

THE PETROGRAPHY OF CORBALEY CANYON

by

AARON WATERS

A thesis submitted for the degree of

BACHELOR OF SCIENCE IN

GEOLOGY

UNIVERSITY OF WASHINGTON

1926

TABLE OF CONTENTS

Acknowledgments	II
Introduction	1
Formations involved	3
Physiography	8
Deformation	15
Tertiary Deformation	15
Pre-Tertiary Deformation	18
Petrography	19
Ribbon Cliff Gneiss	20
Intrusive Rocks Older than the Corbaley Canyon	
Porphyries	22
Columbia River Basalt	24
Corbaley Canyon Porphyries	24
Injection Phenomena	28
Contact Phenomena	37
Petrographical Relations of Dike Types . . .	45
Summary	53
Plates	65

ACKNOWLEDGMENTS

This thesis has been prepared under the direct supervision of Professor George E. Goodspeed, assistant professor of Geology in the University of Washington. Professor Goodspeed's constructive criticism has been of great value in the preparation of the thesis. The writer also wishes to acknowledge assistance and help from discussions with Mr. R. E. Fuller and Mr. A. Allen Weymouth concerning the topics taken up in this report. Appreciation is also due Mr. Weymouth for the construction of the differentiation chart used in the thesis.

The writer also wishes to thank Dean Henry Landes of the University of Washington for information concerning the geographic nomenclature of the area involved in the thesis.

THE PETROGRAPHY OF CORBALEY CANYON

INTRODUCTION

During the summer of 1925, while in the service of Mr. R. E. Fuller, the writer had an opportunity for a rather brief examination of the geology of Corbaley Canyon. Mr. Fuller was primarily interested in the Columbia river basalt but certain features of the pre-basaltic formations in the area were so unusual that nearly an entire day was spent in their examination. The interest aroused by this cursory examination resulted in the writer's return to the district the following winter. This report is the outcome both of the field work done at that time and of the subsequent petrographic work done in the University of Washington laboratories on the material collected.

Corbaley Canyon is a small tributary valley on the east side of the Columbia river in Douglas county, Washington. This canyon furnishes a convenient ascent for the Sunset Highway from Wenatchee to Waterville. The district in which it lies has been topographically mapped by the United States Geological Survey as the Chelan Quadrangle. Locally Corbaley Canyon is called Pine Canyon, the name Corbaley Canyon being restricted only to the main tributary that enters the canyon from the south. It is thought better to use the names adopted by the United States Geological Survey in this report and so,

if not otherwise stated, the name Corbaley Canyon will be used to designate the main canyon, as is done on the Chelan Quadrangle topographic sheet.

The scope of the present paper is restricted almost entirely to that portion of Corbaley Canyon from three-fourths mile below the intersection of the southern tributary with Corbaley Canyon to where the 2200 foot contour line crosses the latter about three and one-half miles west of the town of Waterville. The present thesis represents merely detailed work in a very small area on formations which extend far up and down the Columbia River on both sides and is in no sense to be interpreted as anything more than merely indicative of the general character of the formations as a whole.

Nothing has as yet been published concerning the petrography of this region. Even the areal geology of the district along the Columbia and of the mountains to the west is comparatively unknown. The nearest areas geologically mapped are the Mt. Stuart Folio to the south (1) and a portion of

(1) Smith, George Otis. The Mount Stuart Folio. U.S.G.S. Folio No.106, 1903.

the Okanogan Highlands contained in the Colville Indian Reservation to the north. (2). Geologists have, from time to

(2) Pardee, I. T.: Geology and Mineral Deposits of the Colville Indian Reservation, Wash. U.S.G.S. Bull. 677, 1918.

time visited Lake Chelan, to the northwest of this area and the Grand Coulee to the northeast and comments on the general

geology noted on these trips appear in various articles.

The glacial geology has also received very little attention, though more than the areal geology. In this regard the writer wants to call especial attention to an article published in the American Geologist by William L. Dawson, in 1898 (1).

(1) Dawson, William S. Glacial Phenomena in Okanogan County, Wash. Amer. Geol. Vol. 22, pp. 203-217. 1898.

In contrast to the meagre information concerning the areal geology, the physiographic history and the Tertiary deformation of the district have been very carefully worked out by Bailey Willis (2). Professor Willis made several

(2) Willis, Bailey. Contributions to the Geology of Washington, Part 2, Physiography and Deformation of the Wenatchee Chelan District, Cascade Range. Professional Paper, No. 19, U.S.G.S., pp. 41-102, 1903.

excursions into this district and into the Cascades immediately to the west during the interval from 1895 to 1900. The Tertiary physiography and deformation of this region are taken up very carefully in his paper and it remains to this day as the most authentic and complete work regarding the history of the eastern Cascades that we have. To this paper the reader is referred for the details regarding the physiographic history of the district.

FORMATIONS INVOLVED

In Willis' paper the rock formations of the district

are segregated into the Columbia River Basalt and the Pre-Tertiary Metamorphics. The metamorphics include granite, gneiss and schist together with intrusive dikes and veins older than the feeders of the Columbia River Flows. In the present work these older rocks have been further divided into the Ribbon Cliff Gneiss and the Corbaley Canyon Porphyries.

Ribbon Cliff Gneiss.

The term Ribbon Cliff Gneiss is used to include a widespread series of schistose and gneissic rocks of igneous origin. The exact extent of the formation is unknown. They can be traced continuously from Wenatchee northward into the Okanogan Highlands. To the east they disappear beneath the eroded edges of the Columbia River Basalt. On the west they extend far up to the summits of the Cascade Range and may represent the gneisses that reappear on the western side of the range in the upper Skagit river valley. The age of this gneiss is purely conjectural. In the Mount Stuart Quadrangle George Otis Smith maps a schist of sedimentary origin which has been correlated with the Ordovician of the Skykomish Basin (1). At the headwaters of the Middle Fork of Mad River

(1) Smith, Warren S. The Stratigraphy of the Skykomish Basin. Jour. of Geol., September-October, 1916, pp.560.

in the Entiat Mountains the author has observed a contact between the Ribbon Cliff Gneiss and a quartz-mica schist of sedimentary origin. It is not definitely known, however, that the schist is the same as that which Smith maps, and

in addition it was not determined whether the sediments which formed the schist were actually laid down on the eroded edges of the Ribbon Cliff Series or whether they might have been faulted upon them. The age of the basaltic eruptions in this district is thought to be the same as that of the Yakima Basalt which has been definitely fixed as Miocene from fossil evidence in lake beds to the south. In the absence of other information we can only say that the Ribbon Cliff Gneiss is pre-Miocene. That it is pre-Tertiary seems to be abundantly indicated by its physiographic and structural continuity with the pre-Tertiary areas just to the south.

The Ribbon Cliff Gneiss is a very distinctive and easily recognized rock. It is in general beautifully banded with the black biotite-hornblende lines contrasting strongly with the white feldspar. The rock in most places appears to have been derived from a diorite or quartz diorite. Locally it passes into amphibolitic ^h phases suggesting a gabbroid origin. At least some of these phases, however, are due to later alteration by igneous intrusions.

By far the most noteworthy characteristic of the Ribbon Cliff Gneiss and the feature which gives it its name is the alternating white and dark ribbon-like banding which its exposed faces show. In the cliffs along the Columbia the gneiss is seen to be traversed at intervals of from 2 to 15 feet with thin white bands varying in thickness from 2 inches to 4 feet, and often having a lateral extent of 2 miles or more. On close inspection these bands are seen to

be sill-like injections of material along the planes of schistosity of the gneiss, which vary in composition from pure quartz carrying a little tourmaline and a very few sulfides through alaskitic material into true coarse-grained pegmatites. All transitions from the purest of quartz to coarse pegmatite can be found. At right angles to these injections, and truncating them in places, are thin veins of barren quartz. In places the injections are lenticular as if they had been squeezed by the surrounding gneiss at the time of emplacement. In general they follow more or less clean cut lines with surprisingly little variation in thickness. In one instance a four-inch alaskite ribbon was followed for a little less than one-fourth mile without showing any appreciable change in width. Injections into gneissic material similar to those described above have been abundantly described in the geological literature. They seem to be fairly representative of pre-Cambrian areas of granitic and metamorphic rocks and have been reported from pre-Cambrian areas in widely separated parts of the world. The exact mechanics of injection for these thin sill-like intrusions is still somewhat of an enigma, the solution of which has received the attention of several of the workers on the pre-Cambrian. The best exposures of Ribbon Cliff Gneiss occur at Ribbon Rock, a short distance up the Columbia river from the town of Entiat.

Corbaley Canyon Porphyries.

The Ribbon Cliff Gneiss ~~material~~, together with the

quartz-alaskite-pegmatite^{material} is truncated at many places by later intrusions of igneous rocks. These intrusions are predominantly of dike habit. Two series of intrusions are involved in the area under consideration in the present paper. The older involves a series of porphyritic and non-porphyritic rocks varying in composition from basic varieties to the most acidic. The younger represents the feeders for the Columbia River Basalt.

Because of their typical development in Corbaley Canyon the older series of intrusive dike rocks will be called the Corbaley Canyon Porphyries. From the point where the southern tributary enters Corbaley Canyon to the point where the older formations are covered by later flows of basalt the canyon walls consist of over 40 per cent of dike material. Most of the dikes have a northwest-southeast strike and continue directly across the Columbia and are very abundant in the Entiat river valley. They are not confined to this strip alone, however. Dikes belonging to the Corbaley Canyon Series can be seen at intervals all the way from Wenatchee to Chelan while their physiographic expression betrays them as forming many rugged spires and chimneys throughout the higher parts of the Chelan and Entiat ranges. Nowhere, however, are they so thickly developed as in Corbaley Canyon.

Columbia River Basalt.

The immense extent of this formation is well known. The Columbia river serves as a rough dividing line between the

plateau of basalt on the east and the old metamorphics of the Cascades on the west. Outliers of basalt occur here and there on the western side. The most notable of these forms the summit of the Entiat mountains at their southern end. Lava covers the entire surface of the Waterville Plateau and rises in a broad fold to the summit of Badger Mountain. In Corbaley Canyon the base of the basalt is exposed at the 2200 foot contour line. The basal flows are thin and very finely jointed. They are capped by a very coarsely columnar 70-foot flow that can be seen as a perpendicular cliff marking the edge of the plateau all along the eastern side of the Columbia river. This flow is peculiar in that it has a strong platy jointing at right angles to the columns, which causes it to split into thin pentagonal slabs about 5 feet in diameter. It is much sought after for road material on account of this feature. Two basaltic dikes which probably represent feeders for the flows above were noted in Corbaley Canyon.

PHYSIOGRAPHY

For an account of the Tertiary physiography in this district the reader is referred to the previously mentioned paper by Bailey Willis. Only the very briefest summary of his work can be taken up here.

According to Willis' interpretation the region now forming the eastern slopes of the Cascade mountains had been

almost completely eroded to a peneplain at the end of the Miocene. Occasional residuals stood upon this plain as monadnocks but the general character of the topography was a featureless plain. Upon this plain the forces of diastrophism, beginning in late Miocene or early Pliocene and continuing throughout the Pleistocene and into the Recent, produced the movements which have resulted in the uplifting of the Cascade range. The main axis of the uplift was north and south but transverse to this uplift, extending in a northwest-southeast direction throughout the range are minor warpings and wrinklins which extend as spurs from the main mass far to the southeast on the eastern side of the range. On this newly arched block the forces of gradation began working with rejuvenated activity. They had succeeded in carving it almost to mature topography, leaving the remnants of the old plain as flat topped residuals along the peaks of the mountain ranges before another period of accentuated uplift again rejuvenated the cycle. The effects of the second uplift are seen mainly in adjustments of drainage. Streams that were strong enough to maintain their courses without regard to the uplift have cut deep precipitous gorges and canyons that widen upward on the high banks of the rivers into the old mature valleys of the previous erosion cycle. This later stage of canyon cutting dominates the present topography of the region. During this stage of cutting glaciers filled many of the valleys and modified them greatly. At the present time the rivers are busy removing the

glacial drift.

From this history Willis finds five stages of topographic development indicated. He names these stages after the localities in which they are best developed. The following paragraphs are direct quotations, giving his summation of the topographic development of the region:

Willis, Bailey. Op.cit. PP. 68-69.

"Enough has been said in the descriptions to indicate that several stages of topographic development have been recognized. They are clearly evident in such profile as from the Entiat Mountains across the Columbia Canyon to Badger Mountain. Beginning with the highest, the peaks (5,700 to 5,800 feet) and the flat adjacent to them are considered to be representatives of the oldest stage of which definite evidence remains. They are correlated with Badger Mountain, the Waterville plateau, surfaces in the Chelan and possibly in the Methow Mountains, and the level from which the high Cascades are sculptured. The oldest stage is therefore that of the Cascade plateau, as named by Russell, but now called the Methow Stage. It is also identified by G. O. Smith. The characteristic topographic type of the Methow stage was a plain, upon which residual hills survived. Following Davis, it may be designated a peneplain, with monadnocks.

"Within this plain were carved valleys which appear to have attained nearly mature development. One profile of the

Columbia appears to have been 2,000 or 2,500 feet deep and 7 or 8 miles wide. The smaller streams certainly developed shallower and narrower valleys, but remnants of the Methow plain west of the Columbia were few and limited. On account of its preservation in the basin of the Entiat, this stage is named from that river. The characteristic topographic form of the Entiat Stage is mature. It occurs as a spur or divide below occasional residuals of the Methow stage and above features of the later stages.

"Within the relief of the Entiat Stage there were cut deeper channels, some of them canyons of impressive depth, some of them simply mountain ravines. They constitute the most marked and everywhere the most characteristic features of the topography of the region. Any large stream might be chosen as exhibiting the type, but probably none shows it in various degrees better than the Twisp, which from its junction with the Methow to its source in the Cascades lies in a canyon that varies from a few hundred to 4,000 feet in depth, as can be seen on the Methow topographic atlas sheet. This stage is accordingly named Twisp. The characteristic of the Twisp stage is a canyon, the typical feature of topographic youth, but the development progressed far toward maturity.

"The Twisp stage closed with accumulations of glacial ice, which occupied the canyons and in many instances greatly modified them. Rivers overloaded with drift filled their channels to greater or less extent. Lake Chelan and the terraces of the Columbia near its outlet afford the most con-

spicuous examples of these phases of activity. This stage of glaciation will accordingly be called the Chelan stage.

"With retreat of the glaciers to the highest amphitheatres of the mountains the streams began to reexcavate their channels. The glaciers still linger and the rivers are still engaged in removing drift. To complete the sequence of stages, this latest and present one may be designated from a stream which flows from several surviving glaciers and is clearing its old valley of drift, the Stehekin."

Details of the Physiography of Corbaley Canyon.

Residuals of the old Methow plain are not preserved in the immediate vicinity of Corbaley Canyon. The closest Methow remnants are represented by two small flat-topped hills southeast of Waterville. The canyon owes its present form entirely to the differential erosion that existed between the Entiat and Twisp stages. Entiat topography is easily seen in the topographic atlas sheet as forming the long spurs that originate on Badger Mountain and lead down with uniform gradient until they drop suddenly into the canyon gorge that has been cut by the accentuated river erosion that followed the second uplift of this area. On the north side of the canyon the Entiat topography is not so apparent from the topographic map because of the fact that the older Entiat is severely cut up and gullied by ravines of Twisp date. To an observer walking over this country, however, the Entiat stage is easily apparent. It is seen in a series of spurs

often detached and badly eroded by later Twisp gullies yet nevertheless preserving in detached remnants the outline of the former Entiat topography.

The history of Corbaley Canyon is thus seen to be twofold. Corbaley Creek, together with Moses Creek, shares the drainage of the Waterville Plateau. On this plateau the Entiat topography is everywhere in evidence. Although everywhere of comparatively uniform elevation, the surface of the plateau is intricately sculptured to a mature stage of erosion. The upper part of the Corbaley Creek drainage area is a country of rolling hills of gentle elevation and winding dry stream courses, which leave no portion of the plateau undrained. On the spurs on either side of Corbaley Canyon these same conditions persist to within 1,000 feet above the Columbia river, where the topography breaks off sharply to the river valley below. In following the bottom of the canyon, however, a change is noted. Starting at a point three miles west and one mile north of Waterville, Corbaley creek drops abruptly into a narrow walled gorge, leaving high above the more gentle valley walls characteristic of the Entiat stage. Profiles across one of the canyon walls anywhere from this point to the Columbia are thus seen to be convex upward. This feature Willis notes as being characteristic of stream valleys that have been marked by both the Entiat and Twisp stages of erosion. The steep-walled canyon due to the Twisp cutting, did not extend farther back upon the Waterville plateau probably because of semi-arid climatic conditions

prevailing at that time.

The minor details of the topography of Corbaley Canyon are directly the result of the differential erosion of the rocks exposed in the region. As has already been noted, the edge of the Waterville plateau is usually bounded in this district by a cliff varying from 20 to 50 feet in height caused by an almost flat-lying flow of coarsely columnar basalt. In many places along the canyon walls, and especially where the Entiat topography predominates, this flow is almost completely hidden in its own talus and its position is only discerned by a narrow rocky band exposed at the upper margins of the canyon. Below this uppermost flow the basal members of the Columbia Series extend along the gentle curves of the Entiat stage down into the gneiss below. This gneiss would be topographically continuous with the basalt above were it not for the fact that it is truncated in every direction with acid dikes that are far more resistant than the softer gneiss and stand out above it, breaking the even curves, which would ordinarily be its topographic form.

The dikes are extremely varied in their topographic expression. They are, without exception, harder than the surrounding gneiss and stand above it in a wide variety of forms. Some trend across the country like ruined stone walls with broken and dilapidated tops. Some, on account of a very fine horizontal sheeting, break up into a mass of small loose blocks ~~which~~^{which}, when allowed to remain in place, suggest the stone fences built by farmers from boulders. Others have

a major coarse, vertical, jointing at right angles to the strike of the dike and these give rise to tall, thin cathedral spires and minarets arranged in rows. The latter are often very beautiful in the detail and angularity of their sculpturing. Individual spires sometimes start with a base about 15 x 20 feet and rise upward with many pointed spinose projections to one or more terminal spires 50 feet above.

The basic dikes sometimes have a tendency toward spheroidal weathering, and when this occurs the dike sometimes extends a little above the surrounding gneiss in hemi-cylindrical outline.

In the Columbia River valley the spurs on either side of Corbaley Canyon drop off abruptly to the valley floor. This feature is not altogether a result of the Twisp stage of canyon cutting, but is due in part to a very pronounced system of jointing in the gneiss. This jointing, by lying parallel to the local trend of the Columbia, has resulted in well developed cliffs.

DEFORMATION

Two stages of rapid uplift with deformation taking place more slowly in the interval between are recorded by Willis. In addition to the major uplift, resulting in the uprising of the Cascade block, there were transverse warpings which gave rise to a series of wave-like folds trending across the entire range in a northwest-southeast direction

and representing southeasterly trending spurs from the main mass on the eastern side. Of these minor crenulations two of the spurs and the downwarp between them are of interest as bearing on the problems of the present paper. These are, in Willis' terminology, the Badger Mountain-Entiat Mountains upwarp, the Chelan Mountains upwarp, and the intervening Waterville downwarp. Willis' reasons for postulating the existence of these marginal flexures will now be briefly given.

On the top of Badger Mountain and on the summit of the southern end of the Entiat Mountains residuals of the Methow plain are preserved at elevations over 4,100 feet. On the south side of Badger Mountain in the vicinity of Rock Island Creek these residuals are seen to slope toward the south with ever decreasing elevation. Southeast of Waterville and a few miles north of Badger Mountain two small residuals of the Methow plain still survive at an elevation of 2800 feet. It is thus seen that the Methow plain has been upwarped in the Badger Mountain-Entiat Mountain area into a broad flat fold.

Further evidence for the existence of this fold has been gathered by the author of this article from Badger Mountain at its eastern end, where it is cut across by a tributary of Moses Creek. At this point the northerly dip of the basalt sheets is an obvious fact, and gives strength to Willis' evidence for the existence of an upwarp in this area.

On the same kind of evidence Willis postulates another area of uplift as extending along the Chelan Mountains and across the river to the edge of the plateau north of Waterville, and into the Chelan Butte Region. The structure of the basalt confirms this. Dips in the basaltic sheets are so low as to be determined only with difficulty, but the same thick flow of basalt that occurs at the top of the series of flows in Corbaley Canyon can be traced continuously along the edge of the plateau to where it outcrops seven miles north of Waterville at an elevation of 500 feet higher than in Corbaley Canyon.

The area in which Entiat River, Corbaley Canyon and the town of Waterville lie is thus seen to be a downwarped area between the Chelan Mountains' upwarp on the northeast and the Entiat Mountains-Badger Mountain upwarp on the southeast. The axis of this downwarp passes directly through that portion of Corbaley Canyon in which the specimens for petrographic analysis were taken.

The second period of deformation connected with the building of the Cascades Willis works out by the elevation of the Entiat topography above existing stream valleys of the present day. The fact that the Entiat surface, abreast of the Badger Mountain-Entiat Mountain axis, ends abruptly in a steep scarp 2000 feet above the Columbia River, while at Chelan Butte it is only 800 feet above, is cited by Willis as evidence that the Badger Mountain upwarp took place in two different stages, the later upwarp following the same plane

of weakness as that preceding. Willis notes that there is also a close correspondence in the structure lines existing in the Cascades between the pre-Tertiary and the Tertiary episodes of deformation in addition to the correspondence in the different Tertiary episodes.

Pre-Tertiary Deformation.

Willis does not endeavor to unravel any of the earth movements taking place in this region before pre-Tertiary time. In this connection the author has noticed some phenomena which seem to have a certain amount of bearing in proving that at least in the Waterville-Entiat River downwarp there is a very close coincidence between a depressed area of pre-Tertiary time and the Tertiary downwarp.

As one proceeds up the eastern side of the Columbia river above Wenatchee the Ribbon Cliff Gneiss is exposed on the cliffs all along the river where it cuts across the Badger Mountain-Entiat Mountain uplift. Throughout this region the banding planes in the gneiss have an almost north-south strike with a dip to the east, varying from 10° to 35° . As one approaches Corbaley Canyon, however, these strikes and dips gradually change. The strike swings around northwest-southeast, trending more and more toward an east-west direction, until at the edge of the canyon the banding lines are trending about $N 70^{\circ} W$. The dips grow increasingly steeper until on the southern wall of the canyon they are from 30° to vertical and in a northeasterly direction. In the center

of the canyon the gneiss has been so badly cut and intruded by the Corbaley Canyon Porphyries that strikes and dips taken at this point cannot be safely used as an indication of structure. On the north side of the canyon beyond the main porphyry intrusions no strikes were observed except at one point about a mile above the canyon, where it could be seen from the road that the strike of the banding was north and south by the horizontality of the alaskite intrusions in the gneiss.

While working out the structural history of a region by the banding of gneiss is hardly a geological procedure that can be used without assuming a large percentage of error, it is thought that in this district the increased dips in the banding of the gneiss in the vicinity of Corbaley Canyon over the dip of the basaltic formations above indicates that this was a downwarped zone long before the basaltic floods poured out upon it. Certain structural features of the Corbaley Canyon Porphyries will be noted later that also seem to establish a pre-Tertiary zone of weakness along the Waterville-Corbaley Canyon-Entiat River line.

PETROGRAPHY

Material for petrographic study was collected at several localities but the main work has been done in the small area whose confines were given earlier in the report. Within this area type samples of Ribbon Cliff Gneiss were hard to obtain, as they have, in many instances, been badly metamorphosed by

the later dike intrusions. For this reason some specimens from the Ribbon Cliffs were taken on the east side of the Columbia river about three miles below the town of Orondo. At this point the Ribbon Cliffs are cut only by the alaskitic veining material. A comparison of the material collected from here with that occurring in Corbaley Canyon has been made. Material from the ribbon-like injections at this point was also collected but due to lack of time has not yet been studied petrographically. The petrographic analysis of some of the dike rocks occurring on the spurs on either side of the mouth of Corbaley Canyon will also be included in this report. At these points steep sided cliffs are exposed on which the details of the dike intrusions as well as the structure of the gneiss can be easily worked out. By far the larger part of the material, however, is taken from the small locality in the upper part of the canyon, whose confines have already been given.

Ribbon Cliff Gneiss.

Something of the general features and field characteristics of the Ribbon Cliff Gneiss have already been given. It is at the same time the most varied and the most homogeneous rock in the region: homogeneous in that it extends throughout the Wenatchee-Chelan district with almost identical field characteristics, being banded and cut by highly acidic intrusions in sill-like rows parallel to the schistosity at every point where it is met, and varied in that at no two localities

does the rock show identical characteristics in hand specimen or thin section. Its derivation from a granitic igneous rock is at once apparent in hand specimen, feldspar being much in the majority of the constituent minerals and micas and amphiboles generally exceeding quartz. The texture varies from medium schistose to coarse-grained gneissic. In the upper part of Corbaley Canyon, just before the older formations pass under the basalt, the Ribbon Cliff Formation loses, to a large extent, its gneissic texture. The direction of the banding here can only be made out with difficulty in the hand specimen, although the alignment of the amphiboles is easily seen in thin section.

The gneiss seems to have been derived ^{from} ~~from~~ a related series of igneous rocks of slightly different mineralogical and chemical constitution. The dominant feldspar in all sections examined was albite. In some sections orthoclase predominates after albite; in others, oligoclase. Both hornblende and biotite were found in all sections. In some localities hornblende predominates; in others, biotite. Hornblende is developed along the contact zone of some of the Corbaley Canyon intrusives to such an extent as to convert the gneiss into amphibolite, but these zones are only local and the amphibole shows slightly different characteristics than does the amphibole in those portions of the gneiss far removed from the contact. The gneiss clearly shows the effects of both dynamical and hydro-thermal metamorphism. The dynamical effects are clearly shown in bent feldspar and biotite

crystals such as those shown in Plate ^{15.}~~15~~ Contact effects from both the Ribbon Cliff intrusions and from the Corbaley Canyon intrusives are seen not only in the extensive amphibolization along the contacts but also in the development of typical contact minerals such as tourmaline. Small crystals of garnet are found in the gneiss in all localities. Garnets are noticed in one thin section in the Ribbon Cliff veining material also. Other minor accessory minerals are apatite, zircon, sphene, magnetite, chlorite, epidote, tourmaline and sericite. In one case intergrowths of micropegmatite were observed in the gneiss near its contact with a granophyre dike. These intergrowths seem to represent very fluid extracts that found their way into the gneiss at the time of intrusion of the granophyre and crystallized there as micropegmatite.

Intrusive Rocks Older than the Corbaley Canyon Porphyries.

The intrusive rocks, older than the Corbaley Canyon Porphyries, that cut the gneiss are the series of pegmatites, alaskite and quartz intrusions which form the sill-like ribbons from which the gneiss is named. None of these were examined in thin section. In hand specimen they are seen to consist of very acid material which varies in composition from coarse-grained pegmatites to almost pure quartz. The most common types consist of a coarse-grained pegmatite containing large crystals of orthoclase and quartz, together with minor amounts of biotite, hornblende and plagioclase.

Apatite can sometimes be seen in hand specimen. In most cases the feldspars are remarkably fresh and glassy looking; in a few, kaolinization has taken place. The biotite is altered to chlorite in some of the pegmatites. The relative amounts of feldspar and quartz vary widely in different ribbons and the pegmatite seems to be transitional from a pure feldspar rock on the one hand to alaskites on the other. The alaskitic types are, in the main, finer than the pegmatites. In other respects they do not differ exceedingly, except in the amounts of quartz and feldspar. Many of the alaskites are very quartzose.

Of the quartz material collected two types prevailed. One consisted of ribbon fillings of clear white quartz, not in the least milky, carrying tourmaline; the other, a reddish colored quartz, somewhat darker than true rose quartz, which bore no tourmaline. Some crystals of sulfides were noted in both types but are very rare. Some of the quartz veins carry large crystals of feldspar. Although not examined in thin section, this feldspar is considered to be albite on account of the strong platy cleavage which it exhibits.

The age relations of the different type of ribbon injections in the gneiss are complex. In some cases injections of quartz cut pegmatites and alaskites. In another case a pegmatite stringer was definitely seen truncating a quartz vein. Not enough field work was done to make any definite statements concerning either the method of emplacement or to work out any systematic explanation for the varying types and

their age relations. The whole question of these peculiar sill-like intrusions presents problems the solution of which will require much more detailed field and laboratory work than was done in the preparation of this report.

Columbia River Basalt

Only two specimens of the basalt flows and feeders occurring in Corbaley Canyon were taken for analysis. One was of the thick, 70-foot flow occurring at the top of the series; the other, a specimen of a small dike cutting the gneiss. The dike rock varies somewhat from a typical basalt in that it is exceptionally high in titanium. This is seen in the very purple (ordinary light) augite which makes up over 18% of the rock, as well as in opaque ilmenite individuals which are largely altered to leucoxene. Pseudomorphs of greenish serpentine, containing many irregular aggregates of magnetite, indicate the former presence of olivene. None of this remains unaltered in the section observed. The feldspars are labradorite.

Corbaley Canyon Porphyries.

The Corbaley Canyon Porphyries present by far the most spectacular and interesting series of rocks, from the petrographic standpoint, of any in the region. They occur altogether as a series of roughly parallel dikes with a general northwest-southeast trend. Although dikes referable to the Corbaley Canyon types may be found scattered throughout the

entire Wenatchee-Chelan district they are nowhere so well represented as in the upper part of Corbaley Canyon. At this locality they make up over 40% of the rock exposed and at one point a composite dike representing four chemically different kinds of magma fills a fissure over 100 feet wide. Individual dikes are usually from 10 to 35 feet wide. A few attain a width of 50 feet, and one dike occurring 300 feet below the intersection of Corbaley Canyon with its southern tributary, has a width of 64 feet. This dike is very prominent topographically and narrows the canyon at this point to a slit. Composite dikes are often of much greater thickness.

As one proceeds either north or south from this portion of Corbaley Canyon the dikes rapidly thin in amount in both directions. Toward the south they gradually disappear as one approaches the Badger Mountain uplift until in the heart of this upwarp they cease to be represented altogether. Toward the north they become rapidly thinner, but occasional dikes are perceived breaking the sloping outline of the softer gneiss in jagged chimneys and spires throughout the entire distance to Lake Chelan. Nowhere, except in Corbaley Canyon and in the adjacent Entiat River region, do they make up a large percentage of the rock, however.

In the canyon composite dikes are common, a single fissure often being filled with as many as four dikes of different chemical composition and slightly different times of intrusion. Multiple dikes are also of common occurrence, especially in the more basic magma.

Megascopic Character of Dike Rocks.

Individual dikes in Corbaley Canyon vary greatly in megascopic character as well as in other field characteristics. In color they range from almost black through varying shades of grays into yellows. In texture some show the fine-grained granular aplitic habit, others have a pronounced felty aspect when viewed with a hand lens, while still others are coarsely porphyritic, phenocrysts making up over 30% of the rock. All are of the dense habit; in no case is the ground mass of the rock sufficiently granitoid so that the mineral composition may be determined megascopically.

Although the chemical and mineralogical composition of the dikes is much more easily determined in thin section, certain of the broader features regarding their mineralogical diversity and similarity are easily seen in the hand specimens. Certain black, dense rocks appear in hand specimens somewhat like basalts, but when these are examined more closely it is seen that instead of the common diabasic texture which basalts exhibit, they are more granular with a texture similar to that of an aplite. In addition, the few minerals that occur as phenocrysts are commonly hornblende and biotite, while white patches of carbonate appear here and there, which do not fill cavities but which either solidified directly from the magma or were caught as inclusions in its ascent. The contacts of these basic dikes are extremely irregular, which indicates their high fluidity. The gneiss along the contacts is also extensively altered and this, together

with the carbonate patches occurring in dike rock itself, is taken as indicative of a very high concentration of volatile constituents in the magma itself. For these reasons the basic dikes are thought to represent intrusions from a lamprophyric rather than a basaltic magma.

From these typically lamprophyric injections a gradual transition can be seen to exist in specimens taken from different dikes. Individual specimens can be taken which grow progressively more and more acidic, yet the transition is so complete that every possible variation in the series is represented. If the hand specimens from the 62 dikes that were chosen for petrographic analysis are laid end to end, in order from the most basic to the most acidic, they are seen megascopically to grade from the typical lamprophyric specimens described above to a yellowish rock composed of about 25% of quartz phenocrysts. The same relation also holds when the rocks are examined in thin section, as will be noted at some length below. In detail the gradation appears to be somewhat as follows: The lamprophyres pass with gradual transition into a grayish rock with a distinctly felty texture in some specimens of which phenocrysts of hornblende and orthoclase are easily apparent. This rock, in turn, becomes increasingly more and more porphyritic, with the orthoclase phenocrysts gradually predominating over the hornblende until it passes into a rock of a light yellow to gray color containing about 30% of phenocrysts of which practically all are orthoclase. From here on quartz

begins to enter as phenocrystic material and orthoclase to decrease until finally the series ends with a rock consisting entirely of quartz phenocrysts set in a dense yellowish brown ground.

Age Relations of Different Dike Types.

Because of the especially excellent exposures in Corbaley Canyon definite evidence concerning the relative age of different dikes in the Corbaley Canyon series was easily procured. It was found that in every case individual dikes cut across those that are more basic than themselves and are in turn truncated by the more acidic types. On account of the excellent exposures in the canyon cross-cutting relations could be observed repeatedly and in every case, without a single exception, the rock truncated was more basic than the dike which cut it. Figure 1 is a sketch showing the age relations of three dikes of different composition at one point in the canyon. Figure ~~shows a similar relationship at another point.~~

INJECTION PHENOMENA

Certain phenomena connected with the injection of the Corbaley Canyon Porphyries are worthy of mention as throwing some light on the structural relations of the Corbaley Canyon region in addition to bearing information concerning the relative fluidity and characteristics of the injecting magma at the time of intrusion. The general northwest-southeast strike

PLATE 1

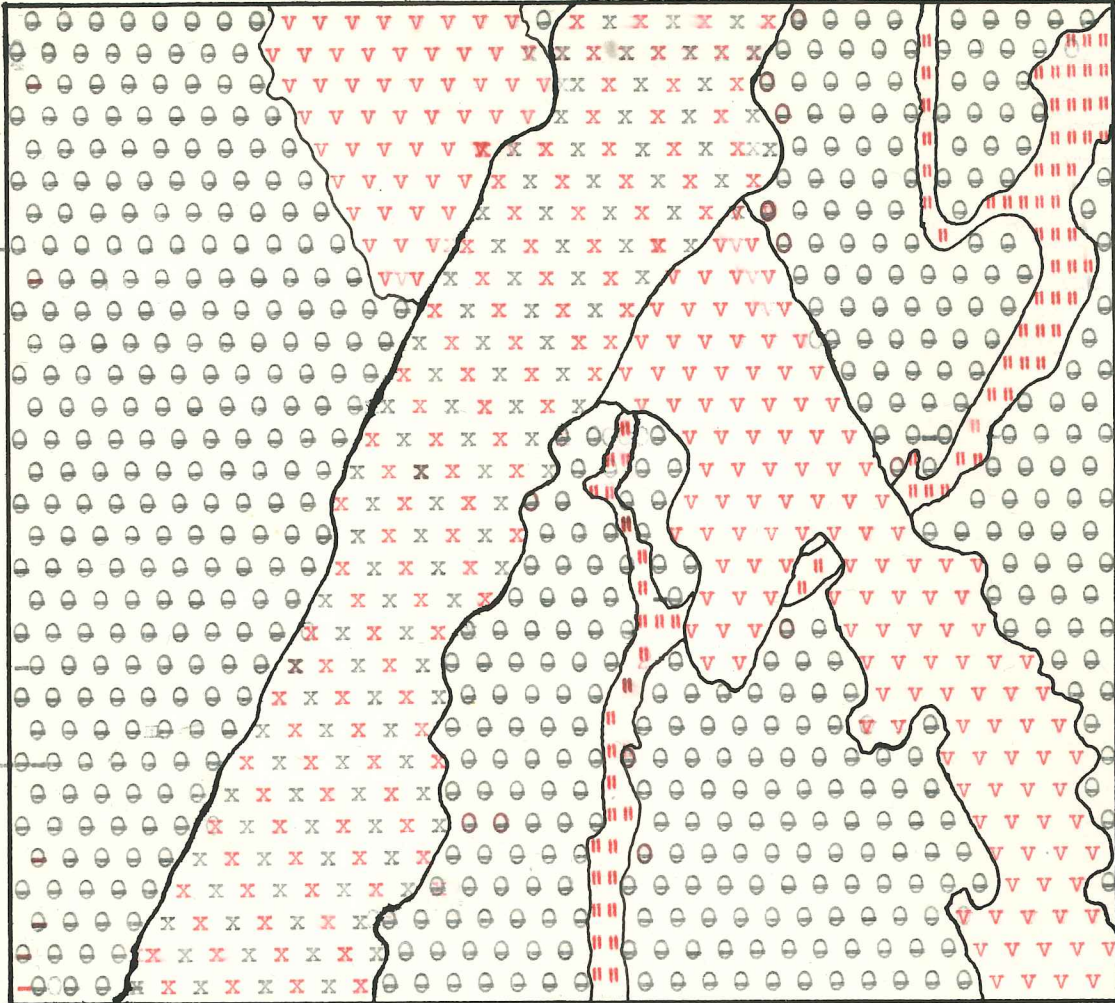


Fig. 1.- Sketch showing the age relations and types of contacts exhibited by three of the Corbaley Canyon dikes.

Sketch

of the dikes has already been noted. This feature is very general throughout the canyon. Individual dikes often deviate from it for short distances, but when followed any distance along their strike are seen to fall in with all the rest in a general northwest-southeast parallelism. It has also been noted that the dikes rapidly decrease in number to the south and north of Corbaley Canyon, but hold fairly constant in number as one proceeds northwesterly along their strike into the Entiat River valley. These facts do not become especially significant by themselves until we remember that this same line was also a zone of Tertiary deformation, the axis of the Waterville-Entiat downwarp passing directly through the region in Corbaley Canyon, where the dikes are most closely spaced and continuing along their strike into the Entiat valley beyond. From this data it becomes at once apparent that the zone of weakness along which the Corbaley Canyon dikes were intruded persisted into Tertiary time, and that during the Tertiary downwarping has taken place along this same structural line at least twice. Certain data have been given concerning the strike and dip of the bands in the Ribbon Cliff Gneiss which seemed to indicate that this was a zone of pre-Tertiary downwarping. The evidence given by the trend of the intruding dikes not only strengthens this theory, but gives actual proof of the fact that a zone of pre-Tertiary weakness existed along the Corbaley Canyon-Entiat River line. That it was also a zone of downwarping is indicated not only by the differences existing in gneissic banding but by the

extensive development of the dikes along this line. It will be remembered that along the axis of the Badger Mountain-Entiat Mountain uplift no dikes were found cutting the Ribbon Cliff Gneiss. In Corbaley Canyon they make up 40% of the bedrock. It would seem that dikes would be most likely to intrude along the axis of a syncline for here the tensional jointing caused by the bending of the strata would be projected downward, while in the anticlines it would radiate out from a central point toward the top. These tensional cracks extending downward from the center of a downwarped area would tend to lead any upward working magmatic body into the center of the syncline. In this way the synclines would become a zone for maximum accumulation of magmatic material. In a similar way anticlinal areas would be a zone of minimum accumulation because the zone of tensional joints produced in them tend to narrow to a line as one proceeds downward. Thus any magmatic material that found its way into the axis of an anticline would tend to be distributed out from the center of the anticline along the diverging lines of tensional jointing. The relations herein outlined are given by sketch in Figure 3. While such considerations are purely hypothetical they appear to be warranted by the facts, and indeed seem essential to an explanation for the prevalence of dikes in the Corbaley Canyon-Entiat River region and their absence along the Badger Mountain-Entiat Mountain axis.

PLATE 3

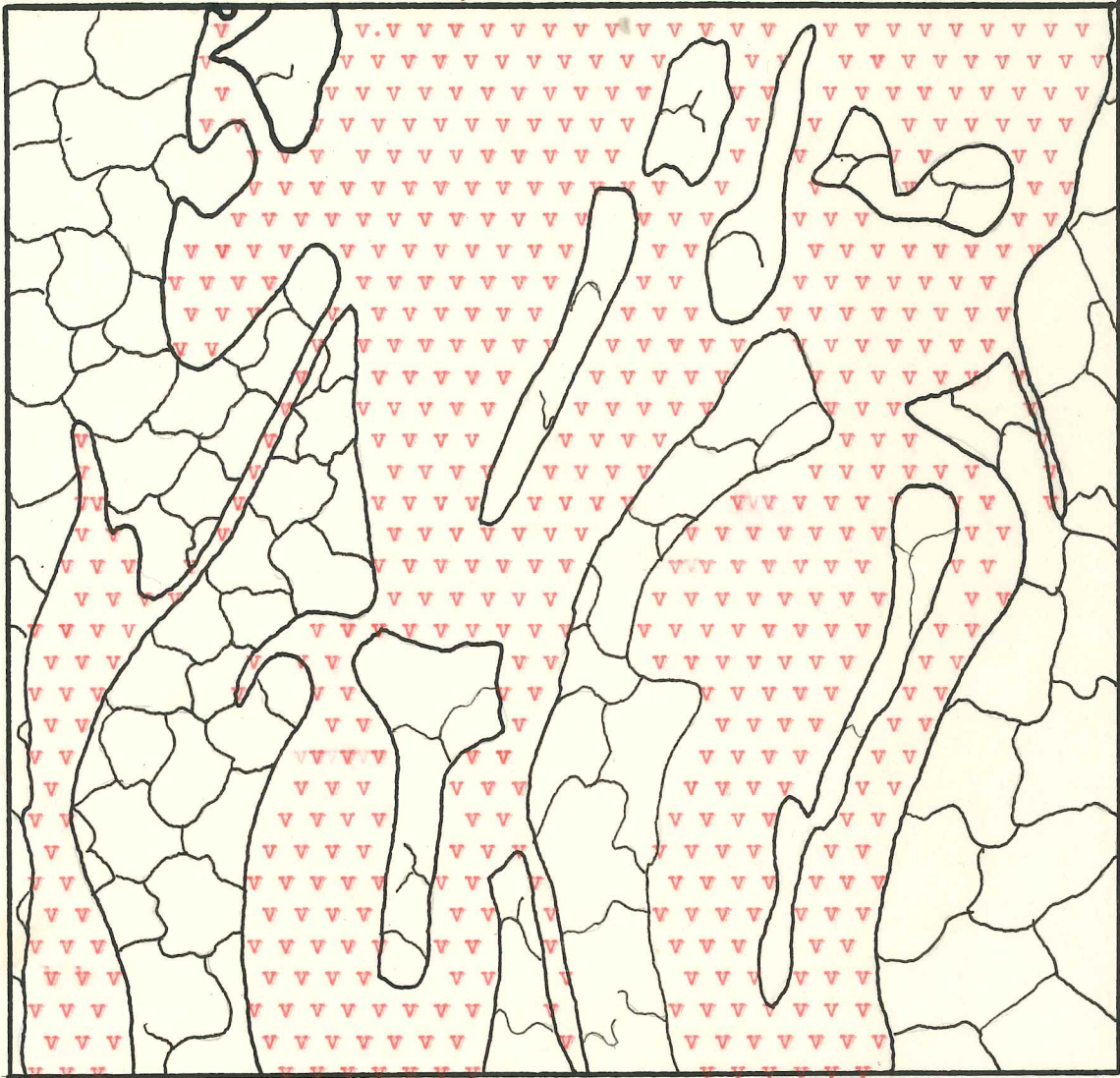


Fig. 2.- Sketch showing irregular contacts of a lamprophyre dike cutting the Ribbon Cliff Gneiss in Corbaley Canyon.

Minor Details.

Certain minor details concerning the injection of the Corbaley Canyon Porphyries are of interest in that they help to bring out certain variations in chemical composition of the different dikes and differences in the physical character of the magma at the time of injection. The type of contact exhibited by the dikes varies widely, depending upon the chemical character of the intruding magma. In general it was found that the basic lamprophyres have very irregular contacts, indicating high fluidity of the magma at the time of injection. The magma apparently became more viscous as it became progressively more acidic, for the walls of the dikes become increasingly straighter and more regular until in the highly quartzose types the contacts are very straight and clean cut.

The contacts exhibited by some of the more basic dikes indicate that they must have possessed exceptional fluidity. Individual dikes will often vary in width along their strike from 50 feet to less than two feet. Thin streamers and apophyses from the dikes penetrate the gneiss in every direction, extensively metamorphosing it as they go. These stringers are often only one or two inches wide, yet they penetrate the gneiss distances of twenty feet, or even more. When viewed in cross section most of the lamprophyre dikes appear to engulf large blocks of gneiss. These, however, when examined closer, are seen to be blocks that are more or less completely surrounded by apophyses of the lamprophyre and

do not represent blocks stoped on otherwise broken off and engulfed in the gneiss. They are continuous with the wall rock at some point not exposed in the section. Individual streamers projecting out into the gneiss often show marked evidence of differentiation. Further mention of this fact will be made in some detail later.

High fluidity in an igneous rock solution is usually accounted for either by super-heat of the magma or else by an extremely high concentration of volatile material. The latter explanation is thought to hold for the basic dikes in Corbaley Canyon. Basalts commonly have a great amount of superheat, yet basaltic dikes ordinarily cut across their wall rocks with exceptionally well defined straight contacts. Although highly heated and exceptionally fluid they chill quickly along their margins and soon encase themselves in tachylite or very fine-grained basalt. Being very dry they have no opportunity for heating the surrounding rock by the expelled gases and so tend to straight contacts and a minimum amount of contact metamorphism. Along the edges of the basic dikes in Corbaley Canyon the contact metamorphism is profound. This, together with the petrographical analyses of the dike rocks, proves them to have been extremely rich in volatile constituents. The high content of volatile matter is assumed to be responsible for the great irregularity of their contacts.

The increasing viscosity of the successively more acidic dikes is easily apparent in the field. Figure 7 shows the

relations at a point in the upper part of the canyon in which the increasing viscosity of the more acidic dikes may be seen by the irregularity of the contacts of the three dikes shown. The most acid dikes represented in Corbaley Canyon are granophyres containing much phenocrystic quartz. In their extreme viscosity they stand in direct antithesis to the peculiar physical condition of the lamprophyres. The acid dikes were so sticky that they oozed up along fractures in approximately the same condition as thick pitch. They show absolutely clean cut walls exhibiting practically no contact metamorphism. The mineralogical analysis shows that the dikes must have been rather high in volatile matter but their highly siliceous character and probably rather low temperature must have rendered them extremely viscous.

The contact relations of a spherulitic granophyre dike outcropping along the Sunset Highway 400 feet below the telephone booth in the upper part of Corbaley Canyon are of especial interest in this connection. At the point where the granophyre joins the highway it is cutting gneiss. On account of its greater resistance to weathering than the gneiss it stands up as a wall as it continues on up the canyon side. About 200 feet from the road it truncates a composite lamprophyre about 25 feet wide, together with the amphibolites derived from the contact metamorphism of the lamprophyre. The walls of the granophyre are peculiarly grooved and striated giving the appearance of rough slickensides. The direction of movement, as shown by the slickensides, is the

same as the direction taken by the intruding dike. That the striations were caused contemporaneously with the intrusion of the dikes is proved by the fact that where the granophyre truncates the lamprophyre an angular fragment of the lamprophyre was found actually frozen into the granophyre while a long trail behind it shows where the granophyre moved past it before it finally froze fast. The glassy contact of the dike around the lamprophyre fragment leaves no doubt that the movement occurred at a time when the dike was still fluid enough to finally freeze around the fragment, but was viscous enough so that the scratches made by the fragment were still preserved when the magma completely solidified. The conditions given above can only be accounted for in one of two ways: Either the granophyre was so viscous at the time of intrusion that it actually scratched its sides against projecting rock particles in the sides of the fissure that it filled, or else after the intrusion of the dike and just before its final consolidation, diastrophic forces caused a movement along the walls of the dike which resulted in the slickensiding of the still semi-molten magma. Further field work will be necessary to definitely prove either of these hypotheses. From the amount of data already collected the author is inclined to favor the second as being more nearly correct. The fact that dikes make up over 40% of the bedrock material in this portion of the Canyon indicates that some diastrophic agency must have been at work almost contemporaneously with the intrusion of the dikes, producing the

fissures which they now fill, and it might easily be that slight movement of the walls of a fissure after a dike had intruded it would produce the phenomena noticed in connection with the granophyre just described.

Notes on Mechanism of Dike Injection.

The features outlined above are of special interest in connection with the deformation of the region. The most obvious reasons for the occurrence of dikes in downwarped areas have already been taken up. It might be added that the conditions outlined there would be especially favorable in those beds which were most competent. The terms competent folding and incompetent folding when used in reference to deformation are applied only to sedimentary beds. Igneous rocks are supposed to give way under deformation by shearing and not by folding. A certain interrelationship is seen to exist between the two, however. The characteristics of rock in which competent or incompetent folding may take place are given by Bailey Willis* as follows:

"In order that any stratum shall be competent it should possess certain inherent characteristics in a degree superior to that in which they are possessed by other strata, These qualities are (a) strength to resist shearing; (b) capacity to heal fractures; (c) inflexibility. On the other hand the conditions which favor incompetence of strata in folding

*Willis, Bailey. Geologic Structures, p. 149. McGraw-Hill Book Co., New York. 1923.

are (a) lack of coherent strength; (b) lack of cementing quality; (c) flexibility."

It can be seen from the list of qualities necessary for a competent bed that gneiss possesses two of them, namely, strength to resist shearing and inflexibility, to a very marked degree. Limestone is considered to be the most competent of sedimentary rocks. The most competent crystalline limestones are very similar to gneiss in strength and inflexibility. Limestone has the added power to heal fractures and in this respect it is practically unique among rocks. Just where we may draw the line between competent folding and shear is not altogether clear. Limestone reacts to stress by shearing to a marked degree. An outcrop of crystalline limestone can scarcely ever be found that is not extensively jointed. In some cases the joints may have been healed but in general limestone shows extensive jointing better than any other sedimentary rock. In the competent folding of a limestone it would seem that the actual deformation took place by shearing, the shear planes being progressively recemented and broken as the deformation went on. The deformation of a gneiss with the planes of schistosity practically horizontal might be expected to proceed in much the same way as the deformation of limestone. Lateral compensation in the gneiss could largely be taken up by slipping along the lines of schistosity while the tensional stresses accumulating through anticlinal and synclinal bending would be relieved in the gneiss by fracturing or shearing. These fractures would

radiate from the axes of the synclines downward and from the axes of the anticlines upward. They would not heal, as in the case of the limestone, but would gape open until filled by some foreign material. The deformation of gneiss by folding would have to be on a very large scale. Small minor stresses would almost certainly be compensated by shear.

Such a condition as here outlined is postulated as having gone on in the Corbaley Canyon district during the time of pre-Tertiary deformation already referred to. It is thought that practically simultaneously with the deformation there were intrusions of liquid material from below which filled the fissures due to the tensional cracking in the gneiss, and which were led into zones of downwarping due to the fact that the tensional jointing radiates downward from the axes of the downwarp. These relations are illustrated by sketch in Figure 3.

CONTACT PHENOMENA

In their contact effects upon the gneiss which they intrude the Corbaley Canyon Porphyries are remarkably varied in the metamorphism which they produce. The metamorphism surrounding the basic dikes is most marked, and as the dikes become increasingly more and more acidic, the metamorphism along their contacts decreases until with the granophyres no contact effects whatever, aside from baking, were noted. The typical lamprophyre in Corbaley Canyon is a basic rock which

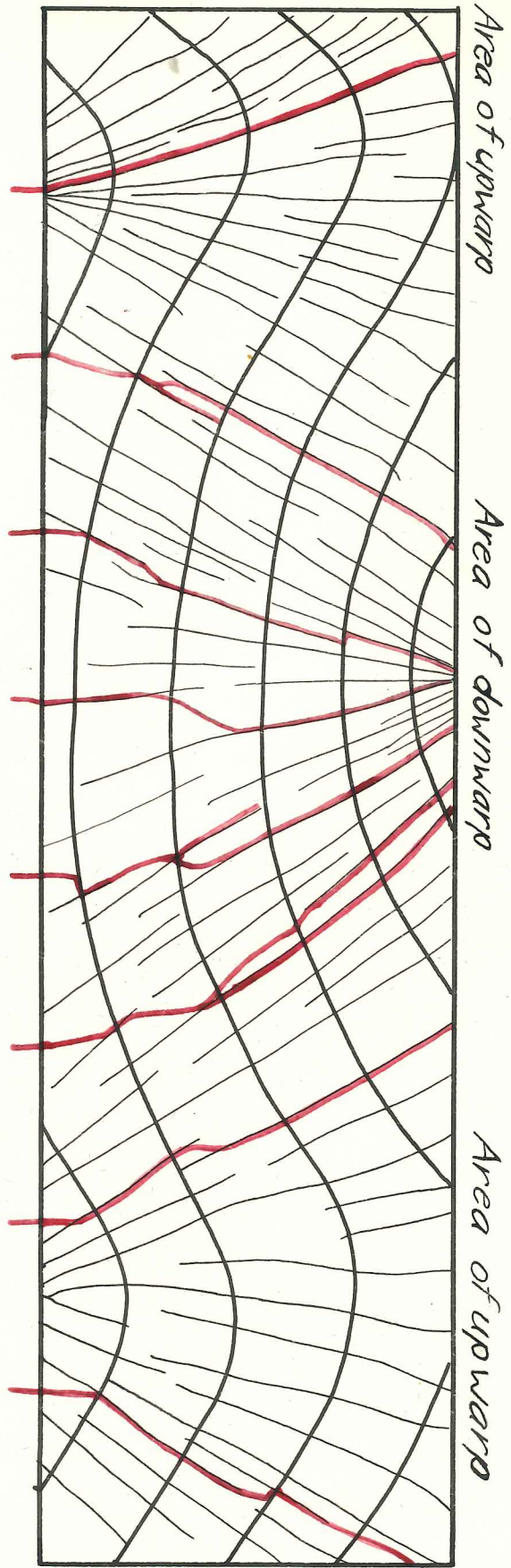


Fig. 3.- Hypothetical cross section to show the relation of downwarped areas in gneiss to zones of maximum igneous injection. The heavy black lines represent the banding in a gneiss which has been thrown into a series of folds. The light black lines show tensional joints in the gneiss, caused by bending. They open upward in the anticlines and downward in the synclines. The red lines are dikes showing how igneous intrusions are concentrated in synclines.

has solidified from an igneous rock solution in which the amount of volatile matter was exceptionally large. The petrographic analysis of a 9 foot lamprophyre dike outcropping 500 feet down the highway from the telephone box in Corbaley Canyon shows it to be an even-grained rock in which the constituent minerals have a distinct idiomorphic tendency. Plagioclase zonary from andesine to oligoclase, and with corroded centers containing numerous inclusions makes up the major part of the rock. Orthoclase is common in large singly twinned individuals. A tendency toward perthitic intergrowth is noted in many crystals and a few have borders which are micrographically intergrown with quartz, forming micropegmatite. Quartz is also present as a minor constituent, but is rare. It fills in the spaces between feldspar crystals in a few places. Corroded felds, principally biotite and hornblende, together with the various products arising from their decomposition, make up a large part of the rock. The biotite is often sharply idiomorphic, sometimes corroded, and usually exhibits a yellow to brown pleochroism. Some individuals of biotite vary in pleochroism even in a single crystal. One part will show absorption from yellow to brown, while an adjoining part in the same crystal varies from yellow to bright green. Hornblende is represented by badly decomposed crystals which are largely converted over into chlorite. A part of the hornblende is often uralitic. Two distinct varieties of chlorite were noted. One type is of a clear bluish green color in ordinary light and is almost isotropic. The other

is more yellowish green, is often clouded and shows the characteristic anomalous blue under crossed nicols. Magnetite is present in granular aggregates, formed mainly as a byproduct in the chloritization of the amphiboles. Apatite is present in long thin crystals. A few altered grains of sphene were also observed. One of the most peculiar features observed in this rock is the presence of large patches of carbonate and chlorite scattered through it. These patches are large enough to be easily apparent to the naked eye. The carbonate is distinctly not filling the blow-holes but occurs filling in the spaces between the other crystals as well as in the patches already referred to. The carbonate, the extensive development of chlorite, the quartz and micropegmatite all point to the presence of an exceptionally large percentage of volatile material in the original magma. The mineralogical analyses of the rock shows:

Andesine	50%
Hornblende	15%
Chlorite, Magnetite and other mafic decomposi- tion products	14%
Orthoclase	10%
Biotite	7%
Carbonates	2%
Quartz	1%
Micropegmatite	(-)%
Apatite and Sphene	(-)%

The contacts of this dike are extremely irregular, and are similar to the contacts of the dike sketched in Figure 2. The alteration of the gneiss along these contacts gives still better evidence than even the mineralogical analysis of the dike itself, that it must have contained exceptional amounts of volatile matter. Long, narrow apophyses project from the dike in every direction extensively metamorphosing the gneiss as they go. Close to the intrusion the gneiss has been almost completely converted over into amphibolite. A series of seven specimens taken at intervals of six feet from the contact outward show the rock to be largely hornblende out for 25 feet from the contact and from there a gradual diminution in the amount of contact metamorphism. The gneiss does not become normal in character, however, until over 100 feet from the dike. The contact amphibolite is a peculiar rock which exhibits a wide variety of textures and mineral composition. The larger part of it is composed almost entirely of hornblende with minor amounts of biotite. Lighter colored spots about an inch long are seen scattered through the rock. These are found to consist mainly of quartz and very badly corroded feldspar, and are thought to represent portions of the gneiss which were not completely replaced.

The six specimens taken from the contact outward are successively numbered RCI-11c1s; c2s; c3s; etc. A brief description of each may be of interest at this point. RCI-11c1s is a specimen of amphibolite through which a quarter inch apophysis from the lamprophyre projects. Practically all of

the feldspars contained in the gneiss of this specimen have been entirely converted over into brown hornblende. The feldspars still remaining are extensively kaolinized and sericitized and all through them minute crystals of uralite, biotite and brown hornblende are seen to be starting to grow. Along the edges of the lamprophyric apophysis the excess iron introduced from the magma has resulted in the formation of a distinct ring of very dark brown amphiboles immediately surrounding the contact. This fades rather abruptly as we go out about two millimeters from the dike, but the hornblende throughout the section is of a distinctly brownish cast. Another interesting feature noticed at the contact and in the dike itself is the development of uralite where particles of the amphibolite have^{been} broken off and engulfed in the magma. The uralite is bright green in ordinary light and is very pleochroic. It seems to be a product of the recrystallization of the hornblende that has been partially reabsorbed by the intruding magma. Uralite also often develops in minute crystals representing the initial stage of the replacement of plagioclase. Cracks through the amphibolite are frequently cemented with secondary quartz. The apophysis of the lamprophyre shows decided differences from the main lamprophyric dike. The extensive development of uralite from the resorption of included hornblende fragments has already been noted. In addition, the dike apophysis is distinctly more acidic than the main dike. Whereas, quartz was a rare constituent in the original magma, it makes up about 6% of the minerals

in the apophysis. Orthoclase is also somewhat more abundant than in the original magma, but comparison with other apophyses seems to indicate that this condition is merely local. Biotite was not noted at all in the apophysis and hornblende of the type characteristic of the main dike is rare. One of the most surprising differences in the mineralogical constitution of the two is the much greater amount of sphene in the apophysis than in the main dike. In the main lamprophyric dike sphene occurred rarely and in small crystals, making up less than one-fourth of one per cent of the entire mineral composition of the rock. In the apophysis it is very abundant, occurring mainly as small, badly altered grains. In the apophysis it approaches three or four per cent of the entire mineral composition of the rock. Micropegmatite is more abundant in the apophysis than in the main dike, but is still exceptionally rare.

Variation of the apophyses from the main lamprophyric dike can be noted in almost any of these intrusions. In the field several apophyses about two inches wide can be noticed to vary in a few feet from a very black basic rock to stringers of a light gray shade containing hardly any mafics. The apophyses in general seem to be more acidic than the main dike and this is thought to be due to the escape of the femic material outward where it produces the extensive amphibolitization of the gneiss.

RCI-11c2s is a specimen of amphibolite taken six feet from the main lamprophyric dike. In thin section it is seen

to be composed essentially of hornblende, biotite and feldspar. The hornblende is a little paler brown than was the case in RCI-11c1s, some of it even exhibiting a greenish cast. Biotite is abundant and in the direction of maximum absorption has a distinctly reddish cast to the brown. The plagioclase is badly altered, shows anomalous extinction due to strain, and everywhere throughout it along cleavage cracks and other planes of weakness biotite has started to develop. A few crystals of the original quartz remain unchanged.

RCI-11c3s shows much the same characters as RCI-11c2s. This was taken twelve feet from the contact. Feldspar is more abundant and is not so badly altered as in the former. Biotite is entirely absent. The hornblende is distinctly greenish in ordinary light in contrast to the two preceding specimens. Chlorite, with associated magnetite aggregates, is abundant. Quartz was not present in the section examined.

RCI-11c4s, taken at eighteen feet from the contact, is approaching more nearly the composition of the original gneiss. In this rock feldspar is in majority over the feldspars. It is still badly altered and its conversion over to amphiboles is easily seen in the small individuals of hornblende that start inside the plagioclase crystals and penetrate them in every direction. Hornblende is abundant and is very pleochroic from yellowish green to dark green. Individuals of brownish biotite very badly decomposed probably represent the original biotite in the gneiss before it was affected by the metamorphism of the lamprophyre. The biotite is of the

ordinary brown variety and shows none of the red characteristic of the fresh unaltered biotite found closer to the contact. Quartz is common but not abundant.

In RCI-11c5s, at 24 feet from the contact, the original gneissic banding is still well preserved. In the sections taken closer to the contact the original banding had been completely destroyed by the contact metamorphism. In c6s, however, the alignment of the green hornblende and brown biotite is easily apparent. The main effects of the contact metamorphism are seen only in the sericitization and kaolinization of the feldspars and in the development of secondary silica filling cracks in the section.

RCI-11c6s, at 30 feet from the contact, shows all of the characteristics of the typical gneiss, except for a rather extreme alteration of the feldspar and biotite. The hornblende appears to be fresher than either the albite or biotite.

From these brief descriptions it can be seen that the amount of basic material introduced into the gneiss from the lamprophyre along the contacts must have been tremendous. In this case the gneiss on either side of the lamprophyre for a distance of 20 feet has been almost entirely converted over into a rock consisting almost entirely of amphiboles and biotite. That the chemical material which produced the amphibolite was introduced from the lamprophyre seems certain not only from the correspondence of the amphibolitized areas with the contacts of the dike, but also from the fact that the replacement proceeds differentially outward from the dike

as is seen in the difference in color of the hornblende as we come farther and farther away from the contact. To accomplish this amount of metamorphism in a thin 9 foot dike we must postulate that the magma was very basic and must have contained immense amounts of volatile material which penetrated into the surrounding rocks carrying certain chemicals which were used in the conversion of the gneiss into amphibolite.

The contact effects just described are typical of a large number of the more basic dikes in Corbaley Canyon. More detailed work was done on this dike because of the excellence of the exposures as well as on account of the excellently developed contact effects at this point.

As the dikes become more and more acidic in composition the amount of alteration along their contacts becomes less and less. In those dikes in which quartz and micropegmatite make up as much as 10% of the total mineral composition contact effects on the gneiss are restricted to a somewhat extensive kaolinization and sericitization of the feldspars and the conversion of the biotite into chlorite immediately at the contact. No effects of the injection of the dikes can be noted more than a few inches from the contact. In the very acidic granophyres no contact effects can be observed either in the field or in thin section.

PETROGRAPHICAL RELATIONS OF DIKE TYPES

At various points in the present report it has been in-

licated that the Corbaley Canyon Porphyries seem to have been derived from one parent basic magma through a process of differentiation. The real proof of this fact is most easily seen by a comparison of the minerals and the minute properties of these minerals with the aid of the petrographic microscope. When this is done the differentiation of the Corbaley Canyon Porphyries from the same parent basic magma becomes not only plausible but indeed this explanation appears to be essential to explain their petrographical relations. Not only are the same minerals found in different dikes in proportions relative to their basicity or acidity, but certain minor characteristics of a certain mineral such as a peculiar type of pleochroism is found to be preserved in the different dikes all the way from the most basic to the most acidic. Petrographical analyses of the rocks discloses differences in the amount of certain minerals present and not in the character of the constituent minerals themselves.

From the 52 different specimens of dike rocks collected in Corbaley Canyon a suite of 15 have been selected to show this differentiation. A detailed petrographic description of these, including the mineral analysis, will be found in the appendix of this report. In addition ~~is~~ a Differentiation Chart showing the relative amounts of the principal minerals occurring in the rock, together with the most important properties of these minerals, has been constructed. In this chart the 15 specimens are listed from left to right by specimen number, beginning with the most basic, RCI-11, on

the left, and ending with the most acidic, D-6, on the right. The constituent minerals in the rocks are listed from top to bottom on the chart. Under each mineral certain special characteristics of that mineral which tend to show a common derivation from a parent magma are listed. If the rock under consideration contains the mineral, and the mineral exhibits one of these properties it is denoted by an X in the column opposite the mineral characteristic. In some cases where a mineral occurred in very small amounts considerable difficulty was encountered in telling whether a mineral had certain characteristics or not. In these cases all of the mineral characteristic columns opposite the mineral are left vacant. The percentage of the entire rock which each mineral makes up is listed in red in the appropriate column.

A close study of this chart together with the petrographical descriptions occurring in the Appendix should convince any one of the common origin of the dikes in Corbaley Canyon. That they are successive differentiates of a common magma would be practically essential to account for the fact that in all cases from the most basic to the most acidic the rocks contain a peculiar bluish-green, very clear pseudo-isotropic chlorite. The same premise must also be assumed in explaining the high percentage of sphene that is found in all the rocks, or for explaining that hornblende exhibiting special properties occurs in several dikes which are widely separated in the differentiation series.

The origin of the rocks as differentiates from a common

magma is also strongly indicated from the field relations of crosscutting dikes, as has already been noted. In every case where definite crosscutting relationships were found the more acidic dikes cut through the more basic.

The magma from which these rocks were derived seems to have been of a rather peculiar type. One of the oldest and almost the most basic rock in the region is RCI-11. It gives a clue to the chemical composition of the original magma from which the other rocks differentiated. RCI-11 is a typical lamprophyre. The mineralogic analysis shows it to belong to that group of lamprophyres known as malchites. These rocks are peculiar in that they combine a large percentage of ferromagnesian minerals with quartz and minor amounts of orthoclase. They are extremely high in volatile matter. In RCI-11 the high amount of volatile matter is seen in the carbonate, micropegmatite and the endomorphically altered hornblende present in the rock.

If an igneous rock solution of the composition of RCI-11 and containing the excessive amounts of mineralizers which this magma must have had was cooled slowly in a fair sized intercrustal basin differentiation would be expected to proceed with ~~the~~ greater ease and rapidity than in any other igneous rock solution that exists. The presence of the mineralizers would cause the formation of various crystal compounds with great rapidity because of their catalytic effect on the formation of certain minerals. In addition these same mineralizers would render the magma exceptionally

fluid so that the newly formed crystals could sink or rise in the liquid, depending on their specific gravities, with the greatest of ease. In this way differentiation would proceed very rapidly and would effect a complete separation of the magma if not stopped by the sudden cooling of the igneous rock body in which the differentiation was occurring. This is exactly the condition that is postulated to have happened in some region near Corbaley Canyon. The Corbaley Canyon Porphyries are thought to represent a series of differentiates that were led off from some intercrustal basin through fissures in the gneiss as the differentiation went on. The earliest rocks in the canyon are the lamprophyres, which probably represent pretty closely the original magma from which all the later rocks were derived. As differentiation went on in the intercrustal basin fissures opened up at intervals and were filled with the increasingly more acidic differentiates of the original magma, so that in Corbaley Canyon we have in the exposed dike rocks a series of samples representing successive differentiation stages that the original lamprophyre~~x~~ passed through.

The details of the differentiation seem to have been somewhat as follows: Starting with a rock composed essentially of andesine and hornblende the magma became increasingly lower in calcium, so that orthoclase gradually takes precedence over plagioclase. At the same time the relative percentages of feldspars diminish and the amounts of quartz and micropegmatite becomes greater. In the more basic rocks the

micropegmatite is commonly of the quartz-plagioclase variety and is not spherulitic. As the rocks become increasingly more acidic the quartz is more commonly intergrown with orthoclase and often shows spherulitic crystallization. The micrographic spherulites usually start from a central orthoclase crystal in the more basic varieties, then from a point as the magma becomes progressively more and more acidic and in the very most acidic dikes micropegmatite spherulites were noted, which start from a centrally located crystal of quartz. As the differentiation proceeds the rocks show progressively greater and greater proportions of micropegmatite. The femic material almost entirely disappears and the rock becomes nothing but a mass of radiating, micropegmatitic spherulites embracing corroded phenocrysts of orthoclase. In the progressively more acidic varieties even the orthoclase phenocrysts begin to disappear until we have a rock composed of over 90% micropegmatite. Finally quartz becomes so much in excess that it crystallizes out in large phenocrysts which are entirely surrounded by micropegmatite.

SUMMARY

The rocks exposed in Corbaley Canyon are entirely of igneous and metamorphosed igneous varieties. They consist of the Columbia River Basalt, a gneiss derived from a granitoid igneous rock, certain parallel injections of alaskites, pegmatites and quartz along the planes of schistosity of the gneiss, and a series of porphyritic and nonporphyritic dike rocks which cut the gneiss but upon whose eroded edges the Columbia River Basalt was poured out. The gneiss, because of the ribbon-like injections of quartz and pegmatite which it contains, has been called the Ribbon Cliff Gneiss. Because of their typical development in Corbaley Canyon the series of dike rocks have been named the Corbaley Canyon Porphyries.

The physiography and the Tertiary deformation of the district have been worked out by Bailey Willis. Close correspondence between Tertiary and Pre-Tertiary structure lines is indicated from evidence concerning the banding in the Ribbon Cliff Gneiss and from the parallelism and distribution of the Corbaley Canyon Porphyries.

Petrographically the Corbaley Canyon Porphyries represent a series of samples drawn off at intervals during the complete differentiation of an original lamprophyric magma. A complete transitional series with a quartz malchite and a porphyritic quartz granophyre as the poles, has been found.

In their contact effects upon the surrounding gneiss

the Corbaley Canyon Porphyries have produced varying results, depending on their relative viscosity and the amount of volatile matter which they contain. The basic dikes have extremely irregular contacts and have extensively metamorphosed the gneiss surrounding them. The more acid dikes show evidence of greater viscosity in their straight line contacts and lack of contact metamorphism. In one case a dike was observed that was so sticky that it appears to have actually slickensided its sides against the fissure walls as it came up.

APPENDIX A

Petrographic Descriptions of the Specimens in the Differentiation Series.

RCI-11: A petrographic description of RCI-11 will be found on page 38 in the text.

RCI-7: A distinctly idiomorphic textured rock consisting essentially of zoned plagioclase. Some of the plagioclases are intergrown on the edges with quartz forming micropegmatites. The zoned feldspars are usually andesine in the center and become progressively more acidic outward. The quartz intergrowths generally have oligoclase-andesine as feldspar. Quartz is fairly common as an interspace filler between plagioclase crystals. Decomposed mafics form a large percentage of the rock. They appear to have been principally hornblende, now largely altered to chlorite. Some of the chlorite is of a very clear blue-green pseudo-isotropic variety. Biotite is present in small, irregular, corroded individuals. Spene is abundant. Orthoclase is present in fair amount, but is subsidiary to plagioclase. The orthoclase is in part perthitic, in part micropegmatitic. Topaz is a common minor accessory. The mineral analysis shows:

Andesine	45%
Orthoclase	15%
Hornblende	12%
Chlorite and other mafic decomposition products	15%

Micropegmatite	4%
Quartz	2%
Topaz	1%

RCI-5: Orthoclase and plagioclase (andesine-oligoclase) are abundant and are often intergrown with quartz, especially along the edges. Perthitic intergrowths of the two feldspars are also common. Quartz not intergrown with feldspar is also present. Decomposition products after mafics form a large percentage of the slide. They consist principally of chlorite. Sphene is extremely abundant, in fact, the magma must have been exceptionally high in titanium to account for the large amount of titanite present. Biotite occurs rather sparingly. Topaz in long thin crystals, showing distinct cleavage, is common. Chloritic material fingers out around and fills the spaces between feldspars. Both ilmenite (partially altered to leucoxene) and magnetite are abundant. The relative amounts of the minerals are:

Andesine (partly perthitic)	50%
Decomposed mafics, mainly chlorite	17%
Orthoclase	15%
Sphene	7%
Quartz	4%
Micropegmatite	3%
Magnetite and Ilmenite	2%
Topaz	(1) 1%
Biotite	(-) 1%

D-1: This is a rather basic rock showing markedly a high concentration of volatile material in the magma. Feldspars predominate and consist mainly of badly kaolinized individuals which show a patchy extinction and have the properties of anorthoclase. Andesine and orthoclase occur in the groundmass, the anorthoclase being almost wholly confined to phenocrysts. In places anorthoclase is minutely intergrown with a finely twinned feldspar, apparently oligoclase or oligoclase-andesine. The andesine and andesine-oligoclase in the groundmass is largely converted into kaolin and carbonates.

Hornblende is a major constituent. It occurs in two generations; (1) in badly bleached and corroded greenish individuals exhibiting a variety of optical properties in a single crystal, and (2) distinctly idiomorphic brown individuals of fresh, unaltered character. The brown variety grows in and around the green varieties and also penetrates and replaces decomposed remnants of a green (sodic?) monoclinic pyroxene. A clear green pseudo-isotropic chlorite replaces the older hornblende in part. Sphene occurs in small anhedral crystals, which are badly altered to leucoxene. Long, thin crystals of apatite penetrate hornblende and feldspar alike. Quartz occurs sparingly, filling in the spaces between the other minerals. It is micrographically intergrown with feldspar along the edges of a few feldspar crystals. The alteration of the rock is clearly endomorphic as is testified by the replacement of the earlier hornblende by the brown varieties. The kaolin, carbonate, brown hornblende,

chlorite and interstitial quartz and micropegmatite are thought to represent the final consolidation products of the magma.

Anorthoclase	30%
Andesine-oligoclase	12%
Orthoclase	13%
Hornblende	31%
Chlorite	4%
Decomposed augite	4%
Quartz	4%
Micropegmatite	1%
Sphene and epidote	1%

D-18: A porphyritic rock containing macrophenocrysts of orthoclase up to $3\frac{1}{2}$ millimeters in diameter, which are in many cases partially intergrown with oligoclase, forming perthites. Aggregates of feldspar phenocrysts are present which suggest the swimming together texture of Voght. Peculiar bleached biotite individuals occur as phenocrysts. Each biotite individual exhibits two different types of pleochroism. One part will show absorption from dark green to light yellowish brown, while another changes from wood brown to black. Patches of brownish to green low double-refracting material seem to represent decomposition products after an entirely altered mafic. These aggregates consist largely of biotite but chlorite and other ferro-magnesian alteration products are also seen.

The groundmass of the rock is medium grained and consists of orthoclase, oligoclase and micropegmatite together with remnants of femics and a few minor accessory minerals. Orthoclase is much in the majority and makes up over 60% of the groundmass. Oligoclase is also common. Around each feldspar crystal and filling the interstices between them is found very fine feathery micrographic intergrowths of quartz and feldspar. These radiate out from the edges of individual feldspar centers, practically never starting from a point. Dusted throughout the groundmass are small patches of chlorite and other remnants of decomposed femics. Other minerals observed are sphene, ilmenite, rutile, magnetite, epidote and albite. The mineral analysis shows:

Phenocrysts	70% Orthoclase and orthoclase-oligoclase microperthite Phenocrysts . 30%
	30% Biotite
<hr/>	
Groundmass	60% Orthoclase
	30% Micropegmatite
	5% Oligoclase
	4% Chlorite and decomposed products . Groundmass . 70%
	1% Sphene, ilmenite, epidote, rutile, albite.

RCI-6: A peculiar ragged textured rock made up almost wholly of decomposition products. The main mass of the rock is composed of a minute cryptographic intergrowth of quartz with both plagioclase and orthoclase. Allotriomorphic quartz crystals occur rarely but no feldspar can be perceived that is not in part at least, intergrown to form micropegmatite.

Decomposition products after mafics consist mainly of chlorite (both the clear variety and the more cloudy types being represented). Carbonates are very abundant. They make up a large part of the rock and occur scattered all through it between the other minerals as though they had crystallized directly out of the magma, or rather, represent the final consolidation products of the magmatic juices. Epidote is present in small grains. The mineral analysis shows:

Micropegmatite	62%
Mafic decomposition products . .	20%
Carbonates	11%
Epidote	4%
Quartz	3%

D-2: A porphyritic rock showing macrophenocrysts of plagioclase almost entirely altered to calcite. Smaller phenocrysts of hornblende now remain as a chloritic substance transitory into uralite. The groundmass is granular and composed essentially of quartz, badly altered feldspar and blotchy patches of micropegmatite. The outlines of the corroded plagioclase phenocrysts are very irregular, the solution of the feldspar taking place differentially so that the edges of certain of the phenocrysts have developed into spongy injection micropegmatite on account of the crystallization of quartz in optically continuous individuals in the solution cavities of the feldspar. Alteration of the feldspars to carbonates has proceeded so far in some of the

phenocrysts that the cross-twinning of the calcite is well shown. Sericite is also present as an alteration product, but is rare. Femics consist mainly of an uralitic type of hornblende, semi-fibrous, pleochroism yellow to bright green. Some of it is a little chloritic. Remnants of what may be augite are now altered to fibrous uralite and carbonates. Titanite is present in considerable quantity, but is largely altered to whitish leucoxene. Some ilmenite is also present but is almost completely altered. Several types of micropegmatite are present. Some of it seems certainly to be of the injection type, other individuals show radiating (spherulitic) structure. Free quartz is present but nearly always has a little thread of feldspar sticking into it as if it were the beginning of an intergrowth. A minor accessory present in small amounts is apatite. A few small crystals and plates of epidote are also present. Mineralogically the rock consists of:

Micropegmatite	66%
Altered feldspar, including kaolin and carbonate	21%
Uralite	8%
Quartz	3%
Titanite and Ilmenite	1%
Apatite, epidote, chlorite	1%

SP-1: A medium grained rock consisting almost entirely of spherulitic and non-spherulitic micropegmatite. Several types of spherulites are found in the rock. Those that

radiate outward from a point and the ones that form in quadrants are the most common. The intergrowths are of a fairly coarse nature and are easily distinguished under low power. The spherulites, especially, consist of coarse micropegmatite, and in no case were spherulites found which consisted largely of feldspar fibers alone as was the case in the other rocks. Remains of femics (biotite and hornblende) are common in the groundmass. Much of this material is decomposed to chlorite (mainly of the clear blue-green isotropic type). Quartz which is not intergrown occurs rather sparingly. The section studied contained one large phenocryst of zonal plagioclase. The rock consists of:

Micropegmatite85%
Quartz	7%
Femics and their decomposition products	6%
Andesine	2%

D-11: Phenocrysts of untwinned orthoclase are surrounded by smaller individuals of micropegmatite which are in part spherulitic and in part not. The individual quartz and orthoclase parts in the intergrowth are of good size and are easily recognized under low power. The intergrowths show a wide variety of types. Coarse spherulites, spongy types and intergrowths in which the two constituents are arranged in layers are most common.

Oligoclase occurs sparingly in phenocrysts. Remnants of decomposed hornblende and biotite (?) appear here and

there, and the groundmass is sprinkled with femic decomposition products. Quartz occurs sparingly as phenocrysts. A few minute grains of sphene are present as well as a little epidote. Sericite occurs as an alteration product after ~~an~~ orthoclase. Mineralogically the rock is found to be:

Micropegmatite	74%
Orthoclase	12%
Hornblende, chlorite, biotite and limonitic aggregates	2%
Oligoclase	1%
Sphene and epidote	1%

D-5: Phenocrysts of badly kaolinized orthoclase are surrounded by large spherulites consisting mainly of fibrous feldspar, which is partially intergrown with quartz on the outer edges. The quartz increases in amount from the center outward in each spherulite. The spherulites sometimes start from a central orthoclase crystal, in other instances they radiate outward from a point. Between the spherulites there are peculiar feathery intergrowths of quartz and feldspar. In addition to the micropegmatite and orthoclase a few crystals of oligoclase are present, while dusted throughout the mass are decomposed remnants of femics. These appear to be mainly bleached hornblende. They are clearly of an earlier generation than the micropegmatite for they are often included within spherulites. A little quartz occurs interstitially between the spherulites. A few minute zircons were observed

as inclusions in feldspar. The mineral composition is:

Micropegmatite	77%
Orthoclase	13%
Quartz	5%
Decomposed femics	2%
Oligoclase	1%

D-12: Phenocrysts of orthoclase, perthitic in part, are embedded in a groundmass of micropegmatic spherulites. Phenocrysts of quartz are also prominent and a few of oligoclase were also noted. Both elements in the perthite were untwinned and probably represent intergrowths of orthoclase and anorthoclase, or at least intergrowths in the potassium-sodium series. Intergrowths are of two principal types. One type follows the outline of a feldspar crystal in shape and the individual quartz and orthoclase parts are arranged according to the crystal structure and orientation of the orthoclase crystal. Other micropegmatite individuals show a spongy type of intergrowth. Cryptocrystalline quartz fills in the spaces between spherulites. Decomposed remnants of femics appear scattered through the groundmass as limonitic aggregates. Many of the quartz phenocrysts are partially resorbed. The mineral analysis gives the composition of the rock as:

Micropegmatite	46%
Quartz	40%
Orthoclase	10%
Microperthite	2%

Limonite and chlorite . . . 2%

D-9: A porphyritic rock consisting of phenocrysts of quartz, orthoclase and oligoclase-andesine in a crystalline groundmass composed principally of micropegmatite. Accessories in the groundmass are greenish uralite, epidote, decomposed feldspar (mostly intergrown with quartz), a little free quartz, and a mineral with very high index and birefringence which appears to be partially altered to leucoxene. This mineral is probably rutile. The mineral analysis shows:

Micropegmatite	80%
Orthoclase	4%
Quartz	11%
Oligoclase-andesine . . .	3%
Hornblende	2%

D-8: A medium grained rock composed almost entirely of spherulites of micrographically intergrown quartz and feldspar. The intergrowths are predominantly of a very fine, wavy, fibrous type. They vary from 0.4 to 0.5 millimeters in diameter. Between the spherulites is a very fine cryptocrystalline groundmass of quartz having the exact character of quartz in quartz dikes. Practically all of the spherulites start from small centrally located orthoclase crystals. The feldspar is sufficiently altered both in the intergrowths and in the crystals to make the spherulites easily visible in ordinary light. Decomposed individuals of greenish hornblende occur both as phenocrysts and as small laths and

particles in the groundmass. A clear blue-green isotropic chlorite occurs in small plates throughout the entire section. Ilmenite was noted here and there. Both sericite and carbonate in addition to kaolin appear as alteration products. A few crystals of orthoclase and a few euhedral quartzes also occur as phenocrysts. Mineralogically the rock consists of:

Micropegmatite	78%
Quartz	16%
Orthoclase	4%
Hornblende, chlorite and ilmenite . .	2%

D-6: Large phenocrysts of quartz are set in a medium grained mosaic of graphically intergrown quartz and feldspar. The intergrowths consist both of spherulites and of irregular sponge-like individuals. A few orthoclase crystals occur as phenocrysts. The orthoclase is extremely badly kaolinized. Decomposed remnants of hornblende are included in the micropegmatite along with limonitic and chloritic aggregates and other feric decomposition products. A few individuals of free quartz appear in the groundmass. The mineral analysis shows:

Micropegmatite	91%
Quartz	6%
Orthoclase	1%
Hornblende, chlorite and limonitic aggregates	2%

PLATE 5



Pine Canyon near Waterville, Wash. 50

Simmes

Corbaley Canyon from Waterville Plateau. Note the dikes outcropping as ridges in the gneiss on the righthand side of the canyon. The large fog-filled valley is that of the Columbia.

PLATE 6

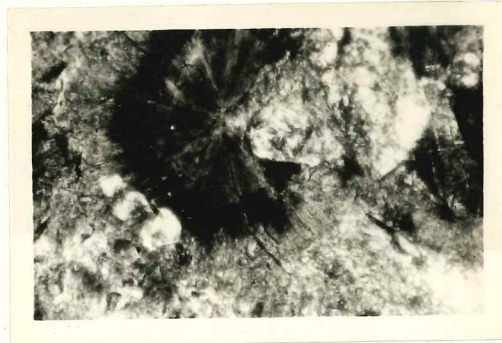


Fig. 4.- Altered spherulitic granophyre. This type of Spherulite consists mainly of thin feldspar fibers which are badly kaolinized. Toward the outer edges of the spherulite it becomes graphically intergrown with quartz. The surrounding groundmass is a fine-grained aggregate of micropegmatite with a few crystals of quartz. Medium power.

PLATE 6



Fig. 5.- Micropegmatite in granophyre. The graphically intergrown quartz and feldspar (which forms over 65% of the rock) surrounds kaolinized phenocrysts of andesine and orthoclase. Some quartz, together with decomposed mafics, occurs in the groundmass. Medium power.

PLATE 7

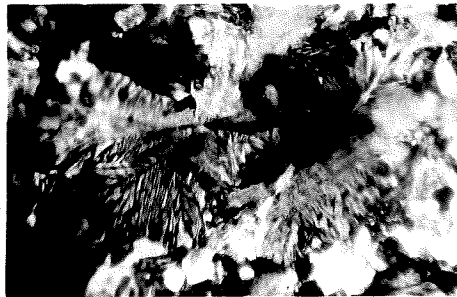


Fig. 6.- Feathery quartz-plagioclase micropegmatite in lamprophyre. In this type of micropegmatite the plagioclase preserves its crystal structure in the intergrowth to such an extent that the polysynthetic twinning of the plagioclase can be seen in the intergrowth. Medium power.

PLATE 7



Fig. 7.- Quartz-plagioclase micropegmatite in spherulitic granophyre. The quartz and feldspar extends out from a central point in quadrants. The small white patch in the center of the intergrowth represents a part of the plagioclase crystal that is not intergrown. Medium power.

PLATE 8



Fig. 8.- Spongy intergrowths of quartz and orthoclase in spherulitic granophyre.



Fig. 9.- Interstitial micropegmatite filling in the spaces between hornblende, biotite and andesine crystals in a lamprophyre. Medium power.

PLATE 9



Fig. 10.- Very fine micropegmatite encroaching into the borders of plagioclase crystals in lamprophyre.

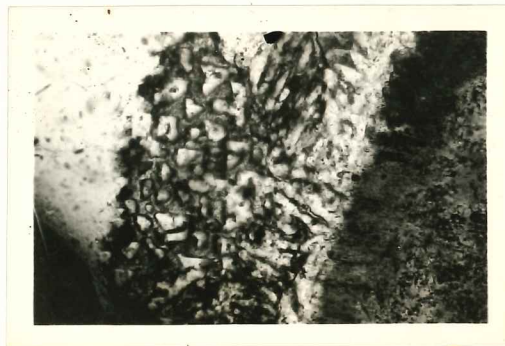


Fig. 11.- Resorption micropegmatite along the borders of a quartz phenocryst in granophyre. The phenocryst has been partially resorbed with the formation of micropegmatite along the edges. High power.

PLATE 10



Fig. 12.- Micropegmatite starting to develop along the edges and in resorbed patches in an orthoclase crystal (black). The clear white patch is a quartz phenocryst. Medium power.



Fig. 13.- Group of micropegmatite spherulites in granophyre. Low power.

PLATE 11



Fig. 14.- Resorbed anorthoclase phenocryst in spherulitic granophyre. Note the extremely fine micropegmatite surrounding the crystal. Medium power.

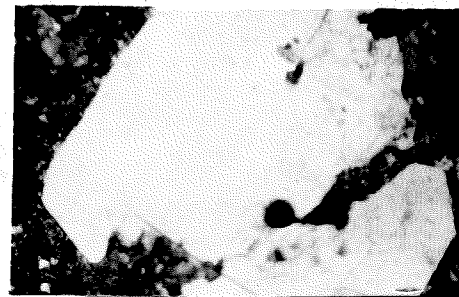


Fig. 15.- Resorbed quartz phenocryst in spherulitic granophyre. Medium power.

PLATE 12

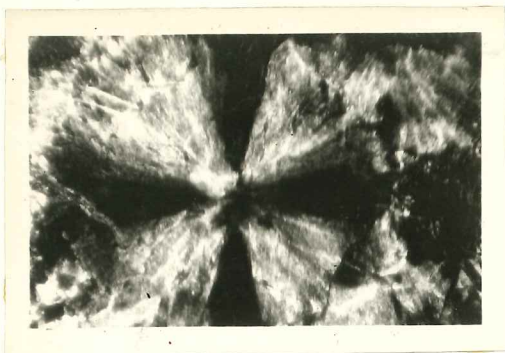


Fig. 16.- Large spherulite in granophyre. This type of spherulite is composed mainly of fine feldspar fibers and shows the black cross of extinction. Medium power.



Fig. 17.- Injection micropegmatite in zoned andesine crystal. The center of the crystal has been partially resorbed and quartz has crystallized out in the cavities. Note the lighter zone at the edge of the feldspar. Lower power.

PLATE 13



Fig. 18.- Large patch of chlorite in lamprophyre. Patches of chlorite and carbonate of this type are common in specimen RCI-11.



Fig. 19.- Patch of carbonate in lamprophyre (RCI-11).

PLATE 14



Fig. 20.- Texture of lamprophyre. Distinctly zoned crystals of andesine interlock with euhedral individuals of hornblende. Filling the spaces between the crystals is fine micropegmatite and a little quartz. Note the strong idiomorphism of the minerals. Medium power.

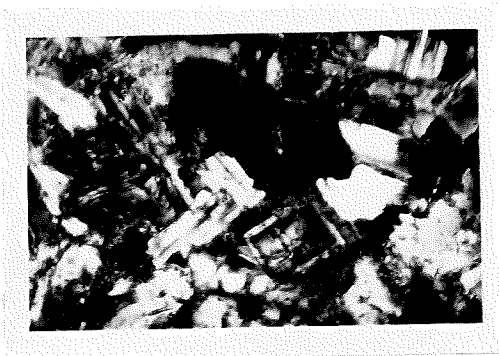


Fig. 21.- Photomicrograph of lamprophyre showing plagioclase zoned from andesine to oligoclase, biotite, hornblende, and chlorite with interstitial quartz and micropegmatite. Medium power.

PLATE 15

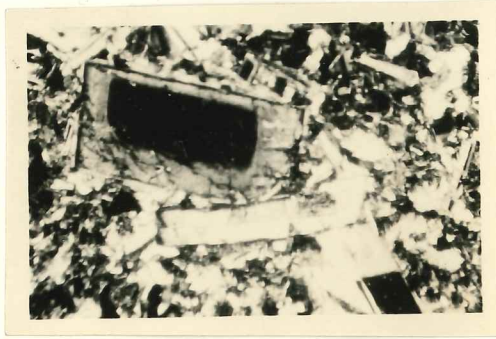


Fig. 22.- Zonary plagioclase in lamprophyre. Low power.



Fig.23.- Photomicrograph of albite crystal in gneiss. Note the curvature of the albite twinning lines. The band through the center of the crystal represents where it has been broken and then recemented with secondary silica. Low power.

