THE GEOLOGY OF THE NORTHEASTERN PART OF CEDAR LAKE QUADRANGLE WITH SPECIAL REFERENCE TO THE DE-ROOFED SNOQUALMIE BATHOLITH

by

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ABSTRACT

This paper commences with a general description of the topography and the physiography of the area covered in this report. In the conclusion of this preliminary treatment the author suggests a possible explanation for the prevalence of tandem cirques in the Cascades.

It then proceeds to a geological description of the observed formations, of which four out of six had to be named by the author. The oldest of these is the Twin Falls Formation, a series of metamorphosed sediments composed largely of dark gray quartzite and black argillite. In absence of fossil evidence it was considered on lithologic grounds as late Paleozoic. Next in age is placed the Ragnar Volcanics. It is represented by highly metamorphosed andesitic rocks, probably correlating with the Vancouver Volcanics of the Jurassic. Probably of a somewhat similar age is the unfossiliferous North Bend Formation, composed of coarse grained arkosic sandstone. These three formations are intruded or indurated by the Mount Si Complex, which presumably represents a border phase of the Index Post Jurassic Batholith.

The bulk of the area is covered by the Keechelus Andesitic Series and the Snoqualmie Batholith, which were

previously described in the Snoqualmie Folio and there proved to be of the late Miocene. The author has endeavored to prove that the unindurated lavas in the western part of the area, previously described as the "Enumclaw Volcanics," formthe lower part of the Keechelus Series. This entire series is considered as derived from the Snoqualmie Batholith which itself exhibits phases ranging from gabbro to granodiorite. The vast quantity of fragmental material is considered to have been formed during the actual de-roofing of the batholith at the granodiorite stage. The pyroxene diorite, described in the Snoqualmie Folio as grading into andesite, is considered a near vent phase of granodiorite, which owing to the escape of water vapor, formed pyroxene rather than hornblende. The vast loss of volatile constituents caused a premature solidification of the batholith and a general curtailment of differentiation. These two factors are considered to be largely responsible for the scarcity of ore deposits and of late differentiates.

INTRODUCTION

Cedar Lake Quadrangle lies on the western slope of the Cascades. Its northwestern corner is within twenty miles of Seattle and slightly south of due east.

This report covers a rectangular area of approximately one hundred and seventy-five square miles in the northeastern corner of the quadrangle. Its eastern border coincides with that of the topographic sheet and extends for about eleven miles. The northern boundary includes two-thirds of the quadrangle line, a distance of some sixteen miles.

The region is remarkably accessible to Seattle for both the Sunset Highway and the main line of the Chicago, Milwaukee and St.Paul traverse it.

The original purpose of this investigation was to map and describe the areal geology in the district between the Snoqualmie Quadrangle,* which has already been described, on the east, and that part of the Cedar Lake Quadrangle already

*Smith, G.O., and Calkins, F.C. Snoqualmie Quadrangle, U.S. Geol.Surv.Folio 139.

covered by George W. Evans in "The Coal Fields of King County."!

!Evans, G.W. Washington Geol. Surv. Bull. No.3.

Flanking these two quadrangles on the east and west lies the territory covered in the Mount Stuart Folio and in the Tacoma Folio. In consequence, this work completes the first series of geologic maps across the Cascades in the state of Washington.

The unusual relationship of the two largest rock masses in the area, the Snoqualmie Batholith and the Keechelus Andesite, formed the most important and the most fruitful subject of the investigation. A theory advanced by the author to account for their relationship and the necessary evidence substantiating it, form a large part of this report, which is submitted to the University of Washington in partial fulfillment of the requirements for a degree of Master of Science in Geology.

In mapping, the author has used the location method with a Brunton compass and an aneroid barometer on enlargements of the topographic sheet. The excellence of the map, together with the marked topographic relief made this system reasonably accurate. The detail with which the area was covered varies considerably. Reconnaissances of the southwestern corner did not show any prospects of variation to justify further investigation in the limited time. The complexity of the central part, however, demanded careful field work. The roughness of the topography and the thickness of the vegetation frequently limited the detail. With more time, however, a higher degree of accuracy could be obtained.

The author, during the summer of 1924 and the spring of 1925, spent about sixty days in the field. The assistance of Mr. Aaron Waters in the field and the helpful advice of

Professor G. E. Goodspeed and Professor E. J. Saunders in the detailed work of the problem is gratefully acknowledged.

GENERAL TOPOGRAPHY

Although the area does not extend to the divide of the range, the relief is very pronounced. Elevations vary from five hundred to nearly six thousand. The summits of the mountains show the concordance of elevations typical of the second cycle of erosion of the Cascades and increase gradationally from a minimum of about thirty-five hundred feet on Rattlesnake Ledge south of North Bend to a maximum of nearly six thousand in the extreme northeast corner. Valley glaciation of a youthful topography has been the principal factor in the erosion of the region.

A large part of the center of the northwestern quarter of the area is characterized by low rounded hills up to five hundred feet in height, surrounded by flatlying alluviated land. This lowlying part is topographically bounded to form a rough rectangle. On the west rises Rattlesnake Ledge, on the north Mount Si, on the south Mount Washington with Ragnar Hill directly to the west, and on the east Grouse Ridge with higher mountaines immediately behind. This has been the receiving ground for much glacial debris. Its hills may to a slight measure reflect the underlying rock, but are largely due to morainal and outwash material from three valleys that come in from the east. These three main systems draining into this region divide the area into several units.

The largest river is the Middle Fork of the Snoqualmie. This river coming in from the northwest circles around the southern portion of Mout Si in a large irregular bow and then leaves the area to the northwest directly east of North Bend. The upper valley is chiefly in a stage of youthful maturity, although glacial deposits have resulted in a local rejuvenation.

The next main river to the south is the South Fork of the Snoqualmie. It runs diagonally across the district in a comparatively straight line with a general northwest direction. After leaving the valley, its course is more irregular. It continues with the same general trend and leaves the area just west of North Bend and about a mile west of the Middle Fork.

Cedar River and Cedar Lake lie in the southeastern portion in a valley approximately parallel to that of the South Fork and about four miles to the southwest. This valley is of great importance as the source of the Seattle water supply. The lake is typical of the glacial finger lakes and is formed by both the gouging and the morainal deposits of its own valley glacier. The outlet of the lake, superimposed on bedrock, curves around to the southwest and crosses the western border.

MOUNT SI

North of the Middle Fork rises Mount Si. Only the first two thousand feet of it, however, lie within the quadrangle. This part furnishes many exposures. Most of the soil that forest vegetation was gradually building up over the glaciated ledges was stripped off by fire. The subsequent aridity has since thwarted the attempts of a second growth. Now a seasonal tangle of vegetation is added to the rotting timber and the small dead fir trees to increase the difficulty of field work.

To the east and south of the mountain much of the original heavy forest is still standing, but it covers largely glacial alluvial material which forms the high terrace rising eight hundred feet above the river.

MIDDLE FORK - PRATT RIVER

Between the Middle Fork and the South Fork lies a wedge shaped mountain mass. The South Fork's drainage reaches only to the summit of its own valley, while the Middle Fork, through a number of tributaries, drains the rest of the district. The principal tributary is the Pratt River. It runs approximately parallel to the eastern border, and crosses the northern boundary after covering about six miles from its original source in a cirque lake of the same name.

Pratt River receives drainage from several well defined cirque lakes and their valleys. A characteristic of many of these valleys is a tandem cirque at the head. Kullakulla Lake at the foot of Mount Defiance probably forms the best example. The lake is in a very well defined cirque about fifteen hundred feet below the summit. The outlet of this immediately descends some thousand feet over an equally well defined cirque.

West of the Pratt River and parallel to it lie two smaller glacial valleys heading in cirque lakes. These also flow into the Middle Fork. In the case of the three rivers, the tributaries are far better developed and the relief more moderate to the southwest than to the northeast. This is apparently the result of a jointing system in the underlying granodiorite. The drainage to the southwest conforms to the dip of the major jointing, while the main streams follow the strike. This gives a rough grid pattern to the river system.

Plate 1.- Pratt Lake from the South Fork Divide. The mountains in the background form the east wall of the Pratt River Valley. The white exposures are due to the slides of granodiorite.

One of the characteristics of this part of the area is the extensive slides of large angular blocks of granodiorite. These slides, often commencing at the top of a mountain, extend down its side for thousands of feet. For the most part, they are not inclined to move and are slowly being encroached upon by vegetation. In fact, much of the forest land undoubtedly covers such exposures. These slides are also largely dependent on the jointing. The blocks have the tendency to slide down the dip of their major jointing. This has undoubtedly been an important factor in shifting the drainage divides of these valleys to the west, while the eastern slope tends to retain its original wall.

This general division is the most beautiful and at the same time the most inaccessible part of the whole area. There is one principal trail that passes through the district. Climbing over a four thousand foot pass, it connects the South Fork valley with the Pratt River country. It then follows the valley down to the Middle Fork trail and back to civilization. It is a distance of well over twenty miles. The only other trail in the area is up Granite Creek. That has one branch up over a four thousand foot pass to Thompson Lake, the most westerly extension of the Pratt River drainage.

The Pratt River country is noted for an unusually high rainfall, and, in consequence, has a luxuriant undergrowth that renders cross-country work very slow. The slides and the stream valleys form the most convenient routes. The good trails in this district are due to the fact that the

Plate 2.- Typical granodiorite slides on the crest line south of Pratt Lake. The great blocks are sliding down the more gentle slope parallel to the major jointing. On the other side of the crest the relationship of the uppermost blocks is at times still apparent.

Pratt River system lies in the Snoqualmie National Forest.

Since the topographic survey the forestry service has established a few changes and additions in the nomenclature. The principal of these the author has noted on the geologic map. On the government sheet Ollie Lake is at the head of Pratt River. In the forestry maps this lake is known as Pratt Lake, while the name of Ollie is transferred to an otherwise nameless lake, which with Thompson Lake forms the headwaters of the principal tributary to the Pratt River from the southwest. In like manner the fairly large lake at the foot of Mount Defiance was considered to be of sufficient importance to be named, and is now known as Kullakulla Lake.

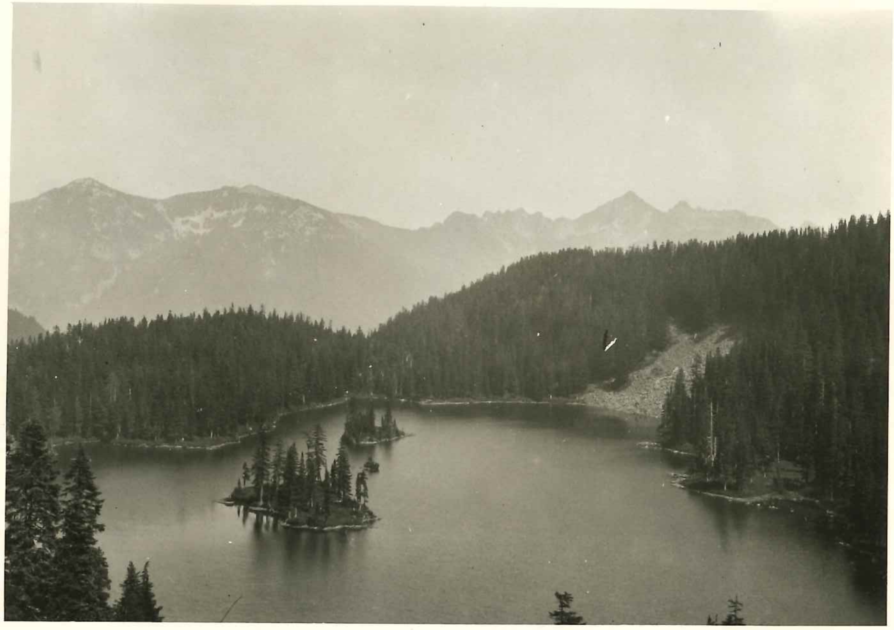

Plate 3.- Thompson Lake and the east side of Pratt River Valley. The more distant rugged crest line to the south, formed largely by the Guye Formation in the Snoqualmie Quadrangle, contrasts with that of the granodiorite which forms the northeastern corner of the area.

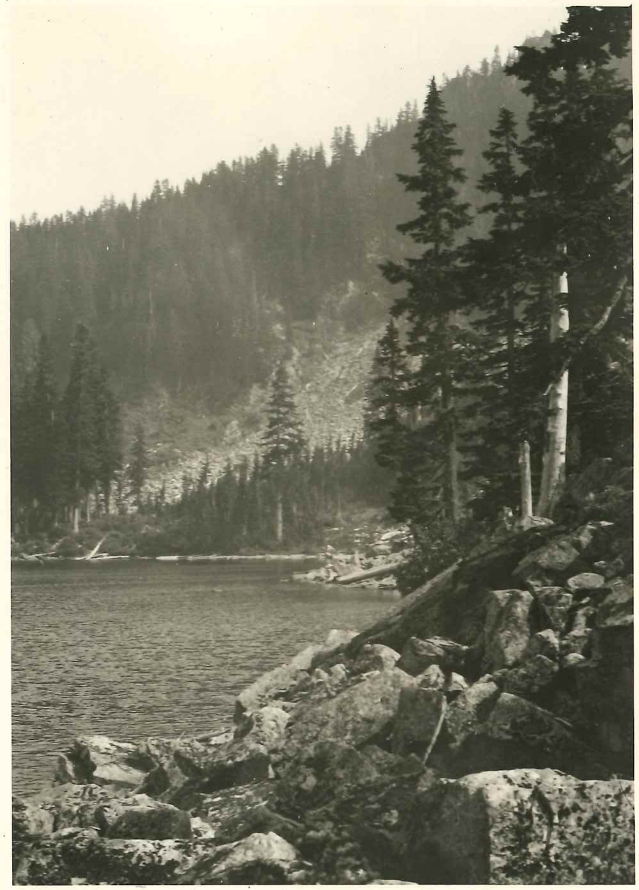

Plate 4.- The great talus slides of granodiorite at the head of the cirque at Thompson Lake.

THE SOUTH FORK OF THE SNOQUALMIE

The South Fork of the Snoqualmie enters the area as a well defined river, that is still in rather a youthful stage of erosion. The valley is so deeply cut at the western margin that the drop in the river is comparatively gentle, except for the temporary base levels established at its several falls. For the most part it lacks the power necessary to move the coarse sediments and boulders that its many steep tributaries are depositing.

Below the station at Garcia it has cut down to bed rock. Farther west it is again on bed rock, but here the valley is broad and the river has undoubtedly been superimposed on its original southern wall by the accumulation of glacial and alluvial material. This same situation together with the resistance of the Twin Falls Sedimentaries has been the factor to form the Upper Falls at the western margin of the valley. Here the river descends by two spectacular cataracts in the course of a hundred yards. These upper falls of the Snoqualmie, locally known as the Twin Falls, are easily available to the highway.

The high glacial deposits both to the north forming Grouse Ridge and to the south above the Chicago, Milwaukee tracks indicate the extent of the deposits that once dammed the river, forming the numerous beds of stratified clay in the upper part of the valley. The river cutting a new channel in the unconsolidated material is now on the more resistant vertical strata of the Twin Falls Formation to the south of its preglacial bed and probably at a considerably higher level.

This valley is very easy of access. It is traversed both by the only highway across the Cascades in the state, and by the main line of the Chicago, Milwaukee, and St.Paul railroad. Shortly after the topographic survey, the completion of the Sunset Highway rendered the old road useless. Consequently the author, in the geologic sheet, has obliterated the old road and in its place has shown the approximate course of the new highway.

Many of the railroad and road cuts furnish excellent exposures. The river, itself, especially at the western margin of the valley, affords important outcrops. For more detailed work, however, conditions are far from favorable. The tributaries are mostly short and very steep, rendering ascent difficult and in many places practically impossible. The valley bottom is so well watered and frequently so poorly drained that the vegetation is very heavy. Even the old highway, although in disuse for only some ten years, is already so overgrown that it is of little help. In many cases the devil's clubs have completely obliterated it and have rendered its use impossible.

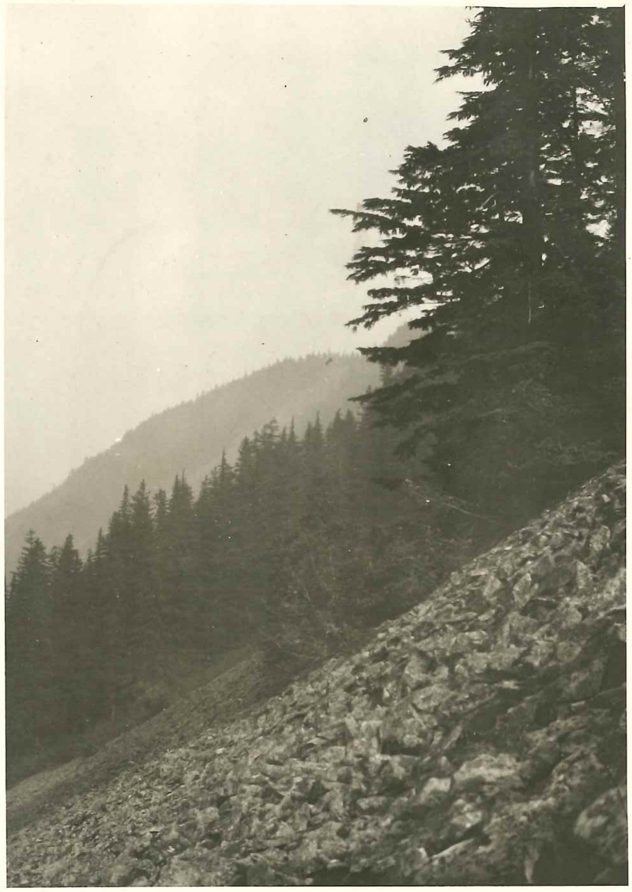

Plate 5.- On the south side of the upper part of Cedar River Valley. Typical talus slides in the Pyroxene Diorite phase of the Snoqualmie Batholith.

For the most part the eastern end of the valley and the district southwest of the lake are heavily wooded. For the first thousand feet, at least, the northern side of the lake has been stripped of its timber and operations are being continued both up the valley and on the south side of the lake.

The eastern part of the watershed has for the time being, been made more accessible by the logging railroads that are in operation. Although there are numerous old trails in the district the one on the north side of the river is the only one that is kept in condition.

Owing to a futile attempt to enlarge Cedar Lake by the building of the New Dam the lower part of the valley has come into considerable prominence. The effect of the great flood that broke through the morainal deposits is still clearly seen in the huge scar just west of Ragnar Hill. The water which still seeps through this scar is the source of a large creek that now forms the main body of the original stream indicated on the map. In consideration of the date of this catastrophe the entire stream is locally known as Christmas Creek.

Aside from this historic interest, the northern end of the valley is of considerable physiographic importance. The lower part of Cedar River flowing at right angles to the direction of its upper drainage leaves the area in a well defined valley cut between Rattlesnake Ledge and the mountain mass to the west of Cedar Lake.

Cedar Lake Valley lies parallel to what little definite structure is apparent, while the lower Cedar River cuts across it at right angles. At some time in preglacial days at least part of the Snoqualmie drainage must have cut through this mountain mass as a master consequent, while the upper Cedar River as a tributary bore a subsequent relationship. Although the Middle Fork valley is directly in line with the lower Cedar Valley, the presence of the resistant northern extension of Grouse Ridge undoubtedly indicates a preglacial barrier to any direct route. At the same time the relation of the Middle Fork to its own lower valley does not suggest any recent change.

Probably the South Fork played the role of the master consequent until the glacial period. Then the ice of the upper Cedar Valley rode across the main river channel and, perhaps thanks to some other subsequent valley opposite, advanced for a couple of miles beyond. The morainal deposits of this glacier naturally completely blocked the South Fork drainage and diverted it to the valley of the Middle Fork.

A recessional morain was undoubtedly responsible for damming the valley which had been previously deepened by glacial gouging. A more general factor, however, must have been responsible for the rather flat lying surface of the deposits between the fifteen and sixteen hundred foot contours. This elevation exactly corresponds to that of numerous terraces exposed in the area. The principal examples of which are found north of the Middle Fork east of Mount Si, and just south of the town of Cedar Falls. This concordance of elevation must be due to a large temporary post glacial lake, which was probably part of the great system formed by the blocking of the Puget Sound drainage by the retreating continental glaciers at the close of the period.

With the subsidence of this body of water, the outlet of Cedar Lake had to cut a new channel in the unconsolidated material that blocked the valley. While still in the initial stage of this action the river, in swinging toward the south, became superimposed on its former valley wall. Although now the water is diverted for power, the deep gorge through the rock and the sharp drop at Cedar Falls to the old consequent valley below indicate a very youthful stage of development.

This result of chance preserved the lake which otherwise would long since have been drained by the rapid erosion of its outlet in the soft glacial soil.

RATTLESNAKE LEDGE

The last unit to be taken up is Rattlesnake Ledge. This lies north of the lower Cedar River. Bounding the area on the west, it has formed a retaining wall that has undoubtedly tended to increase the mass of glacial debris in the open section east of it.

The summit of Rattlesnake Ledge is near its southern end. There it reaches over thirty-five hundred feet, breaking off in a sharp escarpment to the east to the morainal deposits some twenty-five hundred feet below. This escarpment has been accentuated by the lateral plucking of the Cedar Lake glacier during its greatest advance. The western slope of the hill is more gentle and decreases gradually to the southwest. This mountain, as the topography suggests is formed by a formation dipping to the southwest. Towards the northwest the height decreases to two thousand feet and with it the escarpment to the east. The morainal material strewn up the east side for a thousand feet or more has naturally tended to modify the topography.

TANDEM CIRQUES

The tandem cirques developed in the steep glacial valleys of the Cascades were mentioned in the description of the Pratt River region. Apparently this feature has not been described or accounted for in the literature. In consequence the author will digress to state a theory that may logically account for their occurrence.

It is generally granted that a glacial cirque owes its origin to the "bergschrund," a transverse crevasse that always forms at the head of a glacier. The water from the melting ice on the surface of the glacier runs down this crevasse and percolates into the joint cracks of the rock. With subsequent freezing the ice pressure loosens the blocks, which are then carried off by the moving ice. This process, which is known as glacial sapping, is indefinitely repeated. As this goes on, the upper blocks thus undermined fall easy victims of the glacier.

The sapping always tends to form a vertical wall at the head of the glacier. At the same time the downward abrasion by the glacier is rendered especially efficient by the angular joint blocks from the wall. The maximum effect, obtained before the blocks are deeply incorporated in the ice, is usually sufficient to actually reverse the drainage, forming a lake basin in the center of the glacial amphitheatre.

The Alps and the Rocky Mountains furnish most of the text book illustrations of valley glaciation. Here the typical glacier on emerging from its cirque follows a fairly even slope to its terminal moraine. In the Cascades of Washington, however, many of the valley glaciers are characterized by a series of two or more cirques, which are referred to as "tandem cirques." These apparently have been described as features of Alpine glaciation.

In the typical valley glaciation of a fairly gentle valley, the glacier would emerge from the cirque basin and commence its gradual descent without any marked disturbance. In the very rugged topography often found in the mountains of the Northwest the grade of many of the valleys is extremely steep. Here the ice emerging comparatively flat from the upper basin must be transversely fractured on again commencing its steep descent. Sapping would then commence along the bottom of this second bergschrund. Gradually a second cirque would form along this line eating back into the basin of the upper one.

Then in turn depending on the original slope of the valley a third cirque in a similar manner may form at the transverse crevasse where the glacier once more commences its precipitous descent from the second basin. The final result would be a series of steep steps in the valley even if the preglacial floor had been comparatively smooth.

The preglacial topography and the variations both in hardness and in jointing of the rocks would have considerable bearing on this type of erosion. In many cases in the Cascades, however, the tandems are cut wholly in homogeneous

Plate 6.- Mount Defiance from the southeast. Kullakulla Lake, at its base, is formed by the upper cirque. The lower cirque breaks off sharply to the right.

Snoqualmie Granodiorite. This fact eliminates variation in rock structure as a necessary factor in the formation of this glacial feature.

At the low elevations of the Cascade valley glaciers, the tendency toward daily surface melting on the upper part of the glacier would naturally be far greater than in truly arctic glaciation or at the high elevations of the many ice-fields of Europe and the Rocky Mountains. The amount of water trickling down the bergschrunds during the warmth of the day would undoubtedly largely control the rapidity of sapping and the formation of tandem cirques.

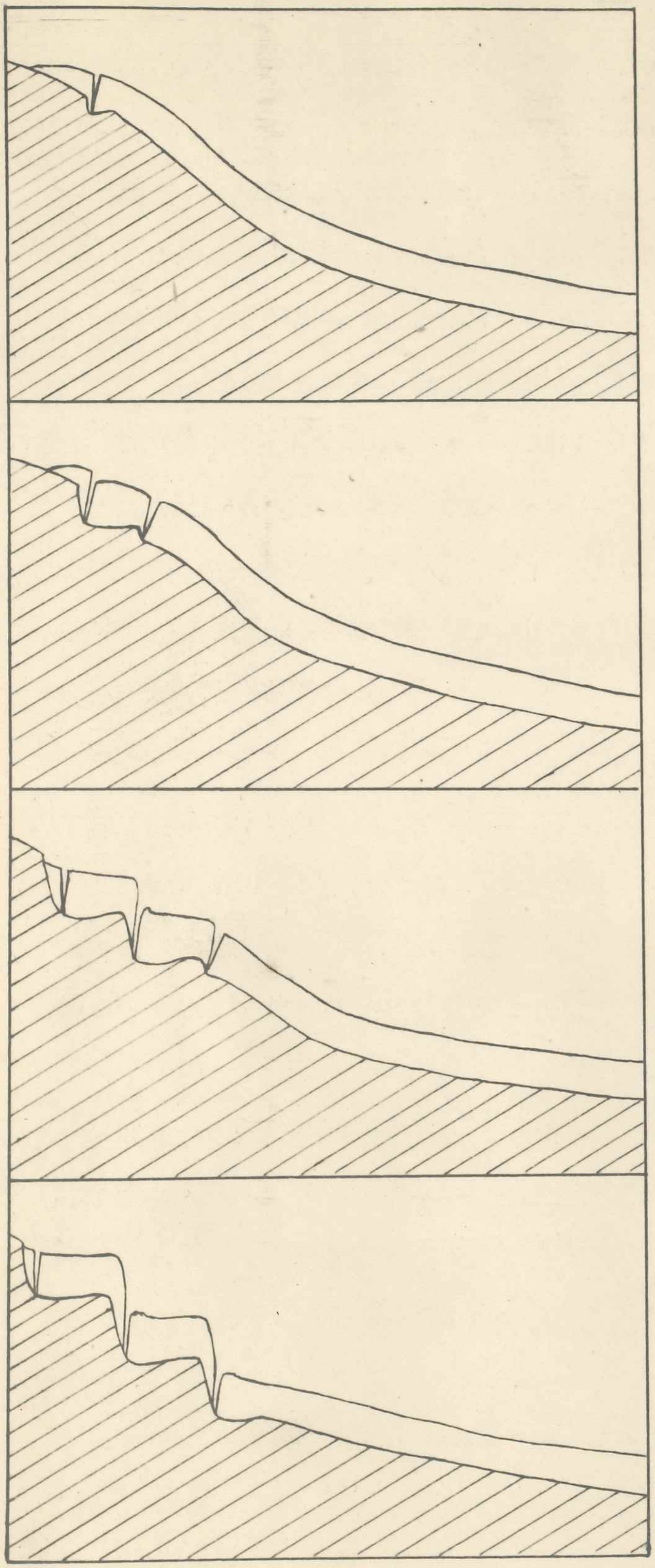

Plate 7.

The initial stage of the first cirque.

Formation of the second bergschrund with incipient sapping of the second cirque at its base.

In like manner the initial stage of the third cirque.

The final result on the given slope.

Longitudinal profile of a valley to illustrate the hypothetical development of tandem cirques.

TWIN FALLS FORMATION

GENERAL DESCRIPTION AND OCCURRENCE

The oldest formation in the area is a series of sediments which the author has named the Twin Falls Formation owing to its exposure at the Upper Falls of the Snoqualmie. It is a series several thousand feet in thickness made up largely of fine grained quartzites and argillites with a minor amount of thin bedded chert.

This series lies in the north central part of the area. The principal exposures are south of the Middle Fork and parallel to it. Here it forms the northern slope of the mountain mass between the two forks of the Snoqualmie. Close to the crest line comes the contact with the intruding Snoqualmie Batholith. It tends to form a rugged topography that at times stands out in marked contrast to the granodiorite.

It outcrops again in the valley of the South Fork forming the Twin Falls, and continues up the side of Mount Washington in the same general trend as far as the crest line. In these exposures the northern margin is intruded by the Mount Si Complex, while the south eastern is overlain unconformably by Keechelus Andesite. On the crest line the formation may extend higher than mapped, although considerably short of the summit.

Two other exposures occur in the area in contact with the Mount Si Complex. North of the Middle Fork above the

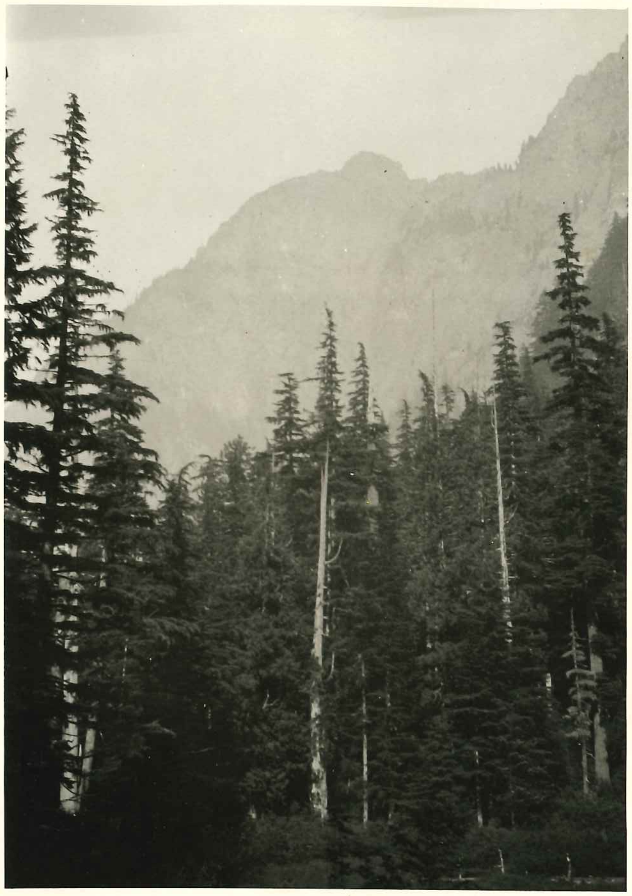

Plate 8.- The western divide of the Pratt River drainage as viewed from the west, showing the rugged exposures formed by the Twin Falls Quartzite at the northern boundary of the area.

glacial terrace contorted sedimentaries are exposed. Directly south of this, the northern extension of Grouse Ridge is formed by a contact between the two formations. The resulting induration probably increased its resistance. This factor undoubtedly contributed to the glacial deposits to the south on Grouse Ridge and to the north in the glacial terrace across the Middle Fork.

The formation is often too contorted to permit a satisfactory determination of its inclination. In general the exposures of the northern part have a strike of approximately east and west and a dip of forty to forty-five degrees to the south. At the South Fork the strike on the average has swung around to a more nearly north and south trend with almost vertical beds. In these readings the strike of the individual bed in the same general exposure frequently varies considerably.

PETROGRAPHY

The formation consists mainly of dark gray quartzite and black argillite. Frequently they are thinly interbedded. Thinbedded chert forms a minor constituent.

The quartzite is composed largely of angular to subangular quartz grains averaging about four hundredths of a millimeter in diameter. Ilmenite or magnetite grains form the most common accessory, with an occasional fragment of feldspar.

Near the contact with the Snoqualmie Batholith the

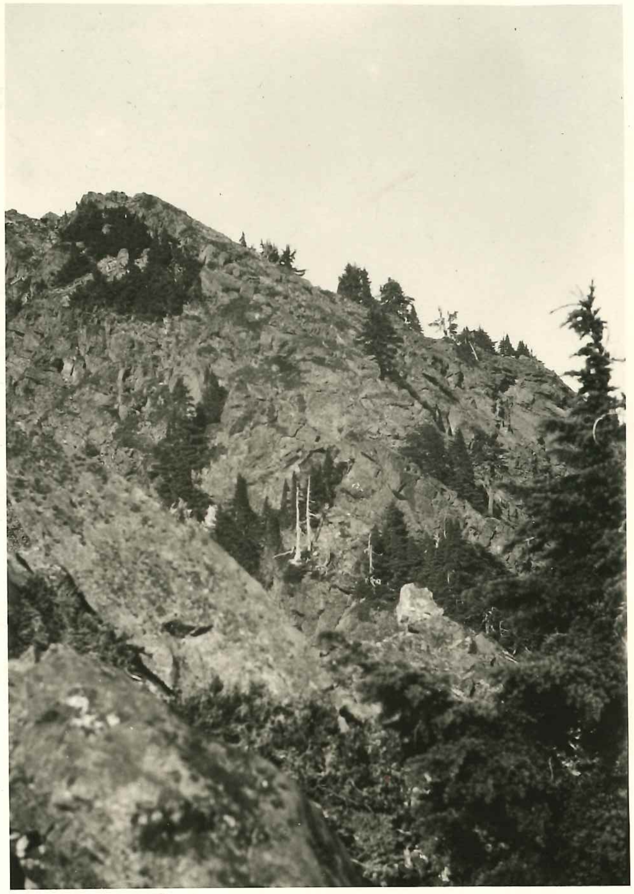

Plate 9.- The western crest line
of the Pratt River Valley,
showing the quartzite
just above the contact
with the intruding grano-
diorite.

quartzite is to a large extent recrystallized to interlocking grains. Here the rock develops a marked conchoidal fracture. A predominant feature of the indurated quartzite is the formation of minute flakes of biotite of a reddish brown variety. Although typical in other respects the reddish tinge may be due to the presence of titanium in the iron oxide dust.

The argillite is a black very fine-grained rock that usually has a very pronounced irregular foliated cleavage, rendering it extremely friable. The Snoqualmie batholith silicified it to a hard aphanitic rock, but the Mount Si intrusion apparently resulted in a mechanical rather than a chemical change. In thin section it shows a high carbonaceous content with only an occasional minute quartz grain. Its fine grain and extremely high carbon content render it very sensitive to pressure. It usually exhibits contortion to a greater or less degree. The incompetence of the argillite in comparison to the quartzite is clearly shown by an exposure on the South Fork at the Mount Si contact. The outcrop is largely of argillite with thinbedded quartzite. Diastrophism resulting from the intrusion has left angular blocks of the quartzite imbedded in a contorted mass of argillite that exhibits marked lines of flowage, giving it the appearance of a tarry mass.

The only exposures of chert were at the Twin Falls. Just above the lower falls light buff colored chert outcrops in a thinbedded contorted exposure. Although it yields no evidence of radiolaria the appearance of stratification suggests marine origin. The compact thin bedding may well be due to the softer intervening shale member being squeezed out during the contortion.

Close by, on the trail to the upper falls, a dark gray chert occurs in a confused mass of green metamorphics veined with calcite. The green stone undoubtedly came from a basic igneous rock, which was probably an offshoot of the Mount Si intrusion. This chert, although similar petrographically, may well be of secondary origin.

AGE AND CORRELATION

Although the formation showed no definite indication of limestone, the presence of bedded chert and the homogeneity of the strata suggests a marine origin. Unfortunately, in spite of rumors of a fossil locality in the vicinity of the Twin Falls, no trace of any life was found either in the field or in the thin section to prove the age or origin. In much of the formation the possibility for the survival of fossil indications after the intense regional and local metamorphism is somewhat problematical.

From a lithologic comparison this formation may well correspond to the Gunn Peak Formation described by Charles E. Weaver* in "The Geology of the Mount Index Mining Region."

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*Charles E. Weaver, Geology and Ore Deposits of the Index Mining District, Wash.Geol.Surv.Bull.7, pp.35-38.

These beds outcrop about fifteen miles to the north. Unfortunately, there too, no fossil evidence was found to determine their age. Although absolute proof was lacking, these sediments were thought to be of the Carboniferous.

The formation also resembles closely the description of the Leech River* Formation of Vancouver Island, which R. D.

*G. M. Dawson, Reports on a Reconnaissance of Leech River and Vicinity, Geol. Surv. of Canada, Report of Progress 1876-77, 95-102, 1878.

C. H. Clapp, Southern Vancouver Island, Ibid. Memoir 13, 35038, 1912.

McLellan** has definitely correlated with strata in the San Juan Islands. Fossil evidence proved these beds to be

**R. D. McLellan, Geology of the San Juan Islands, 1925.

of the Pennsylvanian.

From a rather superficial lithologic resemblance to these formations, both in the type of sediments and in the degree of consolidation, the author considers the Twin Falls Formation to be of the Late Paleozoic and probably of the Pennsylvanian.

RAGNAR VOLCANICS

GENERAL DESCRIPTION AND OCCURRENCE

Probably next in time comes the volcanic formation which the author has named the Ragnar Volcanics, owing to its exposure on the Chicago, Milwaukee tracks near the tool house that constitutes the station of Ragnar. It is a fine-grained rock apparently chiefly of a basic andesitic nature, although some of the rock mapped with it, is largely a mass of secondary femics that suggest a still more basic type. It shows both flow and agglomeritic phases.

Just west of Mount Si, it comprises the bulk of the small sharp hill that rises almost as a part of the mountain to some thousand feet above the river. Here the contact with the Mount Si Complex is in the small soil covered valley that separates them. The rock exposed in the steep eastern wall of the small hill is a highly silicified flow rock cut by dikes. This same rock, only less indurated, is exposed continuously to the south for over a quarter of a mile. For that reason the hill may be in place, although the sharpness of the contact and the general physical appearance suggest that it may have been an immense block that has slid from the upper slopes of the mountain. As yet sufficient work has not been done to possibly correlate it with any higher exposures. Roof pendants of a fine-grained green schistose rock were found both on the eastern side of Mount Si and at the margin of the area at about the twenty-five hundred foot contour. They strongly suggest flow rocks, but their extreme alteration does not permit conclusive correlation.

To the south in a rather similar manner these volcanics form a large part of Ragnar Hill. Here the geology is quite complex. The hill is formed largely of fine-grained andesitic flows and agglomerates intruded by a dioritic phase of the Mount Si Complex. Both of these formations are highly altered to a very friable mass of greenish femics cut by innumerable fine stringers of a white material in part of carbonates. This zone of alteration renders a definite contact indistinct.

Overlying this formation are well defined flows and sedimentaries of the Keechelus Series. These lack the white veins that characterize the contact phase of the underlying rocks. On the eastern side of Ragnar Hill fresh acidic and lamprophyric dikes are exposed cutting the old contact rocks and probably aiding in their decomposition.

Two other outcrops emerge from the mass of glacial debris that separates the two main exposures. Both show the fine-grained friable green metamorphic type identical to Ragnar Hill. In the northern part of each coarse-grained rock of the Mount Si Complex intrude the greenstone. On the North Bend-Cedar Falls road, a series of shallow cuts just south of the South Fork form one set of weathered exposures. The falls on Christmas Creek about a half mile below the railroad bridge form the other.

PETROGRAPHY

In the field the less altered rock often closely resembles quartzite. It is a fairly dark gray rock with an even, fine-grained texture that is usually free from phenocrysts. Occasionally laths of feldspar are visible with a hand lens. The agglomerate exposed at Ragnar Hill is of a lighter gray with small angular to subangular fragments that give it a very irregular fracture. One quite general type is altered and weathered to a green earthy mass that is irregularly veined and spotted with a soft white substance.

In the thin section the fresh rock exhibits chiefly fine thin laths of andesine in a ground originally largely of glass, now a mass of secondary quartz clouded with kaolin and accompanied by secondary femics. The feldspar usually shows distinct flow allignment. The femics are principally a fibrous amphibole, probably actinolite, with usually a minor amount of chlorite. As a rule, these are accompanied by ilmenite grains partly altered to leucoxene and rutile.

The agglomerate has fragments averaging about half a centimeter in diameter. The individuals appear very homogeneous. They are slightly more truly andesitic than most of the formation. An earlier generation of plagioclase is indicated by small kaolinized phenocrysts. The decomposition of the glass formed chiefly kaolin and quartz with a far lower femic content. The cementing material is an opaque white to brownish substance, probably of iron stained kaolin.

Even in the freshest specimens the greenstone shows no trace of its original texture or composition, but it exhibits a higher concentration of the same metamorphic minerals that are found in the rest of the formation. It is composed of matted amphibole and chlorite fibers, with frequent grains of epidote. Ilmenite altered to leucoxene and rutile is very plentiful. The friability appears to be caused by the alteration of the secondary femics to fibrous serpentine.

AGE AND CORRELATION

This formation probably correlates with the Jurassic flows that were first described by C. H. Clapp* as the Vancouver Volcanics. In the San Juan Islands, R. D. McLellan** proved the Eagle Cliff Porphyrite to be of the same age. There it was exposed largely as the dike feeders. In both cases it was intruded by the post Jurassic batholith.

*C. H. Clapp, Southern Vancouver Island. Geol. Surv. of Canada, Memoir 13, 35-38, 1912.

**R. D. McLellan, Geology of the San Juan Islands.

Lithologically the Ragnar Volcanics strongly resemble these formations, both in the hand and in the thin section. In addition it too has suffered intrusion by the Mount Si Complex that is presumably also of the Sierra Nevada Disturbance.

NORTH BEND FORMATION

GENERAL DESCRIPTION AND OCCURRENCE

The North Bend Formation is determined on purely lithologic grounds. There is no paleontological or stratigraphic evidence. In consequence, it may contain deposits of more than one period. Its sediments are thought to be derived in part from the erosion of the Twin Falls Formation. The finer beds are all high in chert, while its conglomerate contains argillite. This fact, although not especially convincing, forms the basis of correlation. In addition, the degree of both classification and consolidation is usually considerably less than that of the earlier series.

The principal exposure that furnishes the name for the formation, lies in a fairly narrow strip that extends for about a mile southwest of North Bend. Here it forms most of the low rounded hills that rise abruptly from the flood plain of the Snoqualmie at the northern end of Rattlesnake Ledge. Its contact with the overlying Keechelus Andesite is confused both by glacial deposits and a heavy second growth. A contact with the Mount Si Complex to the east has not been located, but the high content of chlorite both there and in the small exposure on Mount Washington strongly suggests that it must be older than that intrusion.

The other sedimentary outcrops that the author describes may not be related to the main exposure. They all are too insignificant to demand separate classification. For convenience, a general family relationship permits them to be classed together. None of them is sufficiently large to map. Although a couple of exposures were closely associated with the older series, their relationship with the Twin Falls Series has not been definitely proved. This entire formation was invariably found to be massive, and not once did it permit any determination of its inclination. Additional outcrops, however, might prove fruitful.

South of the Middle Fork near North Bend Timber Company camp, a conglomerate, containing many pebbles of argillite in a well consolidated sand, is exposed in a shallow railroad cut. The argillite is typical of the nearby rocks of the Twin Falls Formation. Its schistosity in the conglomerate shows no common relationship. Therefore, since the metamorphism must have been prior to the later deposition, this bed must be infinitely younger than the main series. But conclusive proof of correlation of this exposure with the main body of the formation is impossible.

At the upper of the Twin Falls there is a small exposure of a rock that lithologically resembles this formation far more than the Twin Falls series. Apparently it is resting unconformably on the upturned older strata.

Again on the crest line of Mount Washington considerably below the Twin Falls Formation a similar rock outcrops. Both in the hand and in thin section it is almost identical to the type near North Bend.

PETROGRAPHY

The rocks classed in this formation are characterized by rather poorly classified grains averaging about three tenths of a millimeter in diameter. The grains are principally of quartz and chert with minor amounts of undecomposed feldspar and occasional grains of femics. They are very well consolidated, but as a rule still show their original outline, even under a hand lens. The rock usually has a high content of fibrous chlorite, which gives it a pronounced green tint. The main exposure is highly veined with calcite.

AGE AND CORRELATION

Unfortunately any attempt to establish the age of this formation must at present be largely hypothetical. Probably at least the main outcrop is of the early Mesozoic. Its sediments appear to be derived from the Twin Falls Formation, which may well be of the late Paleozoic. Its principal exposure is altered by the Mount Si intrusion that is presumably part of the post Jurassic batholith.

Lithologically it has no resemblance to any formation described in nearby areas. Its coarseness and poor classification prove it undoubtedly to be of near shore origin. Since there is no suggestion to the contrary, it was probably formed as a small lake deposit.

A BATHOLITH

Before taking up the remaining igneous formations it will probably add to the clarity of the description if the reader be acquainted with the modern conception of a batholith. For this reason the author will digress to review briefly the recognized stages of an intrusion and of its accompanying volcanics. Although details of the physical mechanism are still subject to dispute, it will be best first to sketch the generally accepted principles.

It is generally acknowledged that a batholith advances chiefly by a process of magmatic stoping.* The stresses and tensions produced by the differential expansion of the overlying rock are considered sufficient to permit a repeated shattering of the roof rock. This differential expansion is due largely to the low temperature gradient and the varying rates of conductivity of different rocks. The large blocks thus loosened would sink to abyssal depth before assimilation and therefore would not immediately alter the composition of the intrusion.

Probably the first stage of the intrusion is as a basaltic wedge following some line of weakness while the overlying rock was under tension. Although extremely hot this magma would not be as capable of stoping or reabsorbing the country rock as its later differentiates. The basaltic lava is

*Daly, R.A. Igneous Rocks and Their Origin. 1914. pp.194-208.

so heavy even when it is expanded by melting that blocks of the overlying rock loosened by shattering or heat expansion would be unable to sink in it. Then again, the limited zone of alteration of a gabbro indicates a dry melt. Without volatile constituents it would be almost impossible to conceive of sufficient heat to melt away the roof rock.

With cooling it has been proved that the femic minerals are the first to crystallize. Then with theirheavy specific gravity they are bound to sink in the still molten magma. Any gases included in these minerals are largely given off when the crystals form. As the differentiation by this fractional crystallization continues, the remaining magma is rendered more and more fluid by the increased percentage of the volatile constituents incorporated in it, even though the actual temperature is lower. At the same time, with the removal of the heavy metallic elements, the specific gravity of the magma decreases.

These physical changes would equip the magma with increasing efficiency for stoping. In the lighter melt the blocks would be able to sink. At the same time the gases constantly becoming more concentrated would increase the zone of alternation as well as the occasional explosive effect. The batholith should thus attain its maximum intrusive efficiency when it reaches its most acidic phase.

A batholith* as now conceived is formed by the irregular

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*Emmons, W.H. Transactions of American Institute of Mining & Metallurgical Engineers, Vol.LXX, pp.975-980. 1924.

advances of one magma during a long continuous period of differentiation. The irregularity of outline of these fluctuations, although in general enlarging the chamber, might permit here and there the survival of a more basic phase already solidified along the margins or in the more isolated stocks and cupolas of the earlier stages. Wherever the offshoot of an intrusion breaks through the overlying rock volcanic activity results of a type corresponding in composition to the stage of differentiation of the plutonic mass. This increased overburden frequently permits the later stage of a batholith to intrude its own earlier volcanics.

The initial stage of all intrusions is as the primary basic magma, while the final product of the cycle is a granitic rock. In like manner the corresponding volcanics range progressively from basalt to the more acidic types. Tremendous variation in the final result is permitted without any special change in the general process. In one case the last advance might remove all indication of the earlier stages of intrusion and leave a homogeneous granitic rock. In some other instances traces of most of the intermediate steps may survive. In addition, owing to chilling or other contingencies, any stage of the intrusion may be complicated by its own border phases as well as by its offshoot dikes.

MOUNT SI COMPLEX

GENERAL DESCRIPTION AND OCCURRENCE

Intruding into these formations is a plutonic mass that appears to be too complex to be classified along any well established lines. It is mapped here as the Mount Si Complex which at present seems justifiable. Although the rocks are remarkably varied, for the most part, they show a family relationship. A large part of the rock is a plutonic or injection breccia. The character of the injected material varies from a gabbro diorite type to a coarse grained rock resembling a granodiorite. As an average, the rocks are nearer to diorite, although the fibrous hornblende usually present suggests a uralitic origin.

Petrographically much of the rock suggests a dike type rather than a plutonic, although the greater part has suffered so much metamorphism as to hide its original features. The bulk of the rock has been distorted to a greater or less degree. Some has developed a gneissic structure with well developed parallel banding. Other is contorted to a confused irregular mass that gives no suggestion of its original texture. In some of the breccia the pressure has been sufficient to distort greatly the inclusions, while in others the blocks retain their original angularity.

More than one age may be present in the rocks mapped as this formation, but it would require very detailed work under far from ideal conditions to prove anything conclusive. A field determination of the extent and relationship of the different units might form some definite theory for the occurrence of the mass, but the local variations and the metamorphism would render the success of such an attempt problematical. Unfortunately the rounded weathered exposures of Mount Si usually furnish no clue to the many variations without the aid of a hammer.

Probably the complex is the result of superimposed border phases and dikes of the post Jurassic Index Granodiorite to the north. The breccia may be the result of the injection of the offshoot dikes or of the intrusive itself into the country rock or more usually into its own earlier border phases. The intense diastrophism that has since taken place would naturally add to the confusion. Additional correlation to the north might prove this hypothesis.

The principal exposure on the southern part of Mount Si gives the formation its name. Directly to the south this intrusive lies at the base of the northwestern slope of Mount Washington. Through the glacial deposits that lie between these, the formation outcrops in several localities. This suggests that it may be continuous. Judging from the boulders in the glacial deposits below Cedar Lake, the Mount Si Complex must also underlie the lower end of that valley.

The complex intrudes the Twin Falls Formation on the east, and the Ragnar Volcanics on the west. As mapped, the contact on both sides appears very regular, but with more detail minor irregularities would be apparent. On the northern extension of Grouse Ridge the exposures along the crest invariably show a contorted contact phase of the intrusive or the sedimentary. Just east of this suggestions of bedding appeared to be at right angles to the contact. The strata of the Twin Falls Formation at the South Fork, however, seem roughly to parallel the contact. This factor probably has some bearing on the intrusion, which otherwise exhibits no suggestion of a sill-like origin.

Two other small exposures were located. Both show the intrusion of the Ragnar Volcanics. One is on the North Bend-Cedar Falls road just above the South Fork, and the other at the Falls of Christmas Creek.

In several places the complex is cut by rocks of the Snoqualmie Batholith. In the valley of the South Fork just below the Upper Falls a fresh gabbro is exposed intruding the complex. Along the Chicago, Milwaukee tracks near Ragnar fresh acidic and lamprophyric dikes of the Tertiary batholith cut the highly metamorphosed earlier intrusion.

PETROGRAPHY

Petrographically the types of rock composing this formation are so varied that they render a comprehensive description almost inexhaustible. The author will briefly describe a few types that appear to be the most widely distributed. Unfortunately, the part the different units play in the complex cannot usually be stated, since in many cases metamorphism has so greatly altered the texture and the mineral content that it is impossible to establish the original rock type with any degree of surety.

Probably the most uniform rock is a gneiss that varies from a diorite to a granodiorite. It forms the predominant type along the railroad from the Twin Falls contact to just west of Ragnar. Usually it is a medium grained rock that shows pronounced thin banding of fairly dark femics with occasionally visible quartz grains. At the base of the southern end of Mount Si it is also exposed. Here it tends into a more acidic (Plate 10) plutonic breccia, which lacks the extreme regularity of banding that characterizes some of the exposures to the south. Although the banding in the breccia may be partly due to flowage the frequent distortion of the xenoliths proves the intense diastrophism.

In thin section the average specimen is quite acidic, but the quartz as a rule appears secondary. The most typical shows coarse roughly rounded individuals of andesine and smaller irregular fragments of common hornblende in a ground of fine grained interlocking quartz.

The plagioclase is always more or less altered to sausserite and kaolin. In extreme cases the feldspar is completely replaced by a semi-opaque cryptocrystalline aggregate, which usually tends to preserve traces of the original twinning. As a rule, the individuals of plagioclase show a pronounced alignment. At times the wavy extinction indicates the extreme distortion. A few specimens undoubtedly show

Plate 10.- Granodiorite gneiss phase of the Mount Si Complex. With plane polarized light x 13.5. Highly altered plagioclase, probably oligoclase, (f) with much interstitial quartz (Q). Hornblende (h) largely altered to chlorite (ch) and serpentine (sp).

primary quartz, but usually it is in a fine mosaic, which if not wholly secondary at least is recrystallized. The highest percentage of the fine grained quartz together with calcite occurs in the zone of alteration of the acidic Snoqualmie dikes east of Ragnar Hill.

The hornblende in this type of gneiss generally was thought to be primary. As a rule, it is in small irregular individuals with approximately parallel orientation. Usually bleached biotite is associated with the hornblende probably as an alteration product. In badly altered specimens the remains of femics are indicated only by local concentrations of magnetite grains and chlorite. Serpentine and epidote are quite common accessories.

Near the Ragnar Volcanics on Mount Si, a coarse grained rock of a more basic character is the interstitial member in a breccia. It is nearer to a gabbro or a gabbro-diorite. Its appearance when etched by weathering renders it quite distinctive, for then the femics, probably due to their high content of iron oxide, stand out in marked contrast to the kaolinized gray plagioclase.

This type (Plate 11) exhibits about equal percentages of femics and labradorite in a hypidiomorphic texture. The feldspar, which is highly altered to sausserite and kaolin, is peculiar in having innumerable fine particles of secondary magnetite following its cleavage cracks. The femics consist in part of primary hornblende with a fairly large amount of uralite that is distinguishable with difficulty from the

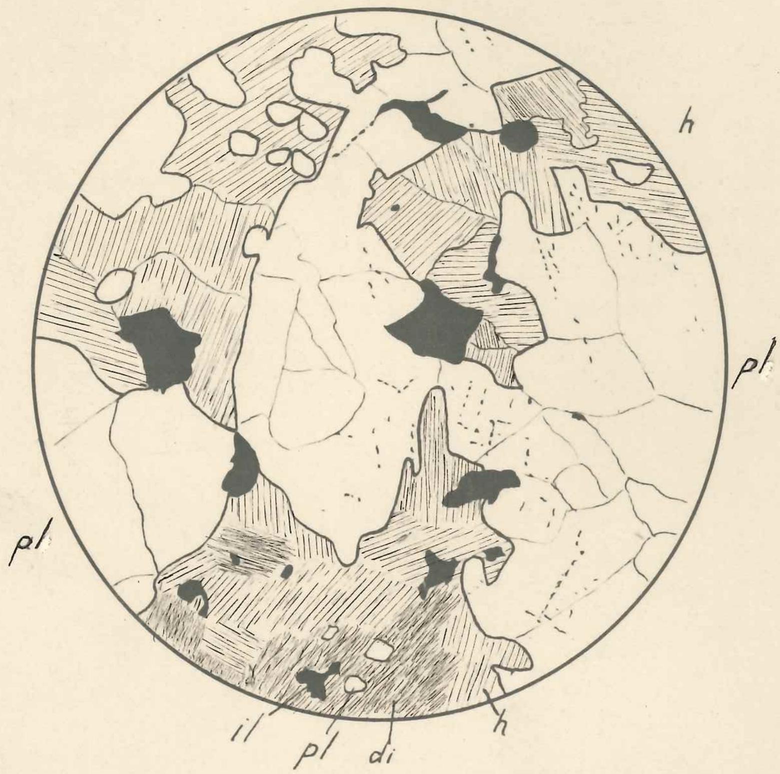

Plate 11.- Gabbro-diorite phase of the Mount Si Complex. With plane polarized x 13.5. The plagioclase (pl) is labradorite largely altered to saussserite and kaolin. Secondary iron oxide follows the cleavage cracks. Hornblende (h) apparently is largely primary. Minor amounts of diallage (di) in part altered to uralite. Large grains of ilmenite (il) partly altered to leucoxene.

remnants of diallage. Large grains of ilmenite, partly altered to leucoxene and rutile, are prominent as a primary constituent.

In addition somewhat finer grained dark colored phases are exposed in the area. They are found chiefly near the Grouse Ridge contact, again on the higher exposures on Mount Si above the plutonic breccia, and also on the Cedar Falls road just south of the South Fork.

For the most part these phases are too greatly altered to be definitely determined. Gneissic alignment and occasionally granoblastic texture usually indicates that the original structure has suffered rearrangement. In thin section common hornblende and highly altered labradorite proved to be the chief constituents. Perhaps owing to complete recrystallization the amphibole usually fails to show a uralitic origin. Occasionally augite and hypersthene are still visible in a mass of the customary alteration. All the most common of the secondary femics are almost invariably present.

AGE AND CORRELATION

The Sierra Nevada Disturbance at the close of the Jurassic has long been recognized as the principal period of batholithic intrusion along the west coast of North America. In adjacent areas various phases of this general intrusion have been described under local names.

On the southern part of Vancouver Island C. H. Clapp*

*C.H.Clapp, Southern Vancouver Island, Geol.Surv.of Canada, Memoir 13, 35-38, 1912.

describes it as the Saanich Granodiorite. To the south in the San Juan Islands, R. D. McLellan* correlates a very var-

*R. D. McLellan, Geology of the San Juan Islands.

ied and complex intrusion with the same period. This Turtle-back Complex is a broader phase of the normal rock to the north.

In the adjacent quadrangle to the north, Charles E. Weaver*

*Charles E. Weaver, Geology and Ore Deposits of the Index Mining District, Wash. Geol. Surv. Bull. 7.

describes the Mount Index Granodiorite of the post Jurassic Intrusion.

To the east in the eastern part of the Snoqualmie Quadrangle and on into the Mount Stuart sheet, the Mount Stuart Granodiorite, while intruding into rocks presumably of the Carboniferous, has Eocene beds lying on its eroded surface. It was, therefore, thought to belong to the same great period of intrusion.

The lack of fossil evidence in this area renders a definite statement of age impossible whenever proof cannot be borrowed from the Snoqualmie Folio. Assuredly the Mount Si intrusion is older than those of the late Tertiary. The Twin Falls Formation, the oldest one that it cuts, may be reasonably presumed to be of the late Paleozoic. In consequence, in view of previous work in the Northwest, it seems reasonable to believe it to have been formed during the Sierra Nevada Disturbance.

Lithologically the Mount Si Complex closely resembles the Turtleback Complex. Just as the San Juan Rock forms the marginal phase of the Saanich Granodiorite, this formation probably is the border of the Index Granodiorite, which Dr. Weaver has described as lying within fifteen miles to the north.

KEECHELUS ANDESITE

GENERAL DESCRIPTION AND OCCURRENCE

The largest formation in the area is the Keechelus Andesitic Series, which has been previously described in the Snoqualmie Folio*. It is part of one of the most extensive rock masses in the Cascades. This series practically bounds the area both on the south and on the east. Although its rocks at present are remarkably varied in their physical appearance, they can be classed largely as andesite.

In the adjacent quadrangle, hypersthene andesite with some dacite forms the bulk of the series while basalt and rhyolite contribute a very minor share. In the limited area covered in this report the rock is almost wholly andesitic. The basal members of the series are classed as basic andesites, while the great mass of later extrusives are of more acidic fragmental material of the same type. No rhyolite, however, was observed by the author and only one small flow of dacite. With these extrusives were interbedded a few small lake deposits formed of water laid volcanic material.

Although complete proof will not be offered until the close of the paper, the author considers that the vast bulk of the fragmental material was formed by the de-roofing of the Snoqualmie Batholith during its final great advance. The eruption of this tuffaceous material would have been caused

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*Smith, G.O., and Calkins, F.C. Snoqualmie Quadrangle, U.S.Geol. Surv. Folio 139, 1906.

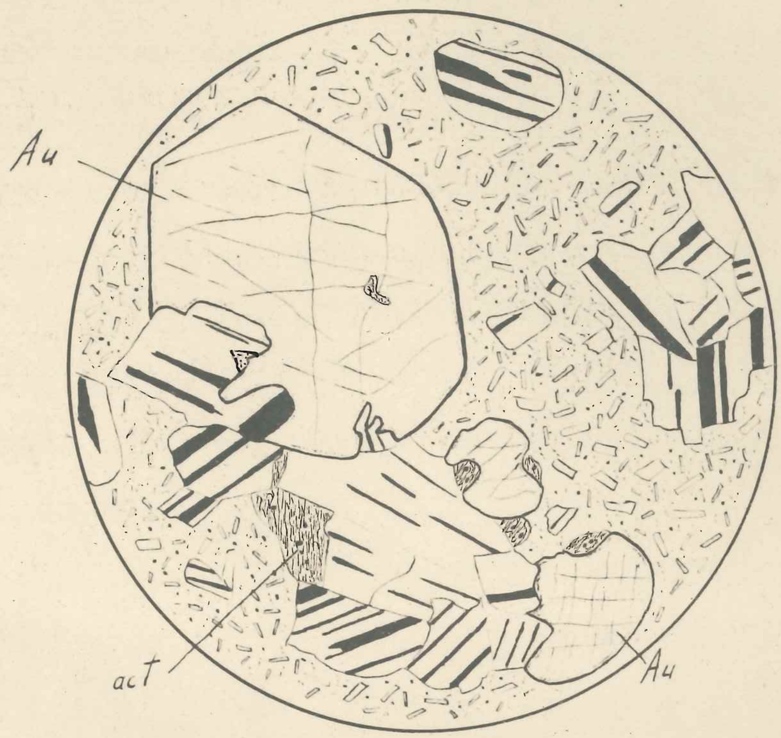

Plate 12.- Basic andesite of the Keechelus Series from the south side of Cedar River. With crossed nicols x 13.5. Large corroded phenocrysts of augite (Au) intergrown with labradorite (lab) in a ground composed of fine laths of feldspar in a devitrified glass. Augite is partly altered to actinolite (act).

by the explosion of the gases imprisoned by the rapidly solidifying andesitic cap which would constantly endeavor to close the vent. The great loss of volatile constituents resulting from this eruption would have caused a premature solidification of the deep seated magma. This necessary cessation of differentiation would explain the lack of the more acidic lavas which would have been expected to end the normal cycle.

Except for very basic types, andesite flows are undoubtedly highly viscous, for they lack the heat of the more basic lavas and the high content of water and other gases of the more acidic flows. This viscosity, together with its consequent fragmental material, is bound to cause a very uneven distribution of phases. Owing to this irregularity the occasional interbedded lake deposit furnishes the only definite clue to structure, but only three such deposits were located. One, exposed in the cut at the New Dan Site, has been previously described by Dr. Weaver. * The others are on Fish Creek

*Weaver, C.E. Wash. Geol. Surv. Bull. No. 13, p. 233.

and on Mount Washington opposite the summit of Ragnar Hill. At the new dam and on Mount Washington the beds show a dip of some thirty degrees towards the southwest.

This parallels closely the inclination suggested by the escarpment of Rattlesnake Ledge and the western wall of Fish Creek. If sections of a single consecutive series are represented by this structure, the formation, with its base at

Ragnar Hill and its upper members west of Fish Creek, must be approximately eight thousand feet thick.

The intrusion of the Snoqualmie Batholith had a vast effect on this formation. Owing to the susceptibility of the agglomerates to alteration the appearance of the formation along the contact is very different from that of the unindurated type to the southwest of Cedar Lake. Near the intrusion the agglomerate forms a very resistant rock that results in a rugged crestline topography. In marked contrast outside the zone of alteration the fragmental rock develops into a deeply weathered type, that produces a far more even profile.

The great number of offshoot dikes of the Snoqualmie Batholith add to the irregular topography of the bordering andesite. In much of the country north of Cedar Valley the dikes may form an even greater mass than the intruded rock. For this reason the contact is clearly reflected in the contour of the crest line in contrast to the more regular outline of the massive granodiorite.

In the valley of the South Fork the shoulder opposite Garcia forms the principal break in the even slope of the northern wall. It is composed of a large roof pendant of the indurated agglomorate cut with dikes and the border phases. Across the valley from this exposure, a similar structure forms the precipitous McClellan Butte. Although the crest of the jagged peaks east of it were not covered by the author, their similarity of topography as well as their scree deposits to the south render their correlation practically positive.

PETROGRAPHY

Petrographically this formation is not so simple as its homogeneity of type would lead one to expect. Most of the detailed work was done along the contact with the Snoqualmie Batholith. The far-reaching effect of this intrusion resulted in the alteration of a large part of the Keechelus Series. In consequence most of the specimens examined were found to be greatly altered, even when they appeared normal megascopically. Frequently the similarity between the porphyrite offshoot dikes of the batholith and the andesite flows is so great that field differentiation in limited exposures is impossible. Even in thin section their resemblance is so striking that they are difficult to distinguish.

The average flow rock shows small phenocrysts of feldspar in a dense ground of a medium shade of gray which, owing to alteration, usually has a pronounced greenish tinge. The phenocrysts, as a rule, are of andesine, although pyroxenes are also present. Although the individuals sometimes preserve a perfect outline usually they appear broken. The ground varies from a matted mass of fine laths of feldspar with little intersticial material to one consisting wholly of a dense glass which usually is completely altered. Flowage is seldom an obvious feature of the texture.

A few of the more basic andesites show no phenocrysts, and in the field resemble basalts, although thin section proves them to be nearer to andesites in composition. In contrast the most acidic rock located is a thin flow of amygdaloidal dacite that forms one of the upper flows overlying the Ragnar Volcanics on the western slope of Mount Washington. Although light buff in color, it weathers to a dark brown rock, which with the leaching of its amygdules appears more like a vesicular basalt. The rock is composed of a felted mass of highly altered fine laths of plagioclase with numerous small quartz grains that appear to be largely primary.

Plate 12 shows a section of one of the most spectacular basic flows in the area. Although it is less than a mile west of the "pyroxene diorite" phase of the Snoqualmie Batholith south of Cedar River it has not suffered any pronounced alteration aside from complete devitrification. It contains many phenocrysts of augite up to half an inch in diameter, some of which are intergrown with labradorite in a gabbroid texture. Most of the crystals exhibit a perfect outline with but slight corrosion to indicate an initial stage of reabsorption.

A large amount of the rock in the series is of a fragmental type, which, away from the contact with the Snoqualmie Batholith, forms a deeply weathered mass. The agglomerate that has been subjected to partial induration, however, has been rendered so resistant that it still appears fresh. This fact has already been noted in the Snoqualmie Folio.

The gases and fluids of the batholith, which easily penetrated the highly porous fragmental material, rendered the zone of alteration very great. When partially indurated this rock is light green and well consolidated with clearly defined fresh looking fragments. With additional alteration it develops into a homogeneous dark gray rock with a decidedly sugary texture. In almost all cases the rock etches with long weathering to show distinctly the agglomeritic structure, although frequently a fresh surface may not afford the slightest trace of its origin.

Under a microscope silification is the predominant feature of the induration of these agglomerates. Their final stage consists almost entirely of very fine interlocking grains of quartz with an occasional recrystallized grain of feldspar. Distributed throughout this mass are innumerable still finer grains of femics, the bulk of which are too minute to be determinable. The variations in concentration of these femics as a rule furnish the only clue to the original structure. In some thin sections fine flakes of green and brown biotite predominate. In others an undetermined green amphibole appears to be the principal accessory. Although fairly complete data clearly indicates an amphibole, the index of refraction fails to correspond to that of any described member of the group. In addition grains of ilmenite partially altered to leucoxene and rutile are usually noticeable.

The flows of the Keechelus Series have also suffered great alteration along the contact, but they lack the extreme results found in the agglomerates. The complete devitrification of the lavas across a very broad area is the most wide spread feature. As a rule the glass breaks down to a fine aggregate composed of quartz grains clouded with kaolin, and accompanied by numerous secondary femics, of which chlorite usually predominates. Frequently this aggregate is partially replaced by interlocking quartz grains. Although the plagioclase is usually highly altered to sausserite and kaolin it is generally still determinable. The primary femics are often wholly replaced by their common alteration minerals. Of these, chlorite and fibrous hornblende, which is probably frequently uralitic, are the most usual, while irregular grains of epidote form a fairly common accessory. As in the agglomerates ilmenite and its characteristic alteration products are often present.

AGE AND CORRELATION

This series of volcanics is a direct continuation of the formation described in the Snoqualmie Folio. By means of fossil leaves in interbedded lake deposits, George Otis Smith proved it to be of the late Miocene. It can be traced in almost continuous exposures across the southern boundary of the area. Its intrusion by the Snoqualmie Batholith is obvious along its entire contact with that body. Although many of the phases parallel closely the previous description, the frequent variation in the flows and agglomerates prevent positive lithologic or stratigraphic correlation. The whole formation, however, shows a pronounced consanguinity, and in a general way exhibits the progressive increase of acidity that would be expected in a unit.

Charles E. Weaver, in the "Tertiary Formations of Western Washington"* considered the unindurated volcanics on

*Weaver, C.E. Wash. Geol. Surv. Bull. 13, pp.232-235, 1916.

Rattlesnake Ledge and also those to the southwest of Cedar Lake to belong to a later series that at the earliest might be equivalent to the final stages of the Keechelus. This opinion was largely based on the fact that at the base of Rattlesnake Ledge the andesite was reported as lying unconformably on quartzite and Snoqualmie Granodiorite.

Fairly detailed work in the heavy second growth failed to disclose outcrops of the granodiorite. The unconformable relationship, however, is due to the fact that the flows lie on the eroded surface of the North Bend Formation, which suffered intrusion by the Mount Si Complex probably during the Sierra Nevada Disturbance. The author believes that these basic flows at the foot of Rattlesnake Ledge form the initial, rather than one of the final members of the Keechelus formation. In consequence the two series are thought to be identical.

If by chance some unlocated exposure of the Snoqualmie Granodiorite is exposed on Rattlesnake Ledge with the basic flows of the "Enumclaw" resting on it unconformably, then that formation must be far younger than the Keechelus. In the light of established criteria the flows in any series should become on the average progressively more acidic. The bulk of the Keechelus formation indurated by the Snoqualmie Batholith is composed of fragmental material that undoubtedly represents the upper part of the series. Consequently, it is impossible to conceive of a reversion of differentiation in the same cycle permitting basic flows to lie unconformably on the eroded surface of a mass that had intruded the upper more acidic members of the series.

Yet no apparent evidence infers that these two formations can be separate. From their very nature two great volcanic series could hardly be expected to be bounded by hard and fast lines. If the andesites on Rattlesnake Ledge are later than the Keechelus, it would seem reasonable to expect some trace of the earlier volcanics between the basal flows and the metamorphosed sedimentaries on which they lie, but apparently none exists. At the same time, surely some remnant of a tremendous series like the "Enumclaw" should still survive in unconformable relation with the intruded Keechelus andesite.

From all evidence this entire series has as its source the great intrusion of the Snoqualmie Batholith at the close of the Miocene. At Meadow Pass the Snoqualmie Folio reports a gradational passage from apparently extrusive andesite to pyroxene diorite. This rock the author considers as almost contemporaneous with the final phase of the batholith. As will be later explained the author considers that the great loss of gases accompanying this series resulted in a premature solidification of the batholith. In consequence in this instance the cycle was largely completed with andesite as its final and most acidic phase.

SNOQUALMIE BATHOLITH

GENERAL DESCRIPTION AND OCCURRENCE

Next to the Keechelus andesite in area and infinitely more varied in its type comes the Snoqualmie Batholith, which has previously been described as the Snoqualmie Granodiorite in the folio of that name. This intrusion covers most of the eastern third of the area and through its broad zone of alteration and its innumerable dikes affects fully half of the territory covered in this report.

To the northwest it cuts the Twin Falls Formation in a well defined line which furnishes a decided contrast to its indistinct boundary to the south. There the intrusion of the Keechelus Andesite is accompanied by such a vast number of varied offshoot dikes, that the contact frequently cannot be definitely determined. In fact in the andesite between the South Fork and Cedar Valley, dikes may frequently constitute a greater bulk than the intruded rock.

In mapping, the author considered the body from the view point of its common genesis, and used the broader term, Snoqualmie Batholith, to include a number of variations that are too far separated petrographically from granodiorite to permit association under that name. Although this intrusion has many unusual characteristics, its general development appears to coincide closely with the modern conception of a batholith, which the author has already stated. This recent conception has considerable bearing on the previous work in the adjacent quadrangle.

In the Snoqualmie Folio, some twenty years ago, George Otis Smith mapped another intrusion as pyroxene diorite. This rock was reported in several isolated masses along the western part of the quadrangle in contact with both the Keechelus Andesite and the Snoqualmie Granodiorite. The two principal exposures at both Meadow and Green Pass were thought to grade directly into Keechelus flows. Consideration of this factor together with the mineralogical similarity caused these exposures to be considered as the roots of the volcanoes from which the Keechelus Andesite was erupted. Although the pyroxene diorite showed marked similarity to the granodiorite in the petrographic description and was thought to be but slightly previous to it in age, no genetic relationship between the two intrusions was suggested.

Under the heading of the Snoqualmie Batholith the author classes a gabbro, a quartz diorite, the pyroxene diorite, the granodiorite and a final pegmatite phase, formerly referred to in the adjacent quadrangle as a "biotite granite." The gabbro and quartz diorite are thought to be remnants of normal stages of magmatic differentiation, while the pyroxene diorite and granodiorite are considered to be practically contemporaneous chilled phases caused by at least local deroofing of the batholith. These rocks form the principal types that constitute the intrusion.

With the hope of adding to the clarity of the description the author will treat each definite type as a unit. With disregard to their areal extent, they will be dealt with according to their increasing acidity, which presumably conforms with their order of formation. The report closes with a statement of the evidence for premature solidification of the batholith during deroofing. In addition, the principal types of dikes, as well as the mineralization are considered to be of sufficient importance to merit individual treatment.

GABBRO PHASE OF THE SNOQUALMIE BATHOLITH

The most basic rock and at the same time the smallest in areal extent is a normal gabbro that is exposed in the valley of the South Fork of the Snoqualmie just west of the contact between the Twin Falls Formation and the Mount Si Complex.

It lies some two miles west of the nearest exposure of the batholith. Although fresh acidic and lamprophyric dikes indicate that the final stages of the intrusion extended even farther west, the main body must have been very deeply seated to permit the survival of this early phase without appreciable alteration.

Unfortunately the alluvial material of the valley bottom prevents the determination of its extent. It appears comparatively homogeneous in the several outcrops along the few hundred yards of its exposure. Both in the field and especially in thin section its freshness stands out in marked contrast to the metamorphism of the Mount Si Complex that it intrudes.

Megascopically it is a medium grained plutonic rock with a dark gray to brownish color. In thin section it is one of the few really normal rocks in the area. (Plate 13). It shows augite, hypersthene, and aegerite-augite intergrown with labradorite in a medium grained allotriomorphic texture. Often bordering these pyroxenes in a clean-cut outline is a pale green amphibole of rather low birefringence. It is undoubtedly primary and must be present as a reaction rim. Ilmenite slightly altered to leucoxene is invariably present as fairly coarse individuals. Occasionally hypersthene shows serpentine along its cleavage cracks. A few patches of actinolite and thin veins of chlorite indicate an incipient stage of alteration.

QUARTZ DIORITE

Probably the next stage of the intrusion that survives is a rock that can be classed as a normal quartz diorite. It is exposed chiefly in the northeastern part of the Pratt River valley. It is quite homogeneous and could probably be fairly accurately mapped as a unit, although its variation from the main body at times appears gradational. Its most coarse grained and acidic type is exposed at Ollie Lake. A more basic and finer grained type is the principal rock to the northeast where it forms the lower part of the mountains

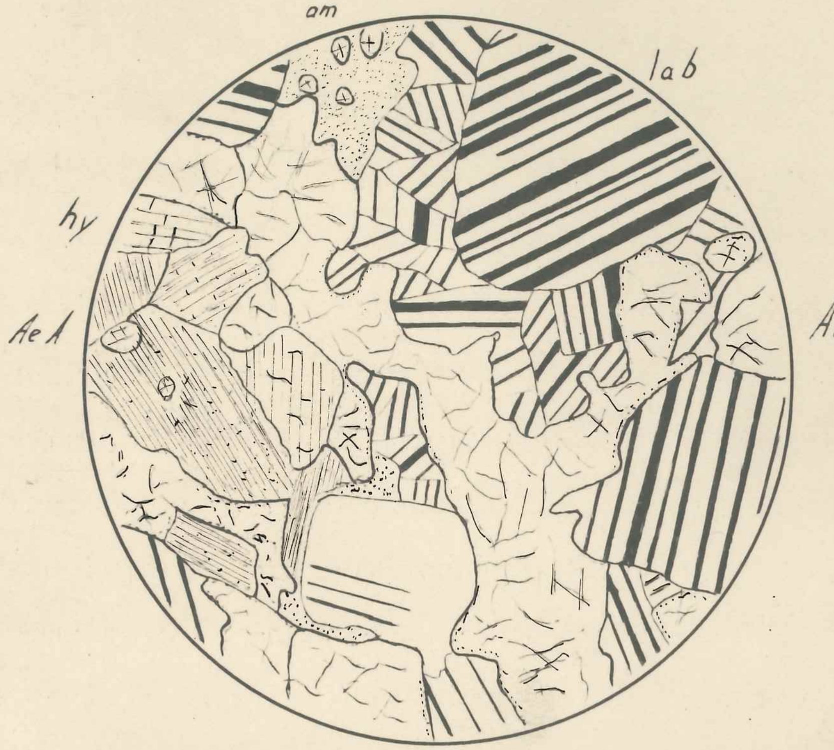

Plate 13.- Snoqualmie Gabbro. With crossed nicols, x 13.5. Augite (Au), hypersthene (hy), and aegerite-augite (AeA) intergrown with labradorite (lab) in an allotriomorphic texture. Reaction rim of an undetermined amphibole.

east of Pratt River. Here the upper portion of the range is composed of a pegmatite phase that cuts the more basic rock in dikes and then spreads out to form an irregular mass.

In the hand the quartz diorite is a medium grained rock with a fairly high content of evenly distributed very dark hornblende in a ground of gray feldspar. In thin section (Plate 14) it shows plagioclase and common hornblende in a hypodiomorphic texture with a minor amount of quartz as a final product of consolidation. The plagioclase, which usually constitutes over half the rock, is principally andesine, although when zonal it ranges to oligoclase. The femics usually constitute about 25% of the rock. Of these hornblende in well shaped slightly corroded crystals is the most important. Biotite forms the most common accessory. It is present both as coarse and as fine aggregates clustered around grains of magnetite. The quartz, which is largely poikolitic, forms from ten to twenty per cent of the bulk.

PYROXENE DIORITE

The "pyroxene diorite" phase, as already mentioned, received its name in the Snoqualmie Folio. The nomenclature was based on the Rosenbusch classification to indicate the association of quartz and pyroxene.

As a distinct and homogeneous rock type the pyroxene diorite deserves to be treated as a unit, although the author, in the later pages, will endeavor to prove it to be practically

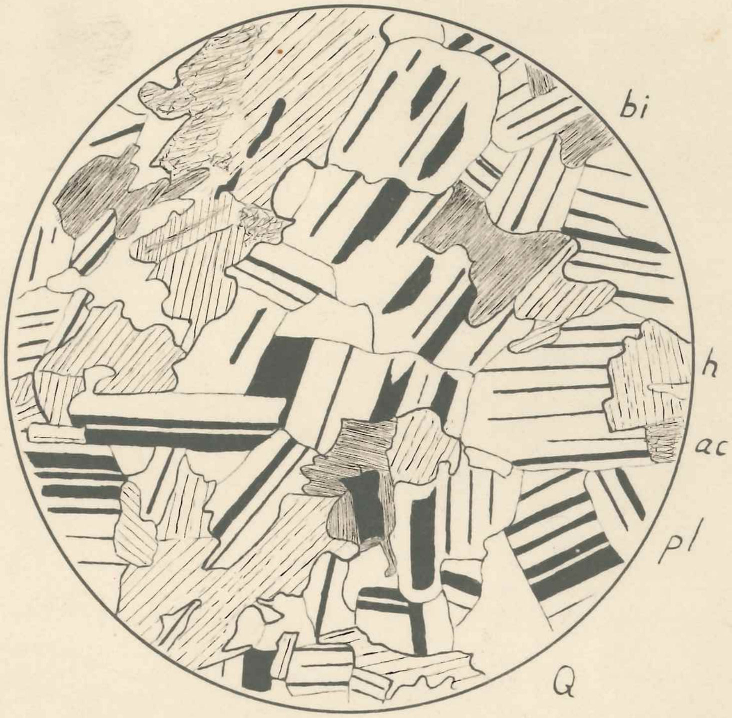

Plate 14.- Snoqualmie Quartz-diorite. With crossed nicols, x 29. Andesine (pl) and common hornblende (h) in a hypodiomorphic texture. Quartz (Q) forms the final consolidation product. Biotite (bi) and iron oxide are the principal accessories.

identical to the granodiorite genetically.

It was found chiefly along the upper Cedar River valley where it forms the bulk of the range on the south side of the valley. Like the granodiorite in the Pratt River valley it forms long slides that in many cases start from the summit. Owing to a finer jointing the blocks that compose these slides are considerably smaller than those of the granodiorite to the north. Occasionally the rock of these slides grades into types that appear like true granodiorite, but since no exposures are left in place the relationship could not be definitely determined in the field.

In the hand the pyroxene diorite is a medium grained greenish gray rock. Unlike the quartz diorite or the granodiorite, the individual minerals are not distinctly noticeable. This is due to the light greenish color of the femics which furnishes no contrast to a similar tone of gray in the feldspar. As a rule only a small amount of quartz is visible.

Microscopically it is a medium grained rock with usually well shaped phenocrysts of zonal plagioclase and badly altered and corroded femics in a variable groundmass composed largely of quartz and orthoclase. As a type it is more truly a porphyry than a normal plutonic rock.

The zonal plagioclase, ranging from andesine to oligoclase, is always more or less kaolinized. The femics occasionally show remnants of the original hypersthene and augite in a mass of fibrous hornblende, which is usually specked with secondary ilmenite already partially altered to leucoxene.

Some of the hornblende, however, appears to be primary rather than uralitic. Biotite in one instance formed a very minor feature. The few flakes observed are probably due to endomorphic alteration.

The feldspar that forms the groundmass frequently is far too altered to kaolin to permit determination. Where it was determined it proved to be orthoclase. The quartz and orthoclase are largely contemporaneous. As a rule the orthoclase, as in Plate 15, appears to be the final product. Here the resulting texture is decidedly monzonitic, although the quartz is in part intergrown with the feldspar.

Except for local gradations towards granodiorite, the pyroxene diorite is remarkably homogeneous. The only marked exception is in a small isolated slide opposite the eastern end of the Valley Hill. This slide shows gradations to a fine grained more basic type. The most extreme is a fine grained greenish gray rock of a darker tone than the usual. Under the microscope it shows coarse laths of labradorite in a diabasic texture with interstitial masses of fibrous hornblende, which are probably pseudomorphs after pyroxene. Grains of iron oxide form the principal accessory. This unusual variation is definitely intruding basic andesite. It strongly resembles some of the very varied border phases of the granodiorite that are exposed along the Chicago Milwaukee tracks near the contact with the andesite. It was probably formed by chilling prior to the final differentiation.

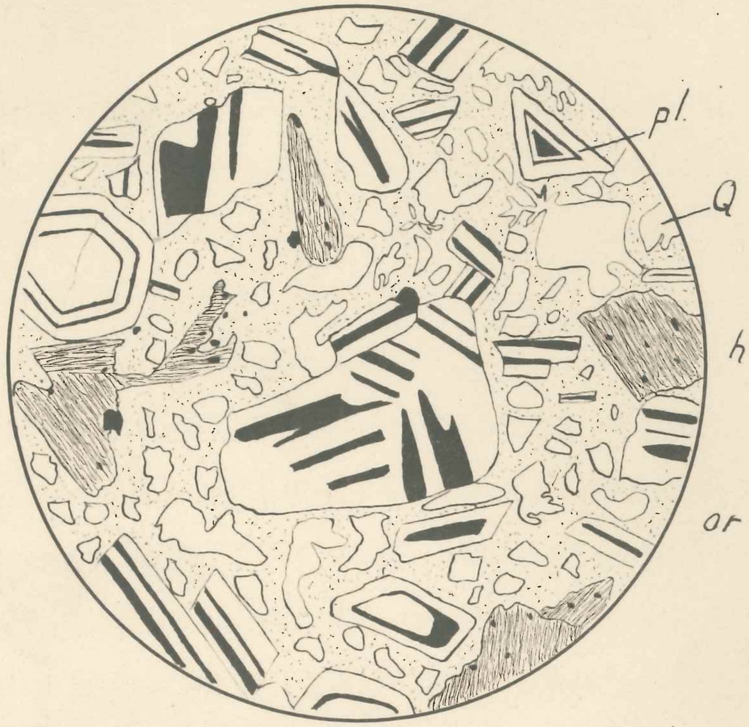

Plate 15.- Snoqualmie Pyroxene-diorite, south of Cedar River. With crossed nicols, x 13.5. Individuals of plagioclase (pl) in part andesine and in zoned from andesine to oligoclase in a monzonitic texture. Fibrous hornblende (h). Quartz grains (Q) in part intergrown with kaolinized orthoclase (or).

GRANODIORITE

Aside from the local border phases the granodiorite composes the rest of the formation. Away from the contact it is usually formed of hornblende, biotite and quartz in a ground of snow-white feldspar well shaped individuals of which are frequently distinguishable.

In thin section the plagioclase showed such a marked tendency to idiomorphism that the rock resembles a porphyry more than a normal plutonic rock. Although as a rule it appears homogeneous in the field, a single thin section often discloses considerable variation. A specimen from just below Pratt Lake apparently well within the body of the batholith forms a good example (Plate 16). Here, although considerable quartz is present as a final consolidation product, part of the section shows poikolitic orthoclase that might have permitted the rock to be classed as a quartz monzonite. This tendency toward a monzonitic texture was noted in several sections.

Zonal plagioclase that ranges from andesine to oligoclase constitutes about a third of the rock. Common hornblende and brown to green biotite are the most common femics. Usually they also show a strong euhedral tendency. As a tule quartz is the principal final product of consolidation although orthoclase is frequently present. Although they were largely contemporaneous in crystallization they seldom are noticeably intergrown (Plate 17). As already pointed out,

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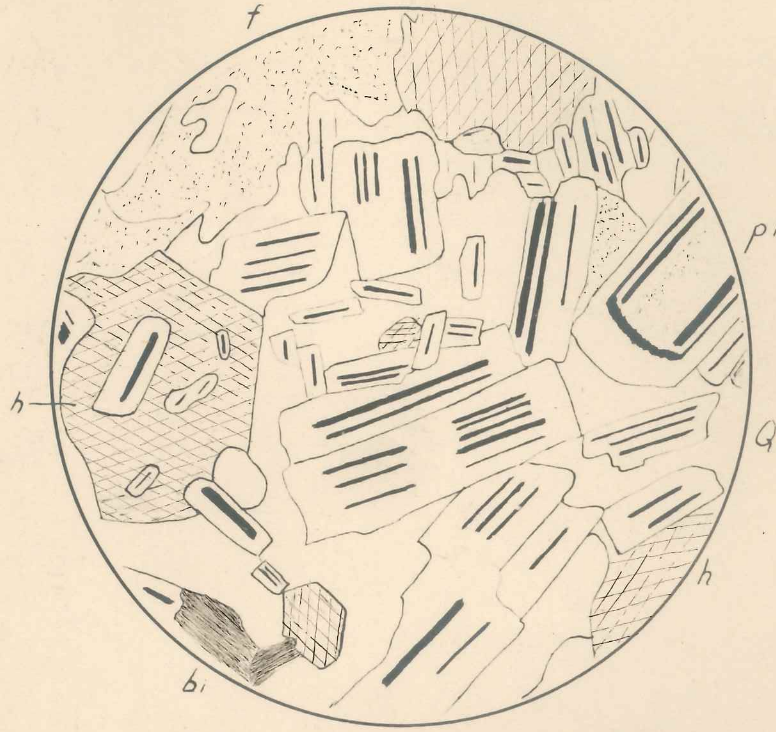
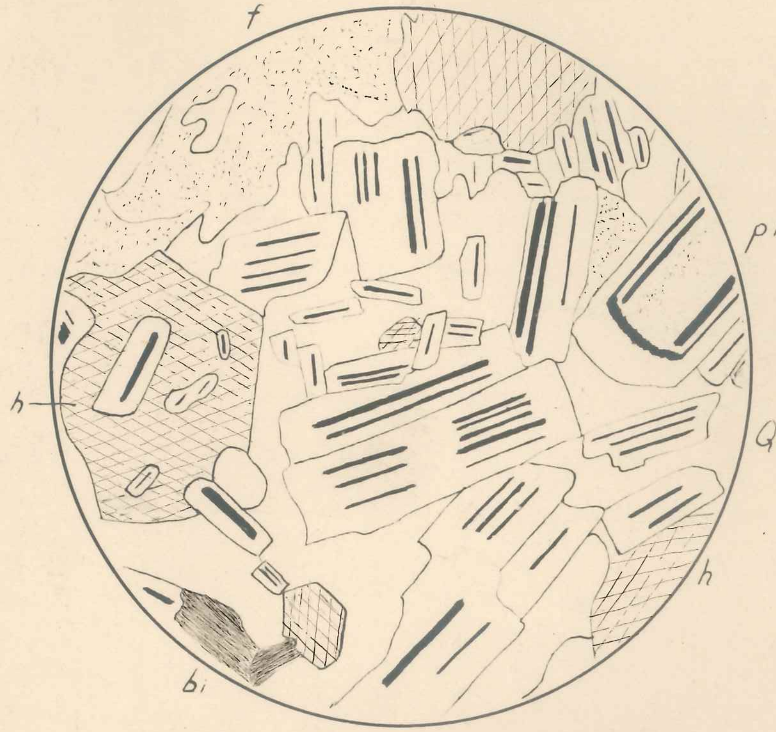


Plate 16.- Snoqualmie Granodiorite below Pratt Lake. With crossed nicols x 29. Phenocrysts of plagioclase (pl), zoned from andesine to oligoclase, and corroded common hornblende (h) in a ground of poikolitic quartz (Q) and orthoclase (f).



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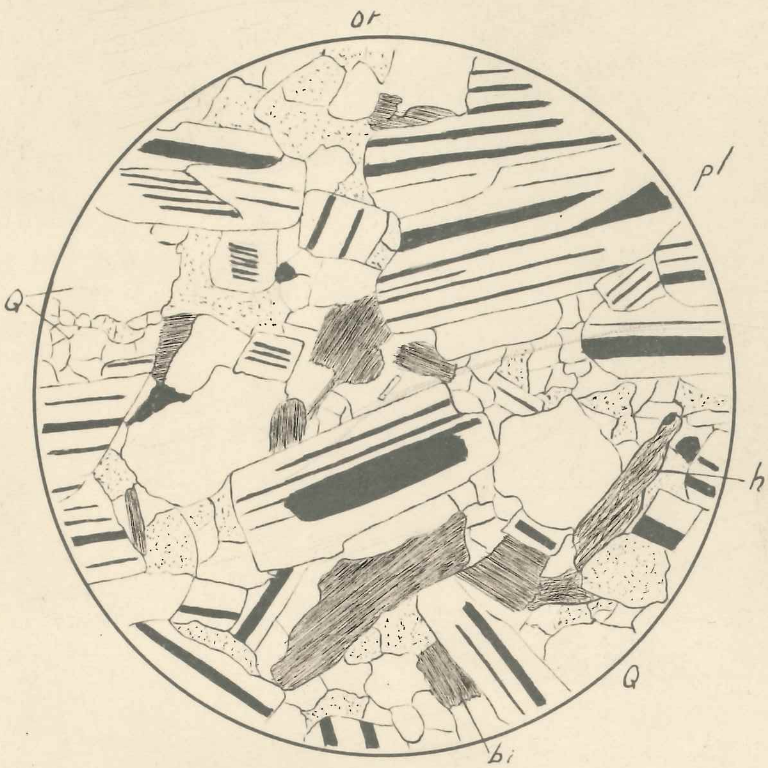

Plate 17.- Snoqualmie Granodiorite from the north side of upper Cedar River Valley. With crossed nicols, x 13.5. Phenocrysts of andesine (pl), in part zoned to oligoclase, in a mosaic of quartz and kaolinized feldspar (or). Biotite (bi) is slightly altered to chlorite, while hornblende (h) is badly corroded and largely altered to chlorite.

large anhedral grains of both quartz and orthoclase, including the early idiomorphic minerals, form a marked feature. As minor accessories small corroded crystals of hypersthene and augite occur in the more basic types (Plate 18).

As a rule, the specimens indicate at least a slight degree of alteration, owing to endomorphic processes. The feldspar is somewhat clouded with kaolin and often specked with sausseritic aggregates. Chlorite and even epidote frequently accompany the femics. The iron oxide as a rule exhibits the characteristic alteration product of ilmenite.

Near the contact the phases are often so varied and so local that they cannot be described in detail. Petrographically they are usually similar to porphyry dikes of a more basic character than the main body. Probably the most general border phase is a normal fine grained fairly acidic type that is exposed near Garcia.

PEGMATITE

Corresponding in description to a "biotite granite" exposed on Snoqualmie Mountain a pegmatite phase is exposed in the northwest corner of the area. East of Pratt River it cuts through the quartz diorite in well defined narrow dikes and then at about 2800 feet spreads out irregularly for at least a couple of miles along the valley. Its vertical extent was not verified. This coarse-grained rock appears more resistant to jointing and has resulted in a rough irregular topography.

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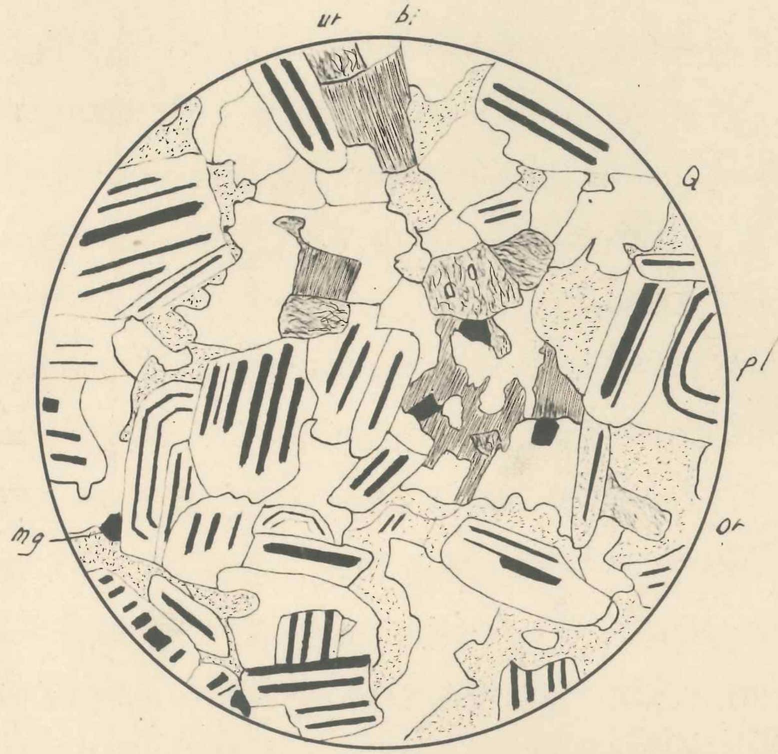

Plate 18.- Snoqualmie Hypersthene Granodiorite from Kullakulla Lake. With crossed nicols, x 29. Hypodiomorphic plagioclase (pl), largely andesine. Little kaolinized feldspar (or) partly orthoclase, intergrown with quartz (Q). Hypersthene as remnants in uralitic hornblende (ur). Biotite (bi) and magnetite are the principal accessories.

Petrographically it consists largely of coarse quartz grains deeply fractured and rounded by corrosion. This makes up over half of the rock. Later hypodiomorphic plagioclase flecked with paragonite shows zoning from basic to acidic oligoclase. The outer border of the plagioclase appears to blend into the kaolinized interstitial material that is partly intergrown with later quartz. A little brown and green biotite partly altered to chlorite is usually present (Plate 19).

This late phase of the batholith does not alter the author's hypothesis of chilling by excessive volcanic activity. Although an entire batholith might conceivably feel the effect of the loss of volatile constituents, away from the vents it might well preserve sufficient gases to continue differentiation, at least, on a local scale. As it is, this phase is at least seven miles from the true pyroxene diorite and perhaps still farther from an important vent.

The offshoot dikes of the batholith are very varied and very plentiful. They form a far more marked feature of its contact with the andesite than with the quartzite to the north. In many places they probably form a greater mass than the rocks they cut. The most noticeable outcrops along the Chicago Milwaukee tracks are between Alice and Wood Creeks east of Garcia and between Hall and Change Creeks at the western contact. Again in Cedar Lake Valley a great many dikes are cut by the two streams that run into the western end of the lake from the north. The eastern end of the Valley Hill also has a number of dikes cutting across it. Again,

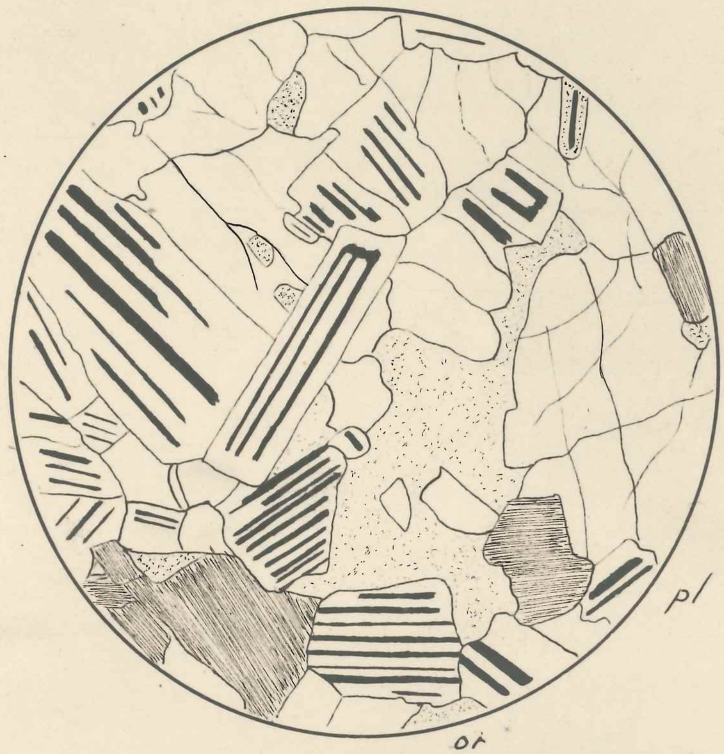

Plate 19.- Pegmatite phase east of Pratt River. With crossed nicols, x 13.5. Hypodiomorphic plagioclase (pl), zoned from andesine to oligoclase, and large individuals of quartz, highly fractured and corroded in kaolinized orthoclase (or) occasionally intergrown with a little later quartz. Biotite is quite plentiful.

along the north south township line south of Cedar River many dike cuts are exposed.

These dikes are mostly of a diorite porphyrite that under similar conditions of alteration strongly resembles andesite, although usually they have a more granular ground mass than the extrusives, which they may have fed. Many of them show undoubted primary quartz rather than secondary. One convenient clue to their origin is their tendency to form granophyres. Here the feldspar and quartz intergrow to form the pseudo-spherulites. Black radiating tourmaline forms a very spectacular accessory of the more acidic dike.

Far less common are the late differentiates. The best examples noticed of this phase are in the railroad cuts at the base of Ragnar Hill. Here several acidic dikes impregnated with sulphides cut the older mass. The gossan from their sulphides cause brilliant rust stains that hide their freshness. The acidic probably resemble the vein dikes described by Spurr.* They are composed principally of quartz and calcite with minute specks of pyrite. The quartz is of chalcedonic low temperature variety that in thin section strongly resembles chert.

*Spurr, J.E. The Ore Magmas, 1923.

A couple of hundred yards east of Ragnar a very fresh lamprophyre dike is exposed. It is of interest as showing differentiation within itself. The dike is a fine, even grained dark gray rock with a very fresh appearance. It contains numerous irregular white patches largely of a coarse grained quartz.

In thin section both show a mosaic of the identical minerals, namely, common hornblende, quartz, plagioclase and magnetite. The true dike rock consists largely of hornblende and magnetite, while plagioclase and quartz form about a third of it. The acidic differentiate contains nearly ninety per cent quartz and oligoclase, while hornblende with a little magnetite forms the accessories.

MINERALIZATION

The little mineralization that was seen in the area occurs as a late phase of the Snoqualmie Batholith. In the past several mines and prospects have been in operation, but none have proved of economic value. The timbering in the three most extensive mines has completely collapsed, rendering it impossible to judge of the original prospects. Occasionally the former ore dumps still yield specimens. Although none of the deposits were carefully studied, the types of veins appeared quite varied.

Judging from a small vein at the head of Wood Creek on McClellan Butte, the deposit of the Alice Creek Mine is probably between a near surface type and an intermediate one. Here a clean cut vein shows a thin seam of pyrite in a crustified quartz gangue that shows well developed euhedral faces. The principal ore mineral is pyrite with chalcopyrite and bornite as minor accessories. These minerals are characteristic of intermediate depths, although the crustification suggests near surface fissure veins.

A prospect was also seen above the lower lake at the head of Granite Creek, where a small vein has been followed into the granodiorite some thirty feet. This deposit also appears to share the characteristics of both near surface and intermediate types both in depth and temperature. The ore is very varied, showing pyrite, galena, sphalerite, chalcopyrite and marcasite in a gangue of quartz and adularia. The vein shows decided banding. Except for the pyrite, the ore minerals and the gangue are typical of a type of near surface deposits.

Overlooking Thompson Lake a more extensive prospect has been in operation. Here the deposit is of a high temperature variety. The ore is principally chalcopyrite with accessory pyrite and bornite. Black radiating tourmaline and quartz form the gangue. The vein shows the extreme irregularity in width typical of this kind of deposit. Although this is the only high temperature ore deposit located, tourmaline is quite widely distributed, principally along the joint cracks of the granodiorite.

Impregnations of sulphides are frequently visible in the indurated Keechelus Andesite and disseminated through the porphyrite dikes. Probably the absence of ore deposits is due to a failure of the batholithic mechanism to concentrate the deposits rather than to a lack of the ore minerals. This poverty of the late differentiates may well be due to the great loss of mineralizers that must have occurred during the eruption of the Keechelus Series. The author has already suggested that this factor may have caused the chilling of the batholith and may have brought differentiation to a sudden close.

THE DE-ROOFED BATHOLITH

The author has compiled the following brief summary from the data contained in the Snoqualmie Folio.* It will give the reader a general grasp of the conclusions resulting from the previous work on the same problem, and will furnish a correct perspective from which to view the evidence brought forward in these concluding pages.

The Keechelus Andesite Series, which is probably the largest rock mass in the Cascades, covers about a third of the Snoqualmie Quadrangle. The series is made up largely of andesite flows and tuffs with some dacite and very minor amounts of basalt and rhyolite. This series was proved by interbedded fossil leaves to be of late Miocene, although on lithologic grounds the authors considered some of the lava to be post Miocene.

Erosion of this great series has in places uncovered masses of plutonic rock which individually range up to an area of some three square miles. This rock, named in the Snoqualmie

*Smith, G.O., and Calkins, F.C. Snoqualmie Quadrangle, U.S. Geol. Surv. Folio, pp. 8-9, 1906.

Folio "pyroxene diorite," was proved in two localities to grade into surface types of hypersthene andesite. In consequence, it was considered as forming the "roots of the volcanoes from which the Keechelus volcanics were erupted."

No mention is made in the folio of the field relation of this plutonic body to the Snoqualmie Granodiorite, which it was thought to precede by only a short time, nor is any reference made to the marked similarity of their petrographic description.

In the folio a comparison of a chemical analysis of a single specimen of both the Keechelus hypersthene andesite and the Snoqualmie granodiorite shows a remarkable resemblance. Unfortunately the specimen of the hypersthene andesite was considered, on account of its freshness, to be of the post Miocene age. The rock sample was taken from the southern part of the quadrangle where the Keechelus Series overlies either the Yakima basalt or the Naches Formation. The black aphanitic glass that formed the ground mass of the lava was proved to be unusually high in silica and potash. On crystallization it would have formed much quartz and considerable orthoclase, and the same final consolidation products as the granodiorite.

CHEMICAL ANALYSES

	Keechelus Hypersthene Andesite	Snoqualmie Granodiorite
SiO_2	62.77	60.49
Al_2O_3	14.96	17.77
Fe_2O_3	1.62	1.98
FeO	4.36	3.29
MgO	1.48	2.94
CaO	3.90	6.20
Na_2O	4.31	3.67
K_2O	2.13	1.37
H_2O at 110	.51	.27
H_2O above 110	2.49	1.13
TiO_2	.79	.69
ZrO_2	.03	.02
P_2O_5	.22	.08
MnO	.10	.09
BaO	.10	.04
SrO	none	.02
	99.77	100.05

This analysis shows the typical granodiorite to be unusually low in silica. At the same time the fresh andesite appears to be practically the extrusive equivalent of the granodiorite. If the andesite is post Miocene, while the granodiorite late Miocene, there resemblance must obviously be the result of a mere coincidence, but the author, after stating his theory, will endeavor to show in later pages the probability of the fresh hypersthene andesite being a final product of extrusion immediately following the main explosive eruptions of the Snoqualmie Batholith.

The author considers the pyroxene diorite to be a near surface phase of the granodiorite formed after the actual foundering of the root rock of the Snoqualmie Batholith during the final stage of the eruption of the great Keechelus Andesite Series. In considering the possibility of this manner of eruption Daly coined the term "extrusion by deroofing."* The great loss of volatile constituents that would have accompanied this feature is considered of sufficient magnitude to have caused the batholith to solidify prematurely.

*Daly, R.A. Igneous Rocks and Their Origin, pp.121-124.

It is universally accepted that a batholith in its later stages is cooled to a point where it can retain its fluidity thanks only to its high content of water vapor and other gases. With its actual deroofing at this stage or even with the intrusion of the magma into its own unconsolidated fragmental material, a vast escape of gas would be permitted. This would affect the magma within a considerable distance, for the gases throughout the batholith would move toward the vent in an endeavor to compensate the local relief of pressure and once more establish an equilibrium. At the same time the expansion of the highly compressed gases must cause a general reduction of temperature, which would be especially effective at the vent itself.

As Daly* pointed out in regard to central volcanic vents,

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*Daly, R.A. Igneous Rocks and Their Origin, p.303, 1914.

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this migration of gases might keep the vent open for a considerable length of time both by "gas fluxing" and by explosion. When the lava reached the surface it would lose its gas and quickly solidify, blocking the vent. While the batholith still contained a high content of volatile matter, the pressure of the gases imprisoned by this constantly forming crust would be sufficient to cause a series of explosions. This would account for the great thickness of fragmental material in the Keechelus Series. The final gradational passage from andesite to pyroxene diorite observed in the adjacent quadrangle would have been formed when the gas pressure had at last diminished sufficiently to permit the survival of its final cap.

At no great depth below this dense andesitic cap the slow heat conductivity of rock would permit a fairly normal final solidification and the formation of a medium grained rock. If the batholith solidified largely from dehydration, the most pronounced final effect might well be expected near the vents and the unconsolidated tuffs where the loss of gas would be the easiest. This factor should explain the formation of the pyroxenes, which require a dry melt rather than the amphiboles which demand water, and thus account for the presence of pyroxene in the comparatively acidic pyroxene diorite magma.

Aside from the formation of pyroxene instead of amphibole, a slightly lower content of quartz and a higher degree of alteration form the only marked petrographic distinctions between the pyroxene diorite and the granodiorite. In the Snoqualmie Folio, the description of the two rocks is almost identical, although attention was not called to the fact. Unfortunately the continuous talus slides that both types invariably form, render it impossible to obtain definite field evidence of a gradational passage between the two phases. In the scree, however, a complete series was frequently observed. Petrographic examination proved far more fruitful.

In both, zonal phenocrysts of plagioclase with a marked euhedral tendency, range from andesine in the center to oligoclase in the outer zone. In both, partially intergrown quartz and orthoclase form the final consolidation product. In both, orthoclase at times predominates sufficiently to permit their classification as quartz monzonites. In the absence of field relations both would normally be classed as dike rocks.

The zone of alteration accompanying the intrusion of the agglomerate is very great. Silicification and hydrothermal action form the predominant feature. It appears reasonable to the author that the escape of silica as a final consolidation into the highly porous tuffaceous material might well account for the slightly lower content of quartz in the pyroxene diorite.

In the final solidification of the batholith, the pyroxene diorite from its exposed position at the vent must have acted as a cap for the partially solidified quiescent magma below. The few remaining pent in gases liberated by the crystallization of the granodiorite are considered sufficient to account for the higher degree of alteration in the pyroxene diorite. The uralite and chlorite resulting from this hydrothermal action are responsoble for the greenish color of this border phase.

There is abundant evidence in the area to prove the chilling of the batholith. The texture of these rocks is invariably closer to a porphyry than to a true plutonic type. Even specimens well within the batholith appear in thin section like dike rocks. This texture must necessarily be caused by the rapid cooling of a partially crystallized magma.

The additional proof of the chilling lies in the great slides that characterize the outcrops (Plates 2 and 5). These slides are due to a very pronounced jointing that is remarkable in a plutonic body. As one would expect, the pyroxene diorite, cooling faster, has a finer system of jointing than the more deeply seated granodiorite. In both, the size of the blocks holds true over large areas. This would signify that the solidification was due to a general simultaneous condition, and not to progressive surface radiation, except perhaps as a side factor for the pyroxene diorite. The only possible general condition that comes to mind is a premature loss of volatile constituents.

A partially dehydrated batholith should be low in the typical products of late differentiation. This condition accords with the observed facts. Lamprophyric dikes and late acidic ones are remarkably few in number, while the early diorite porphyrite types are exceedingly plentiful and, to judge from their granophyric tendency, were remarkably fluid. The only late dikes were observed cutting the Ragnar Volcanics at about nine miles from the nearest probable vent. The late pegmatite phase is a similar distance to the north of the pyroxene diorite in the lower part of the Pratt River. At this distance from a vent the loss of volatile constituents would have been less pronounced and might have permitted local continuation of differentiation.

An additional fact that has bearing on the same problem is the scarcity of ore deposits associated with the Snoqualmie Batholith. These would be expected as final differentiates in the solidification of the magma. But with the premature loss of mineralizers the sulphides could not be concentrated or finally injected into the overlying rocks, in spite of the fact that sulphides were frequently observed disseminated through the offshoot dikes and andesites.

Any one of these points would be an unusual feature in a normal batholith, but apparently they find a logical explanation in consideration of their probable origin. Their combined evidence appears to point conclusively to but one possible solution, a premature solidification of the batholith by dehydration accompanying deroofing.

With this evidence in mind, the author will return to the chemical analyses quoted from the Snoqualmie Folio a few pages back, with the intention of showing the probability of the fresh hypersthene andesite being a definite part of the Keechelus Series and not a product of later vulcanism.

The alteration that usually characterizes this series undoubtedly results both from induration and from endomorphic processes. The fluidity of the porphyrite dikes and the vast explosive energy of the batholith indicate the high volatile content of the magma. But it seems possible that at the conclusion of the explosive phase the more quiescent batholith, solidifying largely from less of gas rather than from loss of heat, might have contained local activity away from actual vents. This possible activity after the explosive energy had been largely spent would result in comparatively dry flows fed by fissures which might be expected to form with the contraction of the rapidly solidifying magma. The walls of these fissures, formed of rock but recently itself molten, would still be sufficiently hot to prevent chilling of the lava while still in the dike.

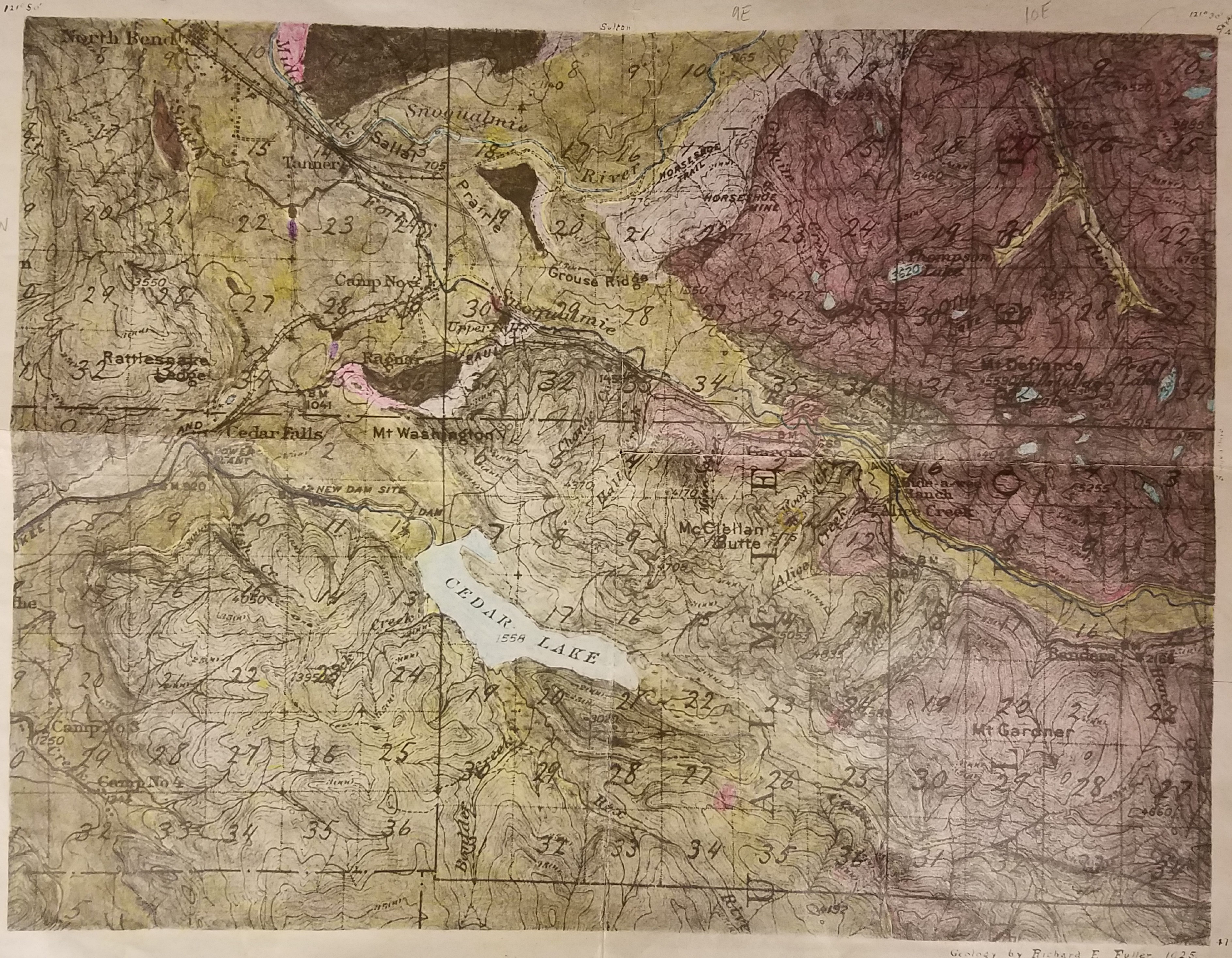
Their low volatile content would render these flows free from endomorphic alteration. If, at the same time, they were isolated from the direct influence of the post volcanic processes, they would retain their original freshness. Thanks to their lack of incipient alteration and to their dense aphanitic texture they would not be subject to the rapid weathering that characterizes the unindurated fragmental material and the devitrified flows.

Although the author has not seen the fresh flows described, it is more than possible that the above explanation might account for them. At the same time, inasmuch as they are definitely overlain by basalt, it would greatly simplify the situation to class them as part of the Keechelus Series. If they belonged to a later series of intrusions and were in turn overlain by basalt, modern conceptions of volcanics would cause one to think of three cycles of vulcanism rather than of two.

In addition, since the granodiorite and the pyroxene diorite are apparently almost identical genetically, and in view of the gradational passage from pyroxene diorite to andesite, the author considers himself justified in believing the chemical sample of fresh Keechelus hypersthene andesite to represent an actual extrusive equivalent of the Snoqualmie granodiorite.

AREAL GEOLOGY

NORTHEASTERN PART OF CEDAR LAKE QUADRANGLE



Geology by Richard E. Fuller 1925.

Scale

1 ½ 0 1 2 Miles

LEGEND

SEDIMENTARY ROCKS

QUATERNARY

Alluvium and Glacial Deposits.

MESOZOIC ?

North Bend Formation (coarse sandstone and conglomerates)

LATE PALEOZOIC ?

Twin Falls Formation (quartzite and argillite with minor thin bedded chert)

IGNEOUS ROCKS

TERTIARY

Late Miocene

Snoqualmie Batholith (granodiorite, quartz diorite, pyroxene diorite and gabbro)

Keechelus Andesitic Series. (extensive lava flows and agglomerates of andesite)

MESOZOIC

Post Jurassic

Mount Si Complex (metamorphosed intrusive body with phases ranging from gabbro-diorite to granodiorite. Presumed border of the Index batholith)

Jurassic ?

Ragnar Volcanics (metamorphosed andesitic flows and agglomerates)