible change in the character of the zones. This is consistent with the conclusion that the doubled reflections represent unmixing and are not due to fortuitous zone effects.

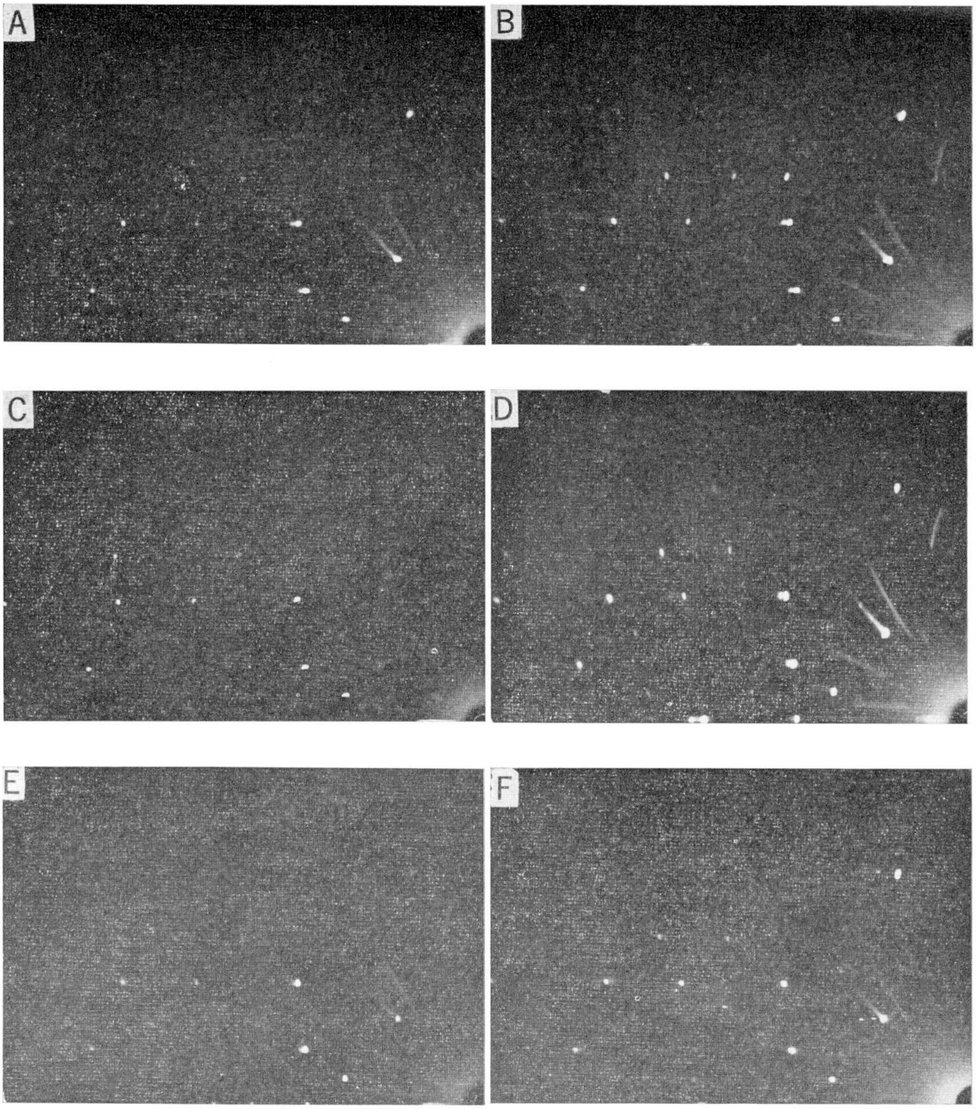

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PLATE VII. Photographic reproductions of 15 degree *b*-axis oscillation photographs of sanidine from Shingle Creek taken with cleavage approximately parallel with the X-ray beam.

A—A cleavage fragment from the rim of crystal 08 showing an unmixed soda phase.

B—A cleavage fragment from the centre of crystal 08 showing unmixing closely similar to A.

C—The same fragment illustrated in B after heating for 20 minutes at 800°C. Doubled reflections have been replaced by single sharp reflections.

D—A cleavage fragment from crystal 012 showing intense reflections for the soda-rich phase.

E—A cleavage fragment from crystal 296 showing weak soda phase reflections.

F—A cleavage fragment from crystal 204 showing a minimum of unmixing. At high theta values diffuse spots are present on the potash side of the main reflection. As this fragment was taken from a narrow zone of high partial birefringence these may represent zoning effects.

The data derived from the single crystal study of unheated sanidine are summarized in Table VII; this table also includes the average optic angle estimated for the whole crystal from which each fragment was taken. The table suggests that the size of the average optic angle in the Shingle Creek specimens may be correlated with the unmixing effects observed in the oscillation photographs. Crystals with average optic angles above 30 degrees tend to show doubled reflections. The data suggest that unmixing has not been a function of composition within the range of compositions present as crystal fragments with high alpha index and birefringence show the least unmixing; however, this argument would not be valid should the content of Ba, Sr, or Rb vary appreciably between zones.

Table VII

Summary of Data for Crystals for which b-axis Oscillation Photographs were taken

Specimen Number	Alpha Refractive Index	Average 2V	Description of Reflections	Type of Plagioclase in Host Rock
73	1.5220	13	one set	albite
204	1.5218	21	one set	albite and oligoclase
50	1.5217	30	one set	albite
12	1.5217	43	two sets	albite
496	1.5215	30	two sets	albite
27	1.5213	29	one set	oligoclase
296	1.5213	42	two sets	oligoclase
08	1.5209	35	two sets	oligoclase

Powder Diffraction

A sample from each of the groups suggested by oscillation study was investigated to compare the character of the $\bar{2}01$ powder diffraction peak before and after heat treatment at 800°C for 20 minutes to see how variation in the degree of unmixing suggested by the oscillation photographs would be reflected in the $\bar{2}01$ powder diffraction record. Samples from specimen 204 showing a single set of oscillation reflections and from 08 showing a doubled set were used; the records are reproduced in Figures 6 and 7. The figures suggest that more advanced unmixing might be correlated with broadening and lowering of the powder diffraction peak. The records for specimen 204 also show some increase in intensity at slightly lower theta values beyond the main peak that does not appear to be present to the same degree in the records for specimen 08. As zoning is better developed in specimen 204 (*see* Pl. VI) than it is in 08, this intensity at low theta values may be due to potassic zones. If this is so, the records suggest that heat treatment has begun to disorganize the cation distribution perhaps within the powder fragments. However, the problem arises that the distribution of partial birefringence intensity for specimen 204 does not appear to be clearly parallel with the distribution of composition suggested by the diffraction peak intensities (compare Pl. VI and Fig. 6).

To test the possibility that $\bar{2}01$ powder diffraction peak characteristics could be used as a simple index to the degree of unmixing attained in a crystal, records of this peak were made for crystals from different parts of the intrusion and compared with optic angle measurements. In general, it was found that crystals with broad low single peaks of the type shown by specimen 08 (unheated) gave average optic angles above 30 degrees. However, some crystals with relatively high average optic angles gave fairly sharp peaks (e.g., 296). Many specimens showed multiple peaks similar to unheated specimen 204 (*see* Fig. 6) but with the secondary peak considerably more intense. Interference of this type renders characterization of $\bar{2}01$ powder diffraction peaks uncertain.

Composition

Precise determination of the composition of the large sanidine phenocrysts of the Shingle Creek porphyry has not been attempted because of the intense alteration of sanidine in much of it, and the ubiquity of small plagioclase inclusions and zoning. However, four partial analyses combined with optical and X-ray data suggest that these crystals have a normal content of Rb, Sr, and Ba and lie in the composition range Or_{60}-Ab_{40} to Or_{80}-Ab_{20}.

Data from the analyses of four of the least altered crystals from the oligoclase phase of the dykes are given in Table VIII.

Table VIII

Partial Chemical Analyses of Sanidine

	Ca	Sr	Ba	Rb	K	Na	Total
Spec. 8[1]	0.5	0.1	0.3	0.02	9.14	2.42	
% Felds.	3.5	0.4	0.8	0.08	65.1	27.6	97.5
Spec. 27	0.2	0.2	0.6	0.02			
% Felds.	1.4	0.7	1.6	0.08			
Spec. 252	0.1	0.1	0.4	0.02			
% Felds.	0.7	0.4	1.1	0.08			
Spec. 299	0.3	0.1	0.3	0.02			
% Felds.	2.1	0.4	0.8	0.08			

[1]Values opposite each sample number represent weight percentages of the element in the sample The figure immediately below shows the weight per cent of the feldspar and member in the sanidine sample

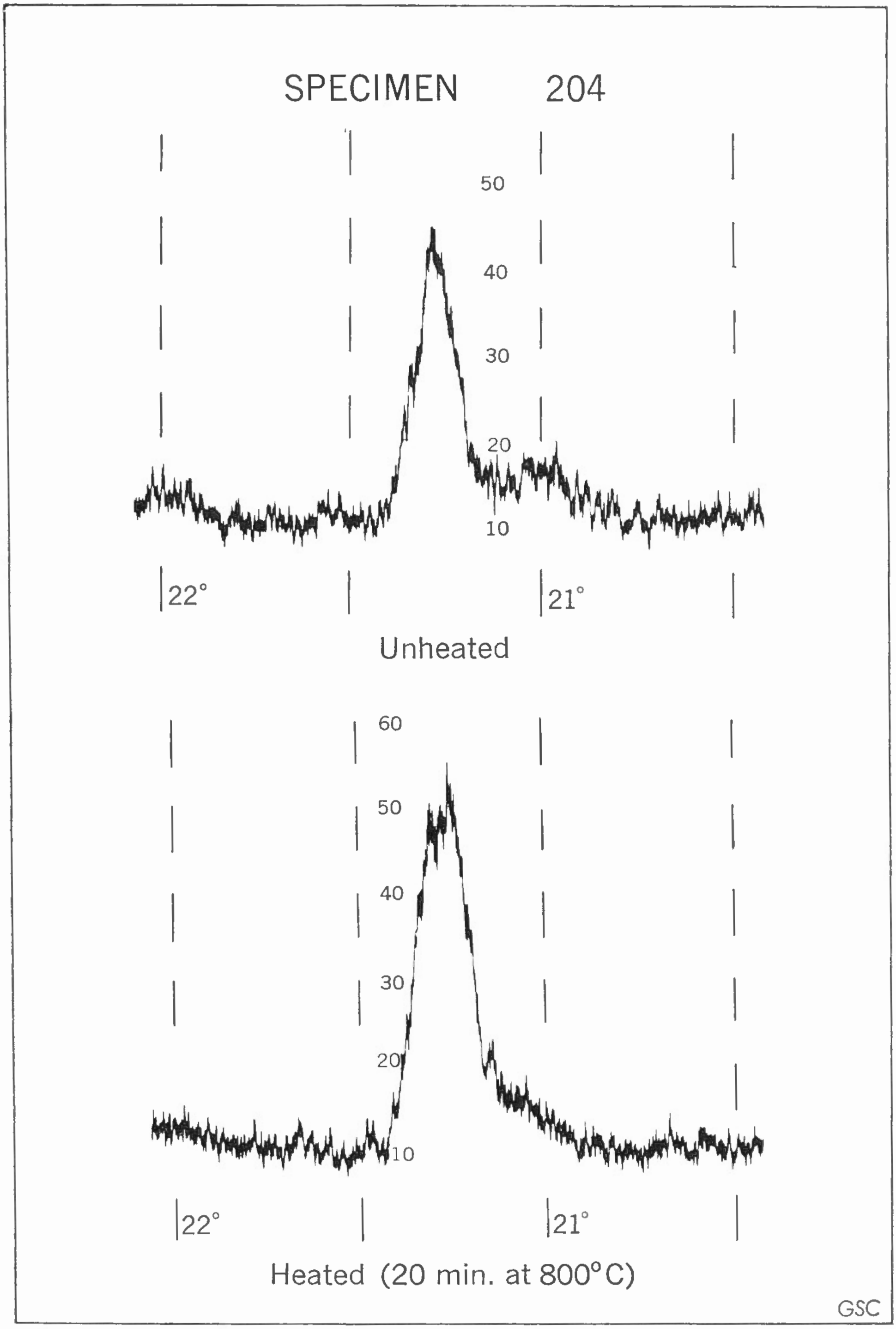


FIGURE 6. A reproduction of 201 powder diffraction peaks for specimen 204 (not clearly cryptoperthitic) before and after heat treatment.

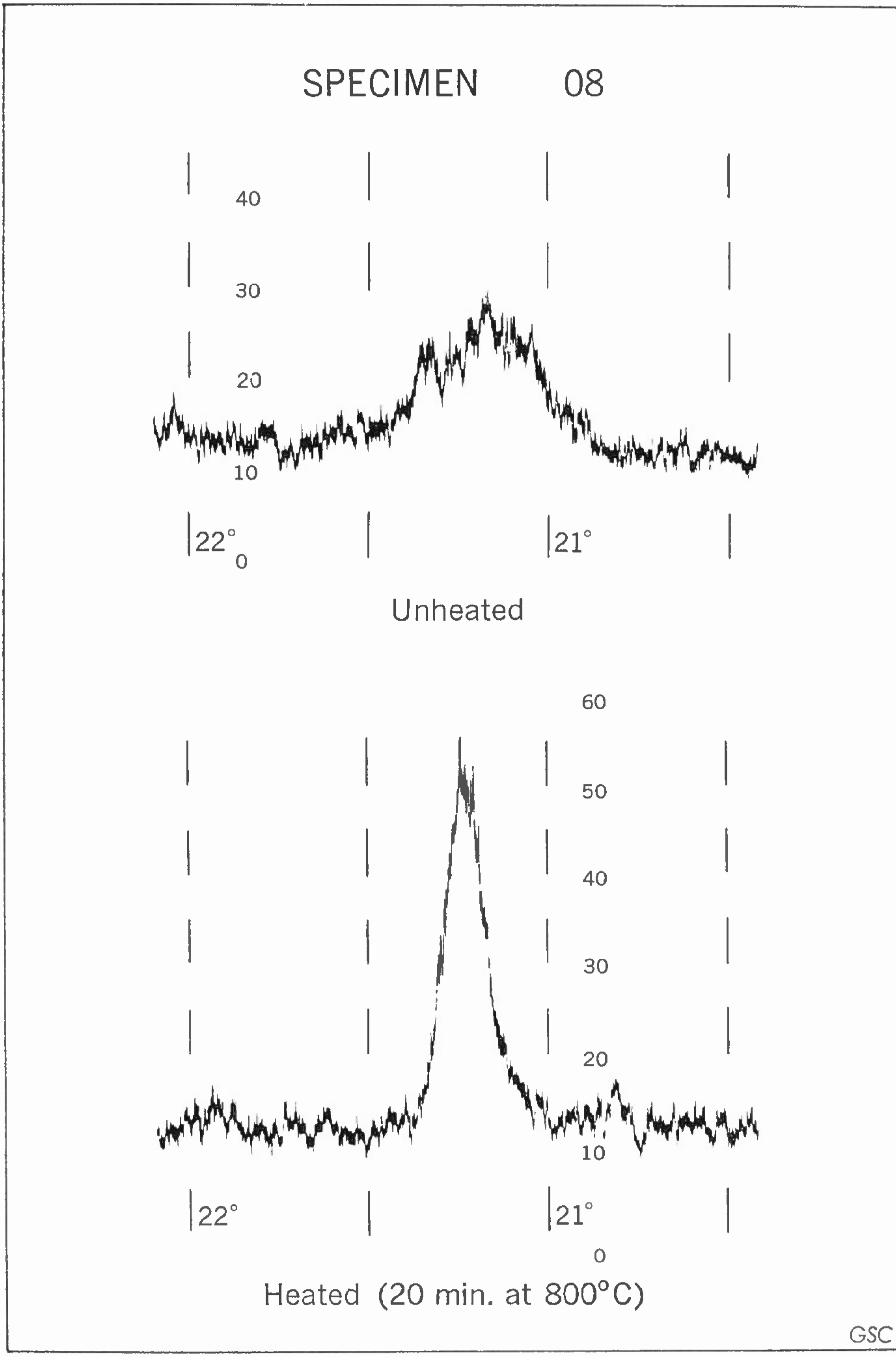


FIGURE 7. A reproduction of $\bar{2}01$ powder diffraction peaks for specimen 08 (cryptoperthitic) before and after heat treatment.

The Or-Ab ratio estimated from $\overline{2}01$ spacing measured on sample 08 (heated) was 75-25 (using the data of Bowen and Tuttle, 1950).

The Ba, Sr, and Rb content of the sanidine from the Shingle Creek porphyry lies well within the limits found for the sanidine examined by Hewlett (1959). Calculation of the Or-Ab ratio of sample 08 from the partial analysis yields a value, Or_{70}-Ab_{30}. However, the ratio of Or is probably slightly greater than that given as some sodic plagioclase was included in the material analyzed which would make the proportions of Ab too great.

The refractive indices (alpha) measured on fragments from nine different crystals ranged from 1.5209 to 1.5220, the former value being that from specimen 08. If the composition of specimen 08 is Or_{75}-Ab_{25} then the alpha refractive index range of the fragments studied suggests a range in composition Or_{75}-Ab_{25} to Or_{60}-Ab_{40} approximately (interpolated from the data of Tuttle, 1952).

An investigation of the character of the $\overline{2}01$ diffraction peaks of a large number of specimens suggested that the sodic component in these crystals did not exceed Ab_{40}. However, a few crystals were found with peaks suggesting a composition more potassic than Or_{75}. The data suggest that the composition of most Shingle Creek sanidine phenocrysts varies between Or_{60}-Ab_{40} and Or_{80}-Ab_{20}.

Plagioclase

Megascopic Features

Plagioclase phenocrysts in the Shingle Creek porphyry are typically euhedral though crystal corners may be more or less rounded. These phenocrysts reach one half inch in length though most crystals are smaller. In hand specimen crystals are commonly recognizably twinned or intergrown.

Alteration of plagioclase is broadly related to the phase of the porphyry in which it is found. Pervasive alteration is typical in albite crystals that are commonly cloudy pink, white, or orange. Oligoclase crystals, however, are commonly clear white in the least altered grey rock but are pinkish and cloudy where the rock is altered pink.

Microscopic Features

Seen in thin section plagioclase commonly forms aggregates of two or more crystals that may be difficult to distinguish from twinned crystals. Zoning is not evident in plagioclase phenocrysts in most thin sections. This may be due to pervasive alteration of plagioclase, or it might be due to development of polysynthetic twinning (Emmons, 1953). Traces of oscillatory zoning commonly can be found in crystals from the least altered specimens of the oligoclase phase, and more rarely strongly calcic cores are evident. Inclusions in plagioclase phenocrysts are rarely seen although single crystals crushed in acetone between two glass slides commonly yield several tiny tetragonal prismatic crystals showing simple prism and pyramid and relatively high birefringence. These crystals are thought to be zircons.

97878—4½

Variation in Alpha Refractive Index

J. R. Smith (1958) suggested that the alpha refractive index of plagioclase, when measured under carefully controlled conditions, provides the best optical means of determining composition. In the present study alpha refractive indices were determined using the double variation procedure of Emmons (1953) from as representative a group of specimens as possible. The results of the measurements are given in Table XVI and are shown diagrammatically in Figure 8. The composition of plagioclase clearly falls in two ranges: An_1 to An_8 and An_{19} to An_{25}. Plagioclase of intermediate composition, though not entirely lacking, is much less common.

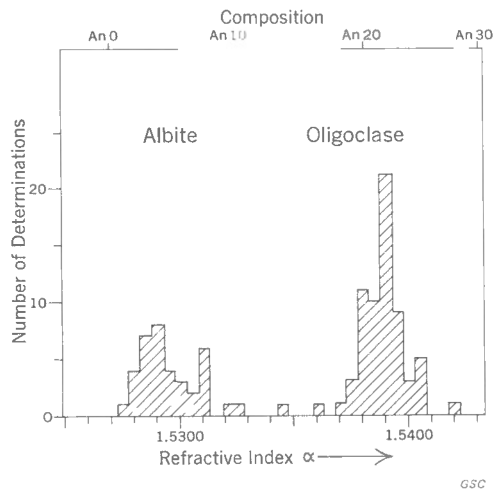


FIGURE 8. Histogram illustrating the proportion, by composition, of different plagioclase phenocrysts from Shingle Creek porphyry.

The values of alpha for albite below 1.5315 and those for oligoclase above 1.5360 were separated into two groups, those from the dykes and those from the neck. Each group was then compared with its counterpart (*see* Table XVII) but no statistically significant difference could be detected.

Optic Angle Variation

The optic axial angle (2V alpha) of plagioclase was measured in thin sections representing the neck and dykes in each phase of the porphyry. Strongly zoned crystals were rare and were not included in this study.

The frequency distribution of optic angles of various values for plagioclase from the albite and oligoclase phases is shown in Figures 9 and 10, and the values measured in each specimen are given in Table XVIII. The locations from which the specimens were taken are shown in Figure 14.

Figure 9 suggests that albite from the Shingle Creek porphyry is similar to the albite of volcanic rocks described by van der Kaaden (1951), though in some crystals 2V alpha is slightly less than in those plotted by him. Optic angles of oligoclase from Shingle Creek fall in the volcanic to intermediate range and are

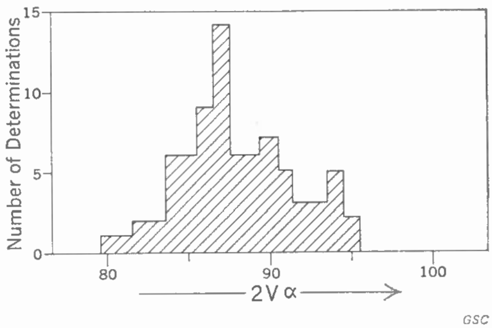


FIGURE 9. Histogram illustrating the frequency distribution of various values of 2V (alpha) of plagioclase in the albite-bearing phase of the Shingle Creek porphyry.

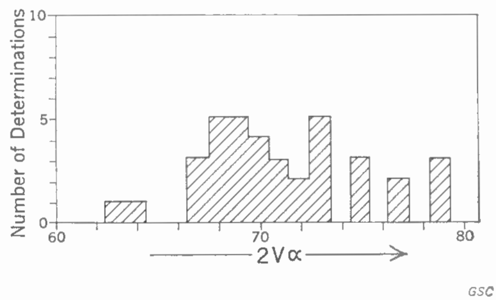


FIGURE 10. Histogram illustrating the frequency distribution of various values of 2V (alpha) of plagioclase in the oligoclase-bearing phase of the Shingle Creek porphyry.

similar to those found by Tuttle and Bowen (1950) in the Bein and Dubhaich granite, though the range toward values typical of volcanic rocks may be slightly greater at Shingle Creek.

The standard deviation of 2V alpha has been estimated for each specimen from the limited data obtained (*see* Table XVIII). The data suggest that two thirds of the plagioclase crystals in most specimens will possess optic angles within 4 degrees of the mean value.

Optic angles of plagioclase from the dykes and the neck were compared (*see* Table XIX). No significant difference appears in data for the oligoclase phase, but for the albite phase plagioclase from the neck may have larger optic angles than that from the dykes. As no significant difference in composition of plagioclase could be shown between the dykes and neck it seems likely that the albite of the neck rocks may have inverted to a slightly lower temperature structural state than that in the dykes.

Quartz

Megascopic Features

Quartz phenocrysts in the Shingle Creek porphyry are chiefly subhedral but both euhedral and anhedral crystals may be found. The crystals are commonly 1 cm long with bipyramidal faces prominent and hexagonal prismatic faces restricted or absent. Rounded corners and vermicular embayments are visible in quartz phenocrysts in most hand specimens.

Microscopic Features

In thin section quartz crystals are commonly seen to be fractured or, more rarely, shattered (*see* Pl. VIII A). Rarely they are shattered and slightly sheared to form schlieren of angular quartz fragments (*see* Pl. VIII B).

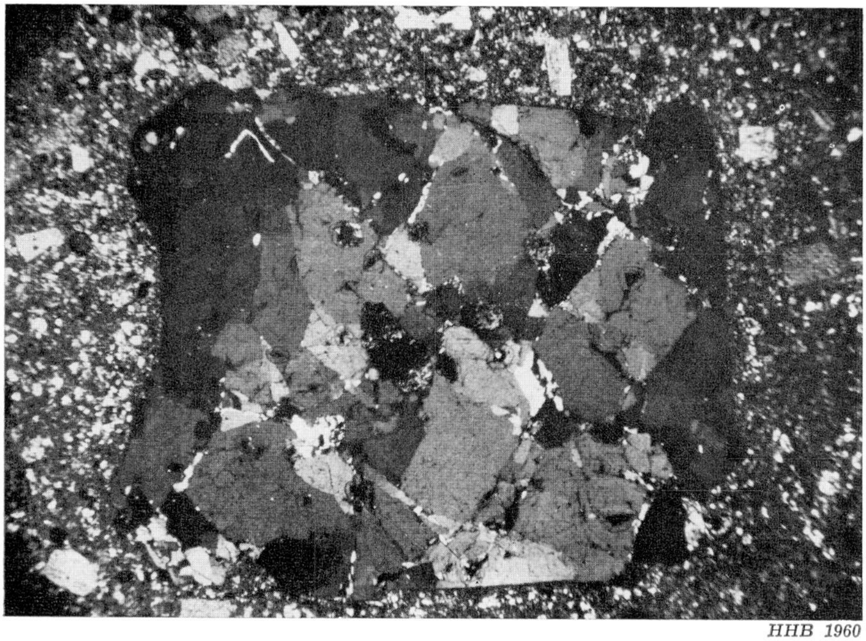


PLATE VIII A. Photomicrograph (x10) showing a shattered but undistorted quartz phenocryst.

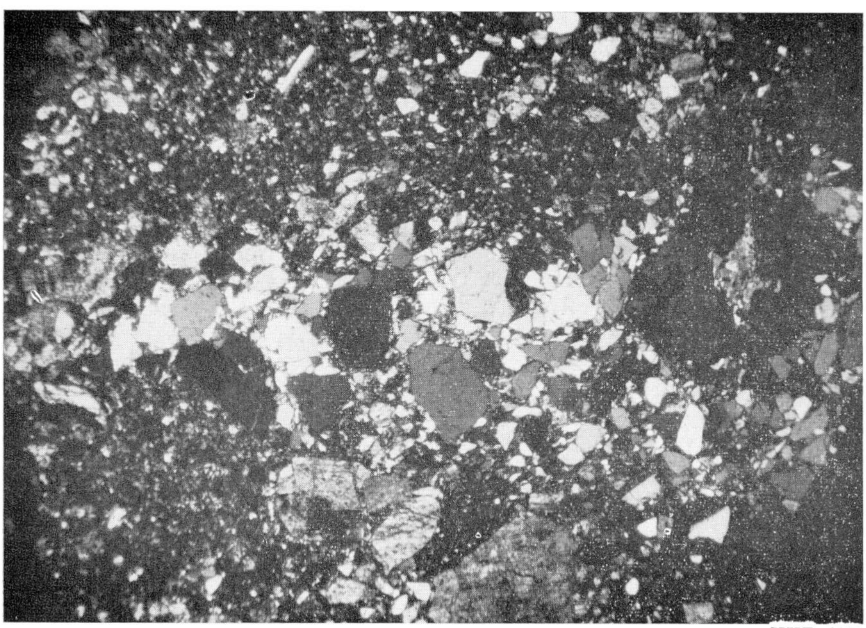
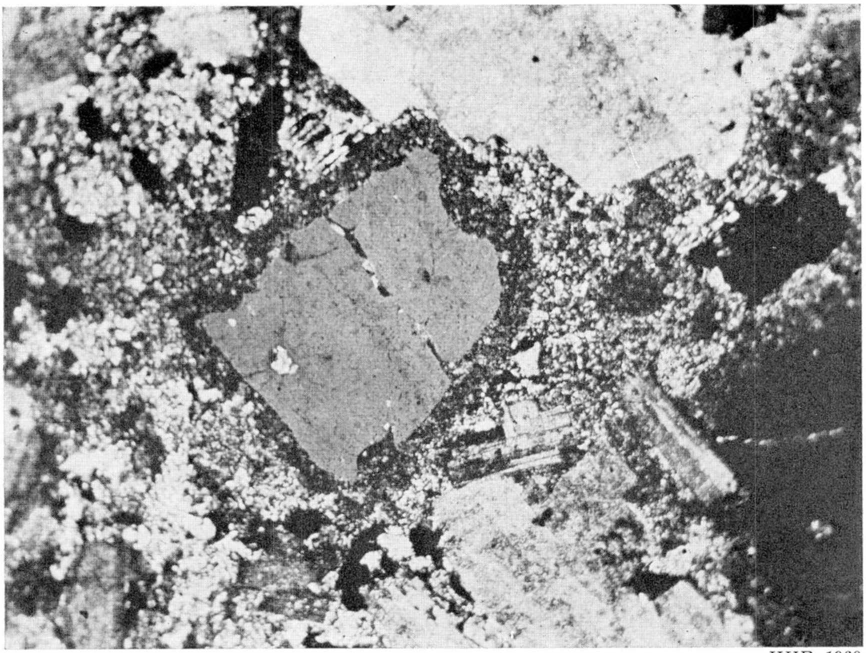


PLATE VIII B. Photomicrograph (x10) showing a fractured quartz phenocryst strung out by late movement of the magma.



HHB 1960

PLATE IX A. Photomicrograph (x10) showing a rounded quartz phenocryst with an unusually thick halo in parallel orientation. Silica in the halo may be chalcedony.

HHB 1960

PLATE IX B. Photomicrograph (x10) showing a fragmented quartz phenocryst with a thin coarse-grained halo in segments oriented parallel with adjacent fragments.

Many specimens of porphyry rocks in which the matrix is not very fine grained show quartz phenocrysts with thin even haloes of parallel oriented quartz matrix grains that typically follow the form of the embayed phenocrysts. Rarely in coarser grained haloes, the corners of the halo may be more distinct than those of the phenocryst within. In general, the character of the halo varies closely with that of the matrix; however, a few specimens with exceptionally thick haloes were found in the dyke division. Grains comprising haloes of the latter type (*see* Pl. IX A) appear cloudy with somewhat lower refractive indices than quartz. Extinction, though apparently parallel with the central quartz crystal under low magnification, may be undulose or radiating in grains seen under higher magnification. Such haloes may contain chalcedony (?) rather than quartz. Haloes about fractured quartz phenocrysts are oriented parallel with the nearest quartz fragment (*see* Pl. IX B).

Comparisons of quartz phenocrysts from albite and oligoclase phases, from neck and dyke divisions, and from porphyry variants with and without large sanidine phenocrysts, show that embayed crystals are present in all varieties of porphyry. Considerable variation, however, may be found in quartz from a single specimen and it is possible that significant differences in average character of the embayments may be present in quartz from certain parts of the intrusion. In particular, embayments in quartz from the oligoclase phase at the east end of the north dyke, where large sanidine phenocrysts are particularly scarce, may be generally more angular and nearly euhedral crystals more common than in the rest of the intrusion. A more quantitative comparison of quartz textures in different parts of the intrusion might prove rewarding in further work.

Matrix

The porphyry matrix is composed chiefly of quartz and alkali feldspar, the latter being slightly more abundant to judge from estimates of refractive indices made on the least altered thin sections. Both quartz and feldspar are anhedral and range in grain size from approximately 0.001 mm to 0.1 mm. Many specimens show matrices more or less permeated with very fine grained alteration products and interspersed with patches of small clear interlocking quartz grains.

Finer grained matrices occur somewhat irregularly along the borders of the intrusion and commonly, though not always, where the dykes appear to be narrow. They were found over extensive areas along southeast contact canyon, in the porphyry lens in the 'cone' deposits south of the neck and along the south margin of outcrops on the north dyke. The occurrence of coarser matrices appears to be sporadic, but that of slightly coarser than normal is common in the dykes north of Shingle Creek.

Structural Features

Depth of Burial

The following features in the central and southeast parts of the porphyry intrusion suggest that the porphyry reached the existing early Tertiary surface:

(1) The larger part of the Springbrook Formation south of the porphyry consists of several hundred feet of rhyolitic tuff containing fragments of the same minerals present as phenocrysts in the porphyry. Bedding, present near the top of the Springbrook Formation at Shingle Creek, dips away from the porphyry centre. This is consistent with the hypothesis that these rocks form the remnants of a volcanic cone developed by porphyry eruptions.

(2) A few cobbles and angular fragments of granodiorite are included in the porphyry near the tops of the hills in the neck area, but similar inclusions were not found on the lower slopes or in the dykes. (The large angular inclusions of country rock in the north dyke are of a different character and there are no cobbles.) This occurrence is consistent with the hypothesis that the present hilltops represent a level in the intrusion not far below the surface debris of lava and country rock fragments that may accumulate in the orifice of a vent.

(3) The optic angles of sanidine from the east and central parts of the neck are low (13 to 30 degrees, *see* Table XIV), a feature that suggests that these crystals were chilled. Possibly differences in volatile content of the magma or rate of its emplacement might influence the degree of chilling and account for some variation in optic angle, but the presence of much lower optic angles in some neck specimens than in any of those from the dykes may well result from severe chilling due to early exposure to surface conditions.

(4) The severe alteration of sanidine phenocrysts in the neck as compared with those in the dykes, and the generally more altered condition of rocks particularly in the eastern parts of the neck, may be effects of meteoric water on hot rock.

(5) Several outcrops of porphyry have been found within the tuff of the Springbrook Formation suggesting the presence of flow rocks though exposures are not good enough to preclude the possibility that these represent a dyke.

(6) Despite the width of the eastern third of the intrusion there is no marked variation in grain size from the walls inward, suggesting that no part of the present surface was far from the original margin of the intrusion.

Although the magma forming the present outcrops of the porphyry in the neck area may have reached the surface, it is unlikely that the magma forming those in the dykes did so. The fact that tuff and agglomerate west of Okanagan Valley are not found in Shingle Creek valley below the elevation of the granodiorite rim south of Shingle Creek is notable in this respect, particularly as these deposits are at least some hundreds of feet thick immediately south of the rim. Furthermore, no remnants of the flows of the Marron Formation occur within Shingle Creek valley, although several post-porphyry dykes are found and a major basic dyke cuts across the head of southeast contact canyon. Shingle Creek valley therefore may be younger than the Shingle Creek porphyry. If so, a projection of the granodiorite surface from the lower limit of the Springbrook Formation south of Shingle Creek to the skyline north of the creek would suggest that the present upper surface of the dykes was some 1,500 feet below the surface of the granodiorite just before the former were intruded. The complete absence of agglomerate cobbles in the dykes west of Okanagan Valley may support the conclusion that the magma of the present outcrops in that area did not reach the early Tertiary surface. This, however, does not imply that the suggested porphyry vent did not extend westward to the region over the dykes.

Contact Features

Most of the contacts observed between the porphyry and its wall-rocks are gently undulating but relatively smooth for distances of as much as several hundred feet. Evidence of shearing in the form of finely brecciated, rotten country rock partly cemented by calcite is common along the smoother stretches of contact. Refusion or welding of this fine-grained breccia was not observed, except for the contacts of the narrow isolated dyke in the extreme northwest. At this location the contact rock was sufficiently indurated to permit a thin section to be cut across the contact. This shows that the country rock (diorite) has been mylonitized along the contact. Andesine crystals from the diorite are broken or bent in a fine-grained cataclastic matrix containing a more than normal amount of magnetite and a brown, fine-grained alteration product. The dioritic part of the section is crossed by narrow anastomosing lenses of magnetite, chlorite, and brown alteration product giving the rock a rough augen-like texture. Shearing is evident in the porphyry also, for quartz phenocrysts along the immediate contact have been broken and strung out into lenses of angular fragments.

Contacts at the east end of the north dyke are poorly exposed; however, irregular short, crooked offshoot dykes penetrate the granodiorite along the north contact in the first major gully cutting the east end of the dyke. It is interesting to note that there the margins of the dyke (albite phase) contain large granodiorite inclusions. Farther to the west the southern contact of the north dyke is relatively smooth and nearly vertical wherever exposed. Unfortunately the north margin of the dyke is nowhere well exposed but the fact that the two sides are roughly parallel suggests that this contact is also nearly vertical.

The smaller dykes, where exposures permit their dip to be estimated, are inclined. The isolated dyke northwest of the north dyke appears to dip about 40°NW and one of the small dykes, poorly exposed on the north bank of Shingle Creek near its mouth, dips approximately 50°W.

Along the south wall of southeast contact canyon, the contacts are steep; on the north wall, however, dips vary. On the west, interbedded tuff and agglomerate strikes approximately parallel with the canyon, and dips from 35° to 50°SE, apparently lying on top of the porphyry. This attitude persists eastward down the canyon to the end of the continuous agglomerate outcrop. Just above the point where the canyon turns south, an inclusion of agglomerate some 45 feet across may be seen in the cliff face. Both vertical contacts of the inclusion are sheared and subparallel shears are present in the porphyry on either side. Except for a small outcrop of tuff, no more country rock is visible along the north wall of the canyon until the mouth of the upper canyon is reached. There an agglomerate remnant perhaps one quarter mile long lies on the porphyry surface. Lentils of sandy tuff and a lens of bedded fine silt and sand 9 feet thick dip as much as 30°E.

Alteration of the Country Rock

Most outcrops of country rock in the immediate vicinity of the intrusion are friable, but some sound rock has been exposed in road-cuts along the course of Shingle Creek. There the coarse-grained granodiorite is jointed into large irregular blocks that show a reddish brown stain penetrating to a depth of several inches. Biotite and hornblende of the normal granodiorite are absent and their place is taken by magnetite and green chlorite. Composition and zoning of the plagioclase grains are like those in the normal granodiorite, but potash feldspar crystals have been severely sericitized. Within a few inches of the contact all mafic minerals except magnetite have been replaced by calcite and a hydromica of low (–) 2V.

Along the southeast margin of the porphyry the Springbrook agglomerate is commonly stained dark reddish brown for a distance of 3 or 4 feet from the contact. The friable condition of the agglomerate in contact with the porphyry is in sharp contrast with the indurated condition of the same rock along the contacts of a later basic dyke probably associated with the Marron Formation.

Joints in Country Rock

Joints in the rock surrounding the porphyry are best developed north of Shingle Creek. Four groups of such joints were noted in eighteen measurements as follows:

(1) N10°W to N25°E, dip 35°W to vertical
(2) N60°E to N65°E, dip 55°NW to vertical
(3) N80°E to N85°W, dip 55°N to vertical
(4) N55°W to N65°W, dip 55° to 80°NE.

The north dyke follows two distinct bearings (*see* Map 1169A, inset); the eastern two thirds is at N85°W, and the western third at approximately N55°E, the change in trend being fairly abrupt. The two fairly consistent trends conforming closely to those of observed joints suggest that the emplacement of the north dyke may have been in part controlled by joints in the country rock.

DISCUSSION

In the preceding sections the author's observations concerning the Shingle Creek porphyry have been described with a minimum of inference. In this section pertinent data are summarized and an attempt is made to suggest possible processes capable of accounting for the observations. Because of the complexity of many volcanic centres and the fragmentary and in part negative evidence obtained from Shingle Creek, such processes should not be regarded as theories but as hypotheses to be tested in the light of present and future knowledge.

Sanidine

Large sanidine phenocrysts from the porphyry have compositions chiefly in the range Or_{70}-$Ab_{30} \pm 10$. A delicate oscillatory zone pattern characteristic of most of these crystals shows zones in pairs with gradational borders within pairs such that the inner member of each pair has the higher partial birefringence (gamma-alpha). An increase in the definition of zones toward the border of most crystals has been noted. The stability of the zone pattern in the face of heat treatment has been shown to be greater than that of unmixing. Some crystals from the porphyry are unmixed on a submicroscopic scale, and such crystals show average optic angles greater than crystals that are not unmixed. The distribution of high and low optic angles suggests that the lowest may be found in the neck division; however, severe alteration of crystals has greatly limited the number studied from this division.

The precise nature of zoning in the Shingle Creek sanidine phenocrysts has not been established, but several possibilities are suggested. Variation in alpha refractive index between zones is consistent with slight changes in Or-Ab ratio (though changes in Rb, Sr, or Ba might produce similar variation). If this is so, then typical variation within zone pairs indicates an inner sodic maximum that progresses gradationally to an outer potassic maximum. The stability of the zone pattern in the face of heat treatment suggests the possibility that a structural difference, such as a change in Al-Si order, may also be present between zones. A correlation between possible Ab-Or changes and oscillations in water vapour pressure in the magma is suggested under *Crystallization of Phenocrysts*.

Investigation of optic angles in sanidine phenocrysts from the Shingle Creek porphyry has suggested that the average optic angle might be used as an index to the degree of cryptoperthitic unmixing attained in various parts of the intrusion. The very limited number of crystals investigated from the neck environment has suggested that the lowest optic angles may be characteristic of this division. It is also possible that optic angles are slightly lower in sanidine from the narrower dykes than in that from the broader dykes. However, lack of outcrops in critical areas that would define dyke width has prevented the establishment of this suggestion.

Plagioclase

Plagioclase in the Shingle Creek intrusion occurs chiefly in two distinct compositions: Albite (An_1 to An_8) and oligoclase (An_{19} to An_{25}). The low frequency of compositions between these ranges is remarkable, in view of the close association of the phases of the intrusion in which the two plagioclases are found.

The occurrence of relatively pure albite and oligoclase in the same rocks has been mentioned by Laves (1954) and Friedlaender (1952). DeWaard (1959) has drawn attention to the scarcity of plagioclase in approximately the same range in the Usu massif, Timor, and suggested that the transition from An_5 to An_{20} took place in a narrow pressure-temperature field during metamorphism.

Laves (1954) and Ribbe (1958) have investigated peristerites (An_5 to An_{17}) from granites and pegmatites and have shown that plagioclase in this range from "low temperature" environments is submicroscopically unmixed. Ribbe suggested that such unmixing occurs on a very fine scale only, because of the difficulty of diffusion of Al-Si over any appreciable distance due to the strength of their bonds. Unmixed specimens were found to be homogenized by severe heat treatment.

At Shingle Creek the absence of plagioclase in the peristerite range might be the result of very slow growth at relatively low temperature. The coexistence of two feldspars of compositions shown (very sodic plagioclase and sodic sanidine) suggests crystallization at low temperature and high water vapour pressure relative to those achieved in dry or moderately wet rhyolites (Tuttle and Bowen, 1958). Slow growth of plagioclase under high water vapour pressure and low temperature would allow maximum opportunity for the attainment of equilibrium and would mean that structures only slightly more stable than their alternatives might be distinctly favoured. If the solvus for the peristerites intersects the liquidus under reasonable conditions of water vapour pressure (phase relations of peristerites are unknown) then the unmixing relation shown by the peristerites might mean that the formation of plagioclase crystals, or zones, of peristerite composition would be prevented.

Alternatively the very low proportion of plagioclase in the peristerite range might arise from fortuitous tapping of a magma evolving toward more calcic compositions. The scarcity of oligoclase overgrowths on albite might arise if magma were tapped before crystallization of the phenocrysts began. Such a condition might be envisaged in a magma produced by differential fusion, very early mixing of select magmas, or very early assimilation of select country rock.

Measurements of the optic angle of plagioclase phenocrysts from the porphyry have indicated that albite is in an intermediate to low thermal state, whereas oligoclase is in an intermediate to high thermal state. Comparison of variations between the dyke and neck divisions of the intrusion has suggested that albite in the neck division has significantly higher optic angles (lower thermal states) than that in the dykes.

MacKenzie (1957) has shown that the thermal state of albite will vary according to the temperature and pressure at which crystals are annealed provided that sufficient time is allowed for equilibrium to be attained. He also showed that the initial temperature of crystallization will influence the response of crystals to annealing. Tuttle and Bowen (1958) have shown that granite magma may be expected to form at sufficient depth at below 650°C, though the presence of sanidine may suggest that temperatures below this were not reached (Laves, 1952). Crystallization of the phenocrysts at Shingle Creek at temperatures of this order would suggest that the plagioclase reached an intermediate thermal state during crystallization. If temperature did not rise appreciably thereafter such crystals would be found at the surface in a similar or lower thermal state than that established at depth. This may explain why the optic angles of albite at Shingle Creek approach that of low albite more closely than they do that of high albite produced in the laboratory. The fact that higher optic angles (and hence lower thermal states) were found in the neck division than in the dyke division might result from one or a combination of the following causes:

(1) The phenocrysts in the neck crystallized at lower temperatures than those in the dykes.

(2) The phenocrysts in the neck crystallized more slowly than those in the dykes.

(3) The phenocrysts in the neck cooled more slowly through the range of temperatures at which Si-Al ordering of albite takes place than did those in the dykes.

(4) The retention of volatiles during critical periods of cooling may have been greater in the neck than in the dykes.

The low optic angles (low degree of unmixing) of sanidine in the neck compared with the low thermal state (high degree of Al-Si order) of albite, and the reverse relationship in the dykes at first appear conflicting. The conflict however may be resolved if the thermal state of albite and unmixing of sanidine have resulted from conditions at different depths. Since unmixing in sanidine involves displacement of alkali cations whereas a change in thermal state of albite probably involves the more difficult interchange of Si-Al, it might be expected that the former would respond to conditions of lower intensity and hence perhaps shallower depth. Possibly wider conduits leading to the neck than to the dykes may have permitted a relatively slower passage of magma through stages critical in the ordering of albite in the former.

Some evidence suggests that magma represented by outcrops in the neck division may have reached the early Tertiary surface, whereas that in the dyke division did not and may have crystallized as much as 1,500 feet or more below this surface. If the intensity of conditions within the magma remained high enough to prevent cryptoperthitic unmixing of sanidine until the magma came to rest, then it may be suggested that the environment of the neck could have permitted the freezing of essentially non-unmixed sanidine whereas that of the dykes at some distance below the granodiorite surface could have permitted a longer period of adjustment toward surface conditions resulting in the more advanced cryptoperthitic unmixing observed in many sanidine crystals from the dykes.

Crystallization of Phenocrysts

Normative calculations suggest that quartz and alkali feldspar components average about 90 per cent of the Shingle Creek porphyry. At the same time the only apparently significant variation in the composition of the porphyry magma is a slight increase in the lime content (averaging less than one per cent) in the final phase of the intrusion. This suggests that the development of the phenocrysts and their textures in the intrusion as a whole might be tentatively considered in the light of the phase relations established by Tuttle and Bowen (1958) for the $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O system.

Tuttle and Bowen (op. cit.) have emphasized that the principal feature of this system is the deep trough on the liquidus surface that exists along the quartz-feldspar boundary. They have also shown that increase in water vapour pressure may shift this boundary by nearly 10 per cent away from the silica apex of the system. Accompanying the shift in the quartz-feldspar boundary, the minimum in the system shifts toward the Ab apex and becomes a ternary eutectic at sufficiently high water vapour pressures. These features are illustrated in Figures 11 and 12.

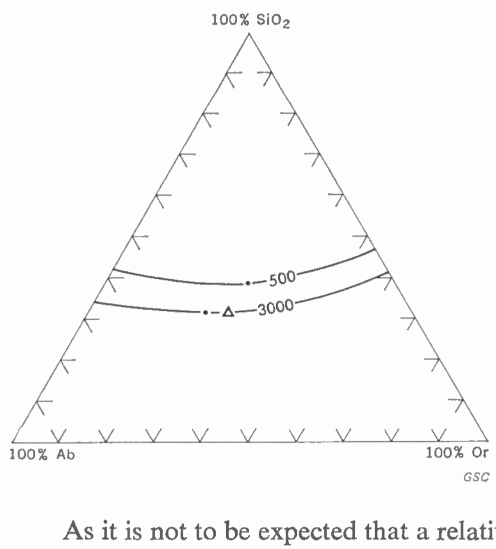


FIGURE 11. Diagram showing the effect of water-vapour pressure on the quartz-feldspar boundary in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O. The upper boundary is at 500 kgm/cm², and the lower at 3000 kgm/cm². The small triangle represents the proportions of normative quartz, albite, and orthoclase of the average porphyry analysis recalculated to 100 per cent. Solid circles show the position of the eutectic at each pressure (boundary curves *after* Tuttle and Bowen, 1958).

As it is not to be expected that a relatively sodic melt such as the Shingle Creek porphyry could crystallize extensively a single feldspar as potassic as the sanidine observed, Or_{60}-Or_{80}, it is probable that plagioclase and sanidine crystallized essentially together. Although it cannot be denied that small amounts of either feldspar may have crystallized first, this might be expected to leave evidence in the form of progressive zoning in the cores of one or other feldspar. Either, reaction has obliterated such cores or they were not formed to an appreciable extent. Tuttle

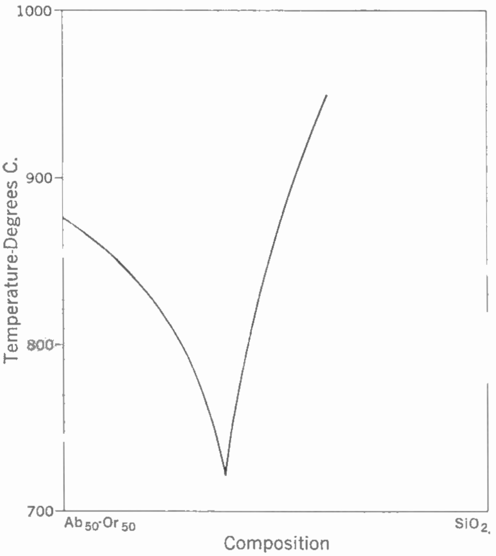


FIGURE 12. A section through the 1000 kgm/cm^2 isobaric prism from Ab_{50}-Or_{50} to the SiO_2 apex showing the nature of the thermal valley along the quartz-feldspar boundary (*after* Tuttle and Bowen, 1958).

and Bowen (1958) have discussed the crystallization of two feldspars in rhyolites and suggest that sodic plagioclase and sanidine may coexist at equilibrium in an anorthite-free melt at water vapour pressures about 3,500 kg/cm^2. They also suggest that the addition of lime will decrease the pressure necessary to permit the formation of two feldspars. Because of the low anorthite content of the porphyry rocks, it seems reasonable to assume crystallization of the phenocrysts at water vapour pressures perhaps slightly lower than 3,500 kg/cm^2. This pressure of water vapour places the quartz-feldspar boundary and ternary eutectic close to the composition of the average porphyry analysis and also suggests that crystallization of feldspar was probably accompanied over most of its duration by crystallization of quartz. Hence, it may be argued that the greater part of crystallization of the phenocrysts occurred under essentially ternary eutectic conditions.

The outstanding textural features of the phenocrysts appear to be: the common growth of unusually large sanidine crystals without substantial change in composition; the plagioclase and a few quartz inclusions in sanidine and locally sanidine overgrowths on plagioclase, but no sanidine or quartz inclusions in plagioclase; the oscillatory zoning in sanidine; and the irregular embayment of quartz phenocrysts. Conditions of crystallization must account for these features.

Comparison of modal analyses (corrected for exclusion of sanidine) between specimens with a maximum of large sanidine phenocrysts and those with essentially none, suggests that the proportion of sanidine to other phenocrysts is considerably greater in the former group. This, and the absence of sanidine inclusions in plagioclase, the occasional inclusion of quartz, the common inclusion of plagioclase in sanidine, and the local overgrowths of sanidine on plagioclase, suggests that the large crystals grew rapidly with respect to quartz and plagioclase phenocrysts (under ternary eutectic conditions). Maintenance of zone thickness in the outer parts of the large sanidine crystals even approximately similar to those in the inner parts, suggests that the rate of deposition of sanidine on these crystals increased as crystallization progressed provided that the period of oscillations in conditions causing the zoning remained constant or decreased. On this assumption it would appear likely that, in some variants of the porphyry magma, a late stage of preferred growth of sanidine occurred. As there is little evidence of general progressive change in the composition of feldspar crystals as opposed to oscillatory changes, it is possible that there was little progressive change in water vapour pressure or temperature during crystallization that might have caused preferred growth of sanidine. Possibly this feature resulted from very slight progressive enrichment of some magma variants in K-Al. The present analyses, however, are not sufficient to demonstrate such enrichment, and other possibilities affecting the rate of sanidine growth may exist.

Large sanidine phenocrysts were estimated to be fewer in most of the albite phase of the neck (the albite porphyry at the southern edge of the neck being the chief exception). In the oligoclase phase large sanidine crystals are least abundant in the wider east end of the north dyke but appear to increase in abundance westward as the size of the dyke diminishes. They are notably abundant everywhere the dykes are known to be narrow, though they are also common in wider parts of the oligoclase phase south of Shingle Creek.

Possibly the large crystals might have been excluded from parts of the magma by some form of filter pressing. However, it would be then difficult to explain why the quartz and plagioclase phenocrysts were not also excluded and why the large sanidine phenocrysts are commonly least abundant in what appear to be major conduits of the intrusion. Rather the distribution suggests either crystallization of the large sanidine crystals in narrower conduits, or different conditions of emplacement of slightly different magma variants separated at depth. The former suggestion may be discarded because it seems to require crystallization of a single alkali feldspar more sodic than the present crystals. If the latter suggestion is true, magma from the upper levels of the magma chamber, perhaps enriched in large sanidine crystals, may have been forcefully emplaced into all conduits. The following magma from somewhat lower levels, at a somewhat earlier stage in crystallization and not enriched in large sanidine crystals, might be emplaced less vigorously and replace the previous magma from the main conduits only. A few large crystals might become included in late rising magma and would account for their presence where large sanidine crystals are generally scarce. This latter suggestion appears best able to account for the observed distribution of the large sanidine crystals.

In order to produce the oscillatory zone pattern in sanidine, oscillations in temperature or vapour pressure of water might be considered. Though either process might result in zoning, it is perhaps more difficult to conceive how temperature oscillations could be widely and fairly evenly transmitted through a magma chamber. Increase in water vapour pressure might result from progressive crystallization and consequent concentration of volatiles in the melt. This increase

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might be periodically compensated for by failure of the overlying rocks due either to attainment of some critical pressure of water vapour or possibly to movement along the Vernon-Sicamous fault. Such movements are believed to have occurred both before and after emplacement of the porphyry magma (see *Structural Features*), and it therefore appears plausible that they might have been in progress during crystallization of the large sanidine crystals. The form of zones in the large sanidine crystals (apparent inner sodic maxima gradational to outer potassic maxima) suggests gradual build up of water vapour pressure followed by abrupt release. Following an abrupt release, sodic sanidine might be expected to crystallize. However, as pressure built up, progressively more potassic sanidine might be expected to crystallize as a result of the lowering of the solidus and its consequent intersection with the sanidine solvus at more potassic compositions. With further rise in water vapour pressure crystallization might cease and the outer surfaces of the sanidine would react toward more potassic compositions. Abrupt release of water vapour pressure would cause abrupt reversion to crystallization of sodic sanidine and the cycle would be repeated.

The development of haloes of matrix quartz in common orientation with the embayed quartz phenocrysts they surround suggests that embayments formed before the matrix crystallized. As embayed quartz crystals appear in all variants of the porphyry, it is probable that the conditions that produced embayment acted on all variants though these may have been modified in some parts of the intrusion as suggested by possible variation in the average character of the embayments. The presence of sodic plagioclase and sanidine has suggested that crystallization of the phenocrysts took place at depth under high water vapour pressure (equivalent to a depth of roughly 11 km) and it may therefore be argued that all variants have undergone a large decrease in water vapour pressure and consequent supercooling attendant on the rise of the magma from this depth to the surface. Possibly embayment of quartz may result from either irregular growth or corrosion, or both, during the ascent of the magma from the depth at which eutectic crystallization occurred.

Rock Variation

The present study has revealed the close similarity in most aspects of the chemical and mineral composition of rocks throughout the Shingle Creek porphyry. However, the data obtained have suggested that a late phase of the intrusion is slightly but significantly richer in lime than the phase that preceded it. This difference has been accompanied by a rather abrupt change in plagioclase composition from albite to oligoclase.

The solvus-liquidus relation suggested for the peristerites might provide a mechanism for concentrating a limited amount of lime in the liquid phase of the magma through the crystallization of albite, although, it is doubtful if this process alone could produce two distinct plagioclase phases without extensive overgrowths. It therefore seems probable that some additional process may have acted to concentrate lime slightly in the later emplacements of porphyry magma. The direction of change in composition with time is inconsistent with simple fractional crystallization from an intermediate or acid magma and may reflect the dominating influence of some other process. Magma mixing, assimilation of country rock, or differential fusion might account for the trend.

Consideration of the composition of the Marron volcanic rocks suggests that admixture of any one of the flows analyzed would be unlikely to raise the calcium content of the magma without affecting significantly all the other major oxides with the possible exception of soda and potash. However, the possibility that a dyke like one of the less basic dykes (not chemically analyzed) exposed at the surface may have entered the Shingle Creek porphyry magma chamber and become uniformly mixed to form the oligoclase phase cannot be ruled out.

Alternatively, analyses of the older plutonic rocks at Shingle Creek suggest that the granodiorite may approach the composition of the Shingle Creek magma in all oxides except that of calcium, which is two to four times more plentiful in the granodiorite. This suggests that assimilation of granodiorite at depth may provide a process capable of increasing the lime content of the porphyry magma without detectably altering the proportions of the remaining oxides. The uniformity in composition of the porphyry, except for the slight variation in lime content, and the low proportion of overgrowths of oligoclase on albite require that either magma mixing or assimilation took place at depth probably before the formation of phenocrysts began.

Consideration of differential fusion requires the inclusion of the anorthite component and is therefore beyond detailed analysis at present. However, if iron and magnesium were minor constituents in the source rock at depth, a small increase in the lime content of the magma forming would probably not be accompanied by a detectable change in the mafic constituents. The granodiorite conforms to these conditions and, furthermore, is the most extensively exposed rock type older than the porphyry intrusion near Shingle Creek. If differential fusion were to act on the same source rock in two pulses, two distinct magmas might be generated and extensive development of oligoclase overgrowths on albite might be avoided.

Structural Features

The disposition of the albite and oligoclase phases in surface outcrops have been described in the previous sections and are shown on Map 1169A. The intrusion has been divided into neck and dyke divisions, the dividing line being formed arbitrarily by the west wall of Okanagan Valley except for the small dykes cutting lower Shingle Creek valley. The westward tapering structure of the intrusion and the greater proportion of phenocrysts to matrix in the dyke division suggest that the east end of the intrusion was probably the most active part during the albite phase. The scarcity of phenocrysts in the oligoclase phase at the broad east end of the north dyke suggests that the centre of activity may have moved slightly westward during the life of the intrusion.

The southward-facing crescentic pattern of the intrusion enhanced by the southward hook at the east end of the oligoclase phase suggests that the fundamental structure of the porphyry might be compared to that of a ring dyke perhaps modified by near surface conditions which allowed the intrusion easiest access to the surface at its east end. In this regard it is notable that, though the north dyke follows two bearings approximately parallel with joint sets in the granodiorite north of Shingle Creek, it has selected only those parts of the fractures consistent with the ring dyke pattern. No major offshoots project northeast toward Penticton.

Billings (1943), who has summarized the characteristics of ring dykes, pointed out that such dykes do not normally form complete circular structures but commonly extend over 180 degrees of arc or less. With evidence gained from New Hampshire, he suggested that the intrusion of vertical ring dykes may have been controlled by a pre-existing annular vertical fracture zone the width of which was comparable to the present width of the dyke. Such a fracture zone, he pointed out, would have been a place of weakness, very susceptible to piecemeal stoping.

Though most of the ring dykes described by Billings are larger than the Shingle Creek porphyry, some structural features of the latter may be consistent with his hypothesis for vertical ring dykes. The steeply dipping intersecting joint sets in the granodiorite north of Shingle Creek (strike N60°E and N85°W) may have aided in the production of a vertical fracture zone the form of which expresses both the surficial planar nature of the joint sets and the deeper environment of the intrusion. The granodiorite inclusions in the albite phase along the margins of the north dyke and the distorted plutonic rock fragments in the agglomerate of the Springbrook Formation support a hypothesis of piecemeal 'stoping' with upward removal of the country rock.

The location of the Shingle Creek porphyry adjacent to Okanagan Valley with its widest section immediately west of the valley floor has been pointed out. Jones (1959) has suggested that the Vernon-Sicamous fault, which he believed to be a system of subparallel, linked faults, extended the complete length of Okanagan Valley in Canada and possibly reached a total length of 170 miles. Regarding the dating of this fault, Jones stated:

> Tertiary lava flows are mostly and characteristically confined to plateau-like cappings of the hills but along the line of the Vernon-Sicamous fault, numerous remnants of basaltic flows are at or near the level of the valley bottom. In one place, where the crush-breccia of the fault is exposed, pieces of basalt were mixed with fragments of granite and gneiss, suggesting post-lava movement on the old Vernon-Sicamous fault. The sequence of events is interpreted to be as follows:
>
> (1) Creation of the fault in pre-Tertiary time.
> (2) Erosion of a valley along the fault.
> (3) Filling of the valley by lava in Tertiary time.
> (4) Renewed movement along the fault.
> (5) Renewed erosion along the line of the old fault valley, leaving remnants of the lava flows.

The length of this fault zone suggests that it may represent a major structural feature in the earth's crust. The close association in space and time of the Shingle Creek porphyry with faulting suggests that the timing and perhaps the generation of the intrusion may be related to energy release during early movements along the Vernon-Sicamous fault zone.

A Sketch of Historical Geology at Shingle Creek

The consolidation of the plutonic rocks in this area has been inferred from age relations reported for similar rocks in the surrounding terrain to have taken place in the middle or late Mesozoic. Late in the plutonic phase the diorite and granodiorite were intruded by granitic dykes. Field relations suggest that the conditions of emplacement of these dykes were marginal between plutonic and hypabyssal.

Uplift and erosion, which probably started before intrusion of the fine-grained granitic dykes, occurred in the last part of the Mesozoic. This was accompanied by movements along the Vernon-Sicamous fault, and the incipient formation of Okanagan Valley. Increased activity along the fault at the close of the Mesozoic or in the early Tertiary may have set the stage for the Shingle Creek porphyry intrusion and eruption.

The porphyry intrusion occurred in two closely associated phases, the first characterized by albite phenocrysts and the second by oligoclase. The albite phase appears to have been the more extensive, as albite occurs at both east and west extremities of the intrusion. The centre of most active intrusion shifted westward from the neck area to the east end of the north dyke during emplacement of the oligoclase phase. Magma in the upper parts of the magma chamber prior to the injection of each porphyry phase may have reached a somewhat more advanced stage of crystallization in which the crystallization of sanidine was preferred. Initial injection is thought to have been most vigorous resulting in the emplacement of large sanidine crystals. The vigour of injection of each phase is thought to have waned as the injection progressed so that later magma, perhaps from slightly greater depth and not bearing large sanidine crystals, displaced earlier magma from the principal conduits.

Great quantities of volcanic ash now present as tuff in the Springbrook Formation south of Shingle Creek likely formed part of an irregular volcanic cone associated with a vent over the present site of the intrusion. The early Tertiary surface probably sloped southward as the upper surface of the plutonic rocks does today, and this may have facilitated collapse of northern parts of the cone deposits into the vent. Stream rounded boulders and gravel in transport from slopes north of the intrusion may have entered the vent and become intermixed with ash and perhaps occasionally with vesiculating lava. Masses of such rock, periodically ejected from the vent, are thought to have formed agglomerate bodies in depressions in the cone.

Though the surface products of the Shingle Creek volcano were mostly pyroclastic, a few restricted flows may have been extruded. At least one porphyry body lies in approximately conformable position within the tuff, but exposure is too meagre to determine whether such bodies are flows or sills.

The Shingle Creek porphyry eruptions were followed by deposition of trachyandesite flows and minor feldspathic tuff which lie on top of the cone deposits at most localities where the cone is overlapped by the Marron Formation. The trachyandesite flows were followed by a series of andesite flows and agglomerate

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that reach a thickness of some 3,000 feet west of Skaha Lake and probably more to the south. These flows are believed to have covered the country to the north as well as to the south of Shingle Creek.

Younger Tertiary sediments were probably not deposited extensively in the Shingle Creek area, though late Eocene or possibly later sediments and volcanic rocks are found in the White Lake basin and Okanagan Falls syncline some 5 or 6 miles to the south.

The Shingle Creek area is believed to have been completely overridden by ice during the Pleistocene. As conditions ameliorated, ice-ponded and dammed lakes were formed in Okanagan Valley and in some of the surrounding valleys. These have left silt terraces at varying levels about the mouth of Shingle Creek and in the upper creek valley. Bursting of the ice-dam below Vaseaux Lake permitted Shingle Creek to carve its present lower gorge some 240 feet into these silt terraces.

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APPENDIX

Tables:

In tables used for the comparison of various parameters between the dyke and neck divisions or between the albite and oligoclase phases the mean and standard deviation (SD) are given. In calculating the standard deviation the following formula, which allows for small sample size (Moroney, 1956), was used:

$$\mathrm{SD} = \sqrt{\frac{\Sigma(X-\bar{X})^2}{n-1}}$$

X = individual value

$\bar{X}$ = mean

n = number of items involved in the mean.

The difference between means is given together with an estimate of the significance of the difference based on the "t" test. The significance levels suggested by Moroney have been employed:

NE = not established; significance level above 5 per cent.

PS = probably significant; significance level between 5 and 1 per cent.

S = significant; significance level between 1 and 0.1 per cent.

HS = highly significant; significance level below 0.1 per cent.

Comparisons in which the "F" test (*see* Moroney, 1956) suggests that the variances of the two populations are significantly different at the 5 per cent level have been marked with asterisks. In such comparisons the "t" test may not be strictly applicable.

Maps:

The small scale maps of the Shingle Creek intrusion in this section show the locations from which the crystal specimens listed in the tables were taken. The specimen numbers refer to the pertinent table only.

Tables and locations or rock analyses are given in the body of the report.

Table IX

Analyses and Norms of Rocks from the Shingle Creek Area (listed in order of decreasing age)

	1	2	3	4	5	6	7	8	9
SiO_2	52.3	61.0	61.4	68.7	70.99	52.4	52.7	57.3	53.3
Al_2O_3	17.7	16.2	18.6	16.6	14.77	17.7	17.7	19.7	16.4
Fe_2O_3	3.2	2.6	3.1	1.0	1.13	2.9	3.9	2.0	2.2
FeO	5.30	3.46	1.91	0.79	0.58	2.60	1.84	2.15	4.86
CaO	7.1	4.8	5.9	3.0	1.46	3.1	5.4	3.8	4.7
MgO	3.2	2.6	1.1	0.7	0.78	2.5	4.1	1.8	4.5
Na_2O	4.0	3.8	5.0	4.6	4.03	6.1	3.6	4.2	2.8
K_2O	2.8	2.8	1.8	3.1	4.23	5.2	5.7	5.7	3.7
H_2O^+	0.98	0.99	0.50	0.55	0.28	4.21	1.62		3.31
H_2O^-					0.71			1.24	
TiO_2	1.2	0.7	0.5	0.2	0.35	0.9	0.9	0.7	1.0
P_2O_5	0.6	0.2	0.2	0.0	0.10	0.9	0.8	0.4	0.7
MnO	0.2	0.2	0.1	0.1	0.00	0.1	0.0	0.1	0.2
CO_2	0.22	0.18	0.02	0.29	0.46	0.64	0.36	0.55	1.73
Total	98.8	99.5	100.1	99.6	99.87	99.3	98.6	99.6	99.4
Q		14.3	12.8	23.6	29.3			2.4	10.9
C				0.9	2.2			2.0	5.2
or	17.0	16.9	10.7	18.6	25.6	32.8	35.0	34.6	23.8
ab	34.7	32.7	42.4	39.5	34.7	36.4	29.3	36.4	25.7
an	22.6	19.2	23.0	13.2	3.8	5.9	15.8	13.2	8.5
ne						10.2	1.3		
di	6.7	2.1	3.9			0.1	3.4		
hy	10.0	9.1	1.2	2.3	2.0			6.0	18.5
ol	0.4					5.6	6.4		
mt	4.8	3.8	4.5	1.5	0.9	5.0	3.4	3.0	3.5
hm					0.6		1.7		
il	2.3	1.4	1.0	0.4	0.7	1.8	1.8	1.4	2.1
ap	1.5	0.5	0.5		0.2	2.2	1.9	1.0	1.8

1. Hornblende diorite south of Shingle Creek
2. Hornblende biotite diorite south of Shingle Creek
3. Hornblende granodiorite south of Shingle Creek
4. Hornblende biotite granodiorite north of Shingle Creek
5. Average of 16 analyses of the Shingle Creek porphyry

6, 7, 8, 9 Analyses of 4 basic flows overlying the Shingle Creek porphyry to the southeast.
6. Trachyandesite
7. Andesite
8. Andesite
9. Andesite

All analyses of Table IX were done by the rapid method by G. Mensah and S. Malone in the laboratories of the Geological Survey of Canada. Norms were calculated using the procedure of Wahlstrom (1947). Abbreviations used are:

Q	—	quartz	di	—	diopside
C	—	corundum	hy	—	hypersthene
or	—	orthoclase	ol	—	olivine
ab	—	albite	mt	—	magnetite
an	—	anorthite	hm	—	hematite
ne	—	nepheline	il	—	ilmenite
			ap	—	apatite

Table X

Comparison of Composition of Specimens from the Neck and Dyke Divisions (excluding large sanidine crystals)

	SiO_2		Al_2O_3		Fe_2O_3		FeO		CaO		MgO		Na_2O		K_2O	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Neck	71.3	1.2	14.8	0.3	1.1	0.1	0.56	0.15	0.9	0.4	0.9	0.3	4.2	0.4	4.4	0.3
Dykes	70.7	1.6	14.7	0.4	1.1	0.2	0.60	0.13	0.8	0.5	0.7	0.3	3.8	0.4	4.1	0.4
Difference	0.6		0.1		0.0		0.04		0.1		0.2		0.4		0.3	
Significance	NE		NE		NE		NE		NE		NE		NE		NE	

Table XI

Comparison of Composition of Specimens from the Albite and Oligoclase Phases (excluding large sanidine crystals)

	SiO_2		Al_2O_3		Fe_2O_3		FeO		CaO		MgO		Na_2O		K_2O	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Albite	71.6	1.1	14.7	0.4	1.1	0.2	0.54	0.10	0.6	0.4	0.7	0.2	4.1	0.5	4.3	0.4
Oligoclase	70.7	1.6	15.0	0.3	1.2	0.1	0.60	0.16	1.1	0.3	0.9	0.4	4.1	0.3	4.2	0.4
Difference	0.9		0.3		0.1		0.06		0.5		0.2		0.0		0.1	
Significance	NE		NE		NE		NE		PS		NE		NE		NE	

Table XII

Comparison of Phenocryst Counts for Rocks from the Neck and Dyke Divisions

	Quartz		Sanidine[1]		Plagioclase		Mafic Mins.		Matrix	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Neck	8.9	2.6	2.8	1.3	23.0	3.7	1.7	0.6	63.8	5.6
Dykes	10.4	1.9	4.7	3.3	26.7	4.4	2.6	0.5	55.7	3.5
Difference	1.5		3.7		3.7		0.9		8.1	
Significance	NE		[1]NE		NE		PS		PS	

[1]Only sanidine crystals less than 1 cm across were included

Table XIII

Comparison of Phenocryst Counts for Rocks from the Albite and Oligoclase Phases

	Quartz		Sanidine[1]		Plagioclase		Mafic Mins.		Matrix	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Albite	8.7	2.4	3.8	2.5	24.1	5.3	2.2	0.8	61.2	7.8
Oligoclase	9.9	2.7	4.0	2.7	24.6	4.2	2.1	0.6	59.5	5.5
Difference	1.2		0.2		0.5		0.1		1.7	
Significance	NE		NE		NE		NE		NE	

[1]Only sanidine crystals less than 1 cm across were included

Table XIV

Optic Axial Angles of Sanidine from the Shingle Creek Porphyry (*see* Fig. 13)

	Albite Phase				Oligoclase Phase			
	Specimen No.	Core	Rim	Mean	Specimen No.	Core	Rim	Mean
N	50	30	30	30.0	27	30	28	29.0
E	73	13	nd	13.0	38	26	27	26.5
C	162	28	20	24.0	171	14	11	12.5
K					174	34	31	32.5
					248	34	34	34.0
	175	24	28	26.0	179	32	33	32.5
	192	30	30	30.0	196	35	32	33.5
	270	37	39	38.0	285	41	43	42.0
	281	36	34	35.0	260	40	40	40.0
	313	38	31	34.5	288	28	30	29.0
	343	29	33	31.0	294	31	31	31.0
	348	32	33	32.5	296	43	42	42.5
D	365	30	27	28.5	362	31	34	32.5
Y	441	37	37	37.0	478	36	34	35.0
K	467	33	27	30.0	01	37	34	35.5
E	484	32	32	32.0	04	38	38	38.0
S	489	32	28	30.0	05	38	32	35.0
	496	29	30	29.5	07	37	37	37.0
	497	29	30	29.5	08	36	34	35.0
	03	36	37	36.5	010	40	38	39.0
	06	34	36	35.0	013	33	34	33.5
	011	25	24	24.5				
	012	43	43	43.0				
	014	36	40	38.0				

NOTE: Values for the core and rim of specimens 204 and 273 in which both albite and oligoclase were found are (21, 20) and (37, 36).

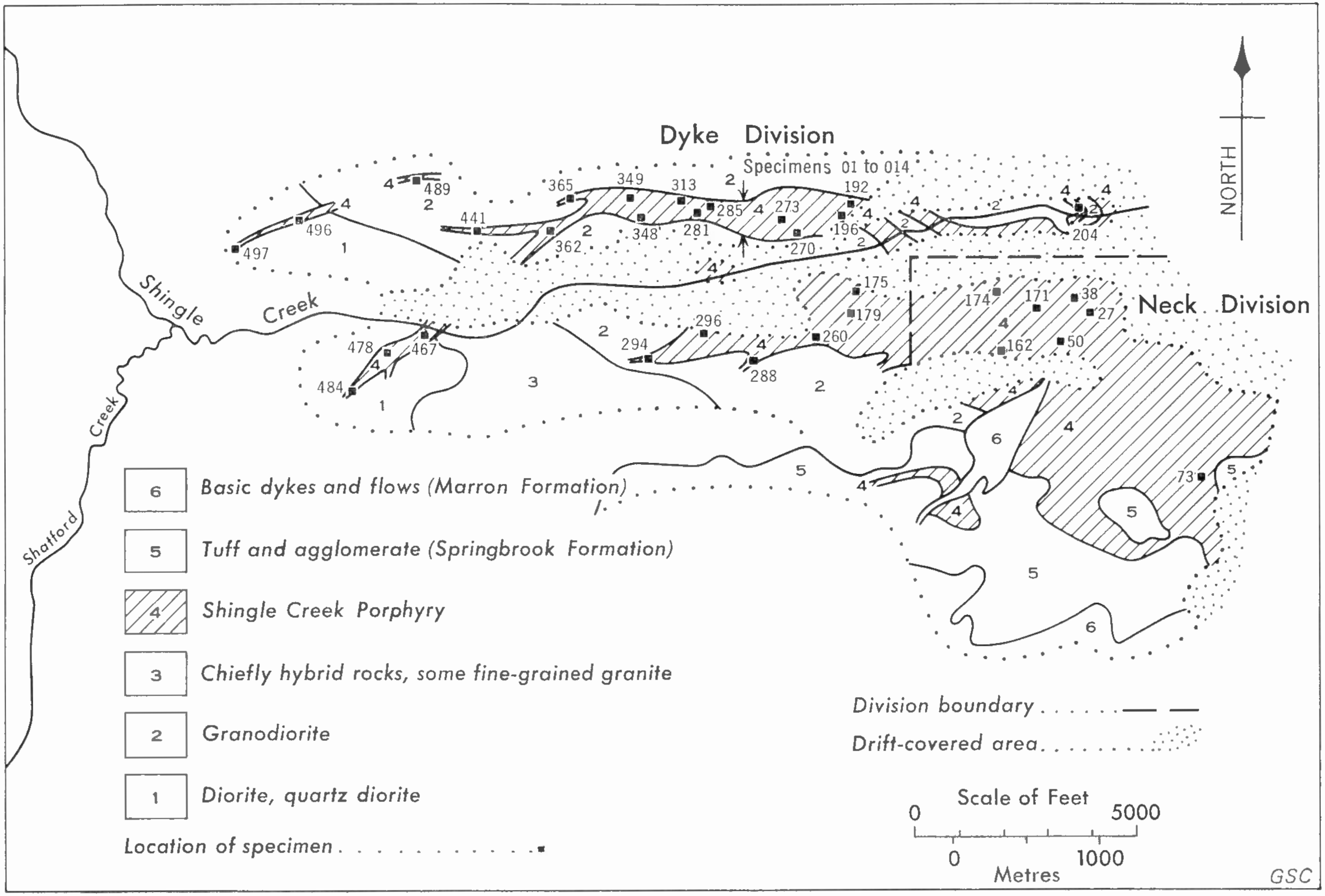

FIGURE 13. Locations of specimens of sanidine crystals on which optic axial angle measurements were made.

Table XV

Comparison of Optic Angles in Sanidine from the Albite and Oligoclase Phases and from the Neck and Dyke Divisions

Albite		Oligoclase		Neck		Dykes	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
31.3	6.2	33.6	6.4	25.2	8.3	33.7	4.9
Difference		2.3		Difference		8.5	
Significance		NE		Significance		PS[1]	

[1]In this comparison the variances are significantly different at the 5 per cent level and the 't' test is therefore not strictly applicable. Since the omission of the two crystals showing exceptionally low optic angles renders the variance of the two groups similar at the 5 per cent level but does not reduce the significance level of the difference in means below probably significant, this significance level is considered established.

Table XVI

Alpha Refractive Index Measurements on Plagioclase from the Shingle Creek Porphyry

Albite				Oligoclase					
Neck		Dykes		Neck		Dykes			
Specimen	RI	Specimen	RI	Specimen	RI	Specimen	RI	Specimen	RI
1	1.5302	19	1.5288	29	1.5372	35	1.5405	101	1.5393
3	1.5285	20	1.5284	30	1.5397	38	1.5388	102	1.5361
9	1.5301	21	1.5310	31	1.5392	37	1.5382	103	1.5374
12	1.5296	23	1.5287	32	1.5379	38	1.5386	104	1.5394
16	1.5273			34	1.5399	40	1.5386	105	1.5393
17	1.5296	60	1.5278			41	1.5392	106	1.5384
18	1.5291	61	1.5283	68	1.5388				
		62	1.5309	69	1.5407	85	1.5388	107	1.5389
44	1.5299	63	1.5290	70	1.5389	86	1.5388	108	1.5385
45	1.5287	64	1.5286	71	1.5388	87	1.5387	109	1.5384
46	1.5288	65	1.5295	72	1.5379	88	1.5391	110	1.5389
47	1.5308	66	1.5294	73	1.5391	89	1.5398	111	1.5379
48	1.5304	67	1.5303	74	1.5404	90	1.5373	112	1.5394
49	1.5279			75	1.5380	91	1.5388	113	1.5395
50	1.5312			76	1.5386	92	1.5382	114	1.5388
51	1.5292			77	1.5395	93	1.5390	115	1.5383
52	1.5279			78	1.5381	94	1.5382	116	1.5425
53	1.5280			79	1.5386	95	1.5406	117	1.5391
54	1.5292			80	1.5379	96	1.5381	118	1.5390
55	1.5287			81	1.5398	97	1.5392	119	1.5394
56	1.5308			82	1.5389	98	1.5388	120	1.5380
57	1.5290			83	1.5405	99	1.5386		
58	1.5310			84	1.5389	100	1.5394		
59	1.5288								

NOTE: Specimen numbers below 43 correspond to those in Table VIII showing 2V (alpha). Intermediate values 1.5343, 1.5318, and 1.5326 were not used in the comparison of albite and oligoclase phases.

Table XVII

Comparison of the Alpha Refractive Indices of Albite and Oligoclase from the Dyke and Neck Divisions

	Albite		Oligoclase	
	Mean	SD	Mean	SD
Neck	1.5293	0.0011	1.5390	0.0009
Dykes	1.5292	0.0010	1.5388	0.0010
Difference	0.0001		0.0002	
Significance	NE		NE	

Table XVIII

Optic Axial Angles of Plagioclase from the Shingle Creek Intrusion

(*see* Fig. 14)

Albite Neck				Albite Dykes				Oligoclase Neck				Oligoclase Dykes			
No.	Mean	SD	Values	No.	Mean	SD	Values	No.	Mean	SD	Values	No.	Mean	SD	Values
1	92.7	2.5	93, 95, 90	19	91.3	2.5	89, 94, 91	29	72.0	4.2	69, 75	35	70.0	2.8	68, 72
2	90.2	1.9	88, 90, 89, 91, 93	20	84.3	0.5	84, 85, 84	30	74.0	1.4	73, 75	36	73.0	0.0	73, 73
3	86.7	1.7	85, 89, 86	21	88.0	1.4	87, 89	31	67.7	0.6	68, 68, 67	37	69.3	1.5	68, 69, 71
4	89.0	2.8	87, 91	22	85.0	4.4	80, 88, 87	32	68.0	1.0	68, 69, 67	38	73.0	0.0	73, 73
5	87.0	1.4	86, 88	23	84.5	3.5	82, 87	33	68.5	2.1	67, 70	39	79.0	0.0	79, 79
6	88.0	3.4	86, 93, 86, 87	24	84.0	2.6	87, 83, 82	34	69.8	0.8	69, 70, 69, 71	40	70.3	0.6	70, 71, 70
7	88.3	5.1	84, 94, 87	25	84.7	0.6	84, 85, 85					41	77.0	2.8	75, 79
8	89.7	1.5	90, 91, 88	26	85.3	1.5	84, 85, 87					42	63.5	0.7	63, 64
9	93.0	1.4	92, 94	27	87.7	2.1	86, 87, 90					43	75.3	2.9	72, 77, 77
10	84.7	1.7	85, 86, 83	28	82.3	2.1	84, 80, 83								
11	84.3	3.5	84, 88, 81												
12	96.3	4.0	94, 101, 94												
13	89.7	4.6	87, 87, 95												
14	89.3	0.6	89, 90, 89												
15	86.5	0.7	86, 87												
16	89.0	3.0	86, 87, 91, 92												
17	87.0	1.0	87, 88, 86												
18	90.7	1.2	90, 92, 90												

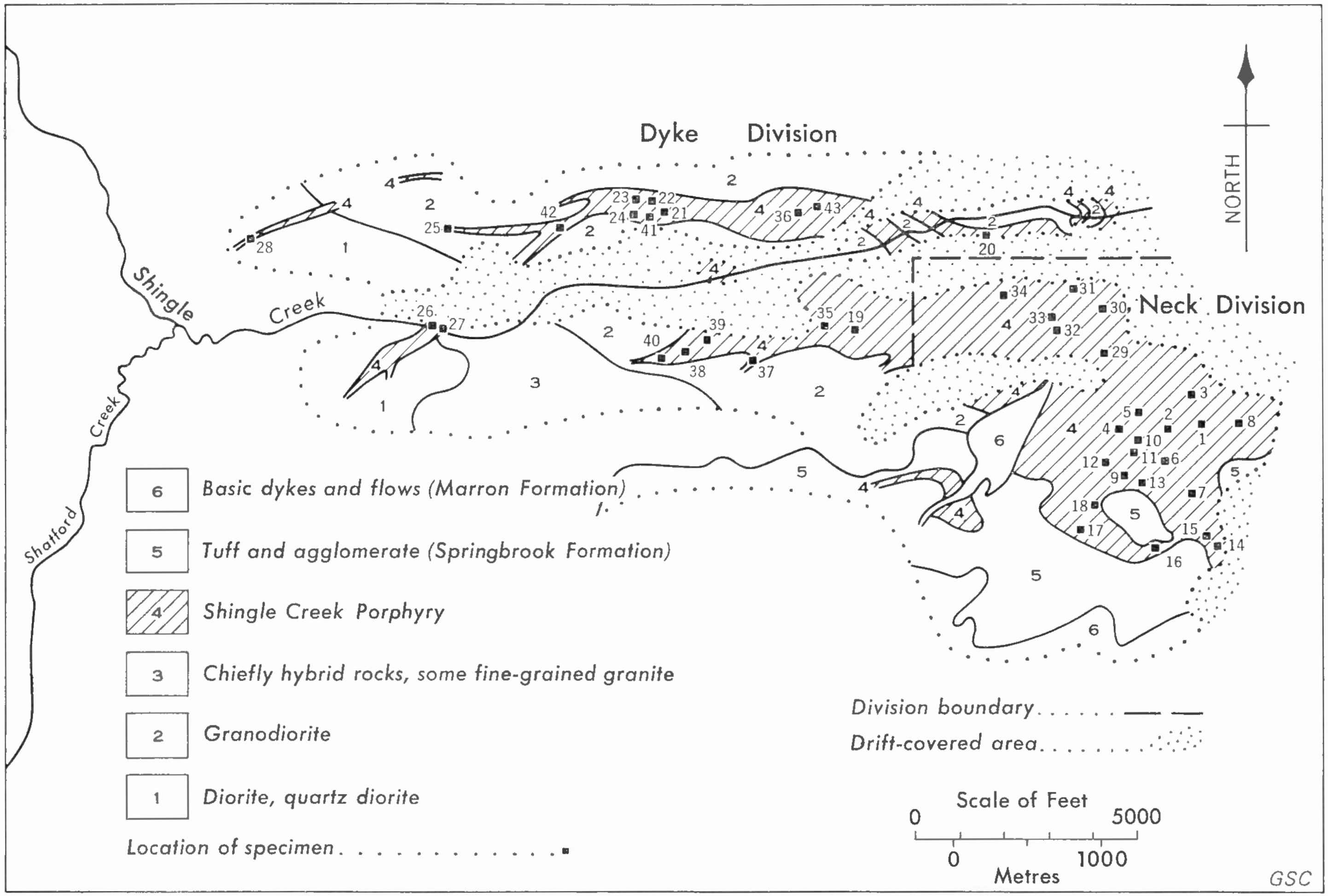

FIGURE 14. Locations of specimens of plagioclase on which optic axial angle measurements were made.

Table XIX

Comparison of 2V (alpha) for Albite and Oligoclase from the Neck and Dyke Divisions

	Albite		Oligoclase	
	Mean	SD	Mean	SD
Neck	89	3	70	3
Dykes	86	3	72	5
Difference	3		2	
Significance	S		NE	

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