UNIVERSITY OF CINCINNATI

~~May 1~~ 19~~38~~

I hereby recommend that the thesis prepared under my supervision by Wayne Moore Felts

entitled A Granodiorite Stock in the Cascade Mountains of Sou th-western Washington

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

John L Rich

Nevin M. Fenneman

Form 668—G. S. and Ed.—1M—7-31

A GRANODIORITE STOCK IN THE CASCADE MOUNTAINS OF SOUTH

WESTERN WASHINGTON

A dissertation submitted to the

Graduate School

of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

1938

by

Wayne Moore Felts

B.S. Oregon State Agricultural College 1934

M.S. Oregon State Agricultural College 1936

TABLE OF CONTENTS

LIST OF PLATES AND ILLUSTRATIONS

Introduction

The presence of a body of granitic rock near Silver Star Mountain in the Cascade Range of south-western Washington has been known to prospectors and mining men of the region for more than fifty years, but no material on the geology of the immediate region has been published. Allen (1) in an unpublished thesis described the granitic rock as a quartz diorite and called the mass "Silver Star Formation" after the highest peak in the area. Any other work that may have been done in connection with mining operations within the area is not publicly available.

The aims of the study summarized in the following paper were, in the main, twofold: (1) to map, both areally and structurally, the intrusive and as much of the surrounding rocks as necessary to determine the time and mechanics of intrusion, and (2) to determine the petrographic character and the petrologic history of the intrusive body and its surrounding rocks.

The work was made possible by a grant from the McMillan Research Fund of the Ohio Academy of Science and was greatly furthered by the able work of the writer's field assistant, Mr. R.H.Howe. The cooperation and assistance given by the U.S. Forest Service men of the Columbia National Forest is also greatly appreciated.

The writer's party was visited in the field by Dr. John L. Rich. Suggestions made by him at that time and constructive criticism of the manuscript later have been of utmost value. Criticisms offered by Drs. Nevin M. Fenneman and Walter H. Bucher and the assistance

given in the petrologic work by Professor O.C. Von Schlichten and Drs. George B. Barbour and A.E. Sandberg is greatly appreciated.

General Features.

Location. The area examined lies in the western portion of the Middle Cascades about twelve miles north of the western end of the Columbia River Gorge. It consists of a rectangle eight miles north - south by five miles east - west whose south - west corner is that of Township 3 North, Range 5 East, Willamette Meridian. The area thus described comprises forty square miles, the northern three quarters of which are within the the Columbia National Forest Boundaries.

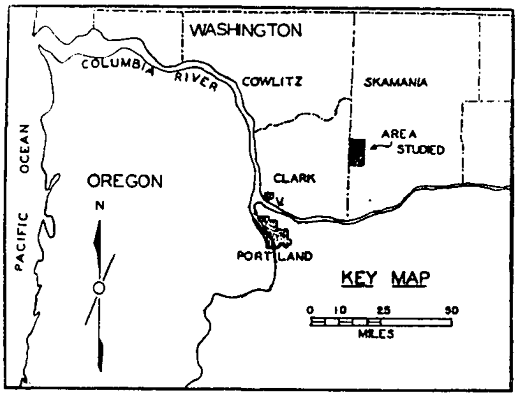


Figure 1. Location of area.

The region may be reached from Portland by U.S. Forest Service roads connecting with the state highway system of Washington at either Hemlock or Yacolt.

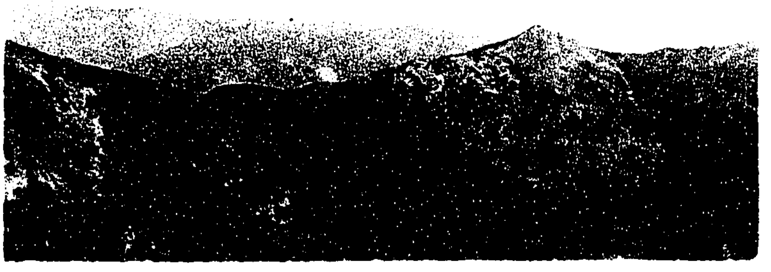
Drainage. The area is drained by the headwaters of both the Washougal River and the South Fork of the Lewis River. The Washougal is a south flowing stream entering the Columbia near Camas. The Lewis flows to the west, is joined by the North Fork, and enters the Columbia near Woodland, about thirty-five miles downstream from the mouth of the Washougal. The headwaters of these two streams have dissected the area in a dendritic manner to a mature stage with a relief of from 2500 to 3000 feet.

A divide, along which are located the highest peaks of the immediate area, separates the opposing headwaters of the Lewis and the Washougal. This divide trends from the north-east corner of the area in a direction a little west of south to the summit of Bluff Mountain in section 16 where it turns at right angles and trends east-west to the summit of Silver Star Mountain where it leaves the area.

The greatest precipitation occurs in the winter months and is, in the higher portions of the area, frequently in the form of snow which forms enormous drifts in the deeper canyons. These drifts linger till past mid-summer in most years and are largely responsible for the perennial character of many of the smaller streams near the heads of the canyons which would otherwise be without water in the late summer.

Since the destruction of the forest cover in the great fires of 1902 and 1929, the runoff has been much more rapid than formerly. The effects of this increased runoff are shown to best advantage on steep soil-covered slopes by the development of young gullies and in some cases by complete removal of the thin soil mantle. Another noticeable effect is the increased severity of the spring freshets that accompany the warm spring rains. Quantitative data on this increased runoff can not be obtained as no figures for the precipitation or runoff in the immediate area are available.

Topography. As was stated under the heading of drainage, the region is a maturely dissected plateau, largely of lavas, with a relief averaging close to 2000 feet and locally reaching a maximum of 3000 feet. The main divide between the Lewis and Washougal drainage basins attains elevations as great as 4400 feet A.T. and has saddles, where



A. Little Baldy from Silver Star Mountain

B. Silver Star from Little Baldy

strong opposing tributaries have been active, as low as 2900 feet A.T. The general elevation is, however, near 3200 feet A.T. From this main divide branch long, steep spurs separating the canyons and the smaller gullies occupied by the individual headwaters. These spurs are very steep, sloping from the elevation of the main divide down to the level where the two streams join; the slopes of the spur crests often are as great as 2000 feet per mile. Their sides are more precipitous, in some cases being vertical cliffs from a few tens of feet up to 1200 feet in height, but more commonly being live talus slopes resting at the angle of repose. These talus slopes, best developed on the granodiorite, cover a large portion of it and are in a few instances more than a mile in length.

Travel over these steep-sided ridges, difficult under the best of conditions, has been made much more difficult by the fallen trunks of fire-killed trees, among which thick underbrush and tangled thorny vines have grown in great profusion.

At the heads of some of the larger canyons are small cirque-like basins in whose bottoms are depressions as much as seventy-five feet deep and 150 yards in diameter. These are separated from the head of the canyon proper by a rock rim or lip. Often they are occupied by small tarns, and snowdrifts persist in a few until late summer. No glacial striae were found on the rock lips and consequently these basins are believed to be the result of erosion by small glaciers, not extensive enough to move very far out of their cirques.

The summits of the ridges when viewed from one of the higher peaks exhibit the same strikingly accordant level that is evident in the Cascades further north. This accordance has been treated by Willis (19), Russell (14), and Smith (16) as representing the trace of an old erosion surface called by them the Cascade peneplain. Regardless of whether it represents a true baseleveling or not, this accordance of summit levels is one of the striking features of the topography of the region.

Areal Geology

Eagle Creek Formation. The rocks of this area fall naturally into three distinct lithologic units. The oldest of these is the Eagle Creek formation (Warrendale formation of Hodge (12) and others) of probable Oligocene (now considered lower Miocene by Chaney (8)) age consisting of volcanic tuffs and breccias, bajada conglomerates, and minor amounts of intercalated andesitic lava flows near the top of the formation. The Eagle Creek is typically exposed in the central portions of the Columbia Gorge where it has been described by Chaney (7) and Hodge (12), and is also widely exposed in its numerous variations in the greater part of the Washougal basin. This formation outcrops along the eastern margin of the area under consideration, especially good exposures being noted in parts of sections 21, 22, and 28 near the headwaters of Dougan Creek. Exposures of the Eagle Creek formation also occur in the canyons of Silver, Bluebird, and Bear creeks along the eastern margin of the area, but in these basins they were not differentiated on the map from the overlying Skamania andesites.

The Eagle Creek, as exposed within the mapped area, consists mainly of cream colored vitric tuffs which usually weather to a yellow

A. Horizontal flows of upper Skamania Series
Silver Star Mountain

B. Silicified Eagle Creek tuffs south of
Bluff Mountain near head of Silver Creek

or white colored soil. Varicolored tuffs, usually green or red, are also found as are some greenish and purplish breccias. The tuffs may pass through the complete range of color within a distance of twenty-five feet along the strike. The lack of assortment and usual lack of bedding of any regular nature within these tuffs suggest a subaerial mode of accumulation. At many places, however, the tuffs and breccias have been reworked by streams and the bedding shows, in these cases, that accumulation was governed by fluviatile and occasionally lacustrine conditions.

Skamania Andesites. The Eagle Creek beds are overlain by a thick series of andesites among which are intercalated minor amounts of breccia and other pyroclastic material. Within the area the contact is nowhere definitely exposed although in many places it can be approximated within five feet. East of the mapped area, in the Washougal basin, the andesites overlie the Eagle Creek in places discomformably and in other places with a distinct angular unconformity representing a period of considerable erosion. At other places, notably on the east edge of the mapped area the andesites seem to interfinger with the tuffs suggesting at least partial contemporaniety or overlapping of the deposition of the tuffs and the extrusion of the andesites.

These andesites compose the bulk of the country rock into which the granodiorite stock forming the subject of this paper was intruded and are the most wide spread of the formations within the mapped area. They are in the form of rather thin and extensive flows that probably were extruded in a very fluid form. Locally these flows may have had rather high initial dips, a fact that complicates quantitative determination of later folding. In the lower two-thirds of the series the flows are only mildly folded except near the walls of the intrusive where dips up to thirty-five degrees have been noted. The upper third or about 800 feet of these flows, exposed only on the upper portion of Silver Star Mountain, is flat lying, the maximum dips recorded being two degrees to the west. This upper portion has also suffered less alteration than the lower partially propylitized andesites. Both the upper and lower portions consist of augite andesites with a marked tendency of the plagioclase phenocrysts toward a glomeroporphyritic habit.

These lavas support most of the steep cliffs within the area, also most of the higher peaks such as Bluff and Silver Star Mountains as well as most of the higher portions of the divides. They are the most conspicuous and best exposed rocks in the area and over wide areas in adjacent portions of Skamania County. For this reason the name Skamania is proposed for this series of andesites.

No definite age has been assigned to this series of lavas but in the opinion of the writer they are the probable equivalent of the widespread Keechelus series so prevalent in the Cascades a few tens of miles to the north. This opinion is based on the following facts: (1) the petrographic character of the andesites in the mapped area and that of the Keechelus as described by Coombs (9) and others is very similar, (2) the Columbia River Basalts exposed in the Columbia River Gorge appear to abut against the lower portions of the Skamania andesites whose age therefore in the lower part must be pre-Columbia Basalt,or, in other words, pre-middle Miocene, which corresponds with the supposed age of the lower Keechelus lavas, is suggested by Warren (18)and,(3) the Skamania andesites are divided in the same manner as the Keechelus into an upper and a lower division. As in the Keechelus, the lower division of the Skamania has undergone more folding and metamorphism than the upper division.

Lavas later than the andesites of the Skamania series occur as intracanyon flows in the canyon of the Lewis River four miles west of the area and in the canyon of the Wind River a few miles to the East. Those in the Lewis River canyon near Sunset Guard Station have been trenched by the river in a narrow gorge exposing old andesitic and dioritic stream gravels cemented together by the andesite of the late flow. The age of these intracanyon flows is probably Pleistocene.

Silver Star Granodiorite. The third lithologic unit within the area is a stock of granodiorite with subordinate amounts of augite diorite and quartz diorite near the borders of the mass. The stock is an elongate body about ten miles long and varying in width from one and one-half to two and one-half miles. Its long axis trends north twenty degrees east. Its walls are very steep as proven by the fact that very deep canyons cutting into the country rock a short distance from the walls (note accompanying maps and sections) do not expose any mappable areas of intrusive rock. Small spots of granodiorite were observed in Star Canyon and in the canyon of Dougan Creek but were not mapped. The southern boundary of the stock, extending to the south for a distance of about a mile, was traced but not in enough detail to be drawn on a map.

This stock cuts the Eagle Creek formation and the lower portion of the Skamania andesites, producing contact metamorphic phases in both formations, and sending small dikes and stringers of granodiorite and aplite into both the tuffs and the andesites. The upper third of the andesites does not seem to have been intruded by this granodiorite. At least no dikes or other evidences of intrusion cut the upper andesites and they have not been subjected to the degree of propylitization that characterizes the lower portions of the series. It would thus appear that there has been some time interval between the extrusion of the lower and upper divisions of the Skamania series.

Swarms of of xenoliths near the contacts with the andesite, and larger inclusions of tuffs and andesites in the upper portions of the intrusive rock indicate that stoping processes had a role in the emplacement of the mass. Some of these inclusions are large enough to have been roof pendants of considerable size. These inclusions are quite thoroughly metamorphosed, usually to hornfels.

The granodiorite is strongly jointed, a fact that allows frost action on the high peaks, such as Little Baldy, to rive the outcrops into rhombic and platey fragments with the consequent production of the long talus slopes previously mentioned. Good outcrops occur only in the stream bottoms and occasional cliffs not yet covered by talus. The boundaries of the stock, where drawn in dotted lines, can be approximated within a very few feet but the actual contact is covered. This lack of suitable outcrops is also responsible for the paucity of structural measurements.

Petrography

The petrographic character of each of the three main rock types and the metamorphic phases developed in each type by contact and hydrothermal metamorphism will be discussed on the following pages.

Eagle Creek Formation. The Eagle Creek formation, as exposed in the area, consists of vitric tuffs usually white or cream colored, and, less commonly, of greenish and reddish hues. The color, in most cases, seems to depend upon the character of the oxidation of the iron compounds within the glass at the time of formation. The material composing these tuffs ranges from partially kaolinized shards less than 0.05mm in diameter to coarse fragments of vesiculated pumiceous material up to three inches in diameter. This pumiceous material has been indurated and made resistant by compaction and cementation. The cement in the majority of the cases is silica, although enough kaolin is present in most cases to also act as a cement.

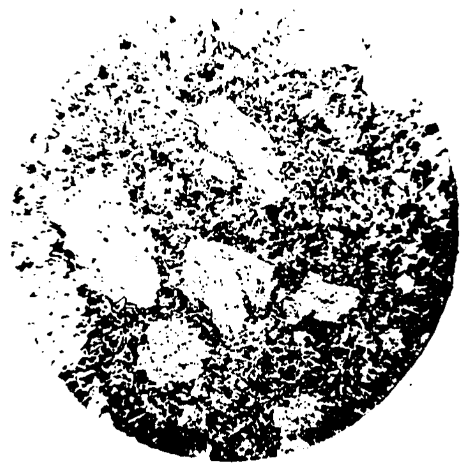
In places where the tuffs have been subjected to hydrothermal solutions emanating from the intrusive body they have been entirely replaced by silica forming a very resistant quartz rock in which are preserved the shard structures of the original tuff. Good outcrops of this silica rock occur in the low saddle in section 21 just south of Bluff Mountain.

Skamania Andesitic Series. The rocks composing this series consist in the main of gray porphyritic andesites with subordinate amounts of tuffs and breccias. The pyroclastics are petrographically very similar to the coarser phases of the Eagle Creek, possibly a little more pumiceous.

The andesites of the lower portion of the series are characteristically gray or grayish-green in color, and are nearly always porphyritic, the phenocrysts being striated grayish white feldspar. The flows in this portion are usually much jointed with epidote and other minerals frequently developed along the joint cracks.

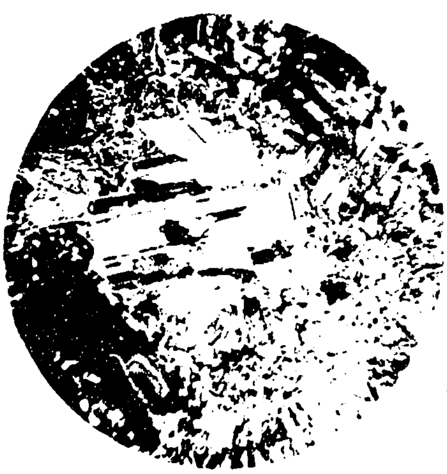
Examination of thirty five slides from the lower portion of the andesite series brings out the following general characteristics. All sections examined were porphyritic with phenocrysts of corroded and markedly zoned plagioclase embedded in a pilitic to intersertal and, infrequently, diabasic groundmass of plagioclase laths, granular augite, and anhedral magnetite, together with varying amounts of chlorite and similar minerals developed from the ferromagnesian constituents. The phenocrysts range in size from 1 to 6 mm and average about 3 mm in diameter. They are blocky and show a marked tendency toward a glomeroporphyritic habit. Their composition becoming more acid outward from the center with each zone. Small veinlets of orthoclase are developed in cracks appearing in these phenocrysts, especially in thin sections taken from near the contact with the granodiorite. Twinning is after the albite, Carlsbad, and pericline laws with all three commonly developed on one individual. These phenocrysts form from 20 to 35 per cent of the rock.

Contact - andesite
and granodiorite.
quarter Sec. 16.



Porphyritic andesite
from upper Skamania
series, near summit
of Silver Star Mtn.

All photomicrographs 15x
crossed nicols



Basic border phase
of Silver Star
granodiorite from
Section 16

Acid phase of
Silver Star granodiorite
from near center of
Section 33.

The plagioclase laths in the groundmass vary in size from 0.01 up to 0.5 mm in length, averaging about 0.3 mm. They vary in composition from basic to medium andesine and may be acid labradorite in uncommon cases. Twinning is commonly after albite and Carlsbad laws, pericline twinning being rare. Often these laths are arranged in a marked fluxion structure. These second generation feldspars comprise from twenty-five to forty per cent of the rock.

The ferromagnesian minerals are nearly always altered to chlorite and similar minerals, but where fresh are anhedral grains filling the interstices between the feldspar laths. These minerals may be either augite or hornblende - usually augite and in rare cases hypersthene. There may have been a considerable amount of hypersthene in some of the rocks but is has since become chloritized. A very few thin sections show relicts of what were possibly hornblende phenocrysts.

The augite of the groundmass occurs as anhedral grains rarely exceeding 0.05 mm in diameter, is pale yellow in plane light, and sometimes shows a faint pleochroism. $N\beta$ averages about 1.69. The augite in the groundmass usually makes up from 15 to 25 per cent of the rock. Magnetite in the form of small anhedral grains and dust is scattered through the groundmass and makes up about 10 per cent of the rock. Epidote developed within the plagioclase phenocrysts and chlorite from the pyriboles sometimes totally destroys the former minerals. Photomicrographs of typical thin sections of this lower division of the Skamania series are shown on the accompanying plates.

The upper division is characterized by fresher rocks of the same general type as those described for the lower division. These rocks are, however, generally more vesicular and in some cases have partially hyaline groundmasses. The rocks are in thin, flat-lying flows exposed only on the upper portion of the main mass of Silver Star Mountain. A few quartz and carbonate veins cut these flows, some of the vesicles are filled with chalcedony, and some of the ferromagnesian minerals in the groundmass are chloritized. Otherwise the rocks are nearly fresh as contrasted with the propylitized rocks of the lower division.

Microscopic examination of fifteen slides from these flows shows the following characteristics. Except in a few holohyaline flows of little importance, all of the flows are porphyritic with phenocrysts of medium andesine averaging about 3 mm in length. These phenocrysts are hypidiomorphic, exhibit strong zoning, marked corrosion, and a tendency toward a glomeroporphyritic habit. Twinning is after the albite, pericline, and Carlsbad laws. Combined Carlsbad and albite twins are very common. These phenocrysts comprise from 15 to 30 per cent of the rock.

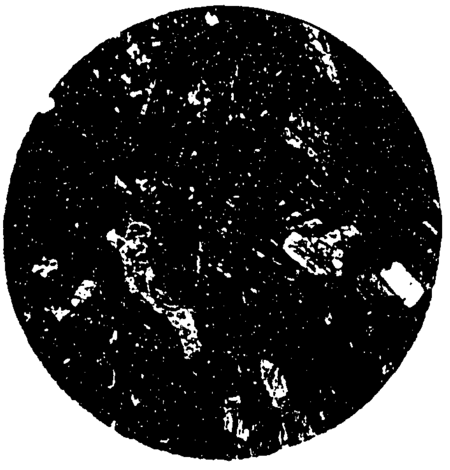
The groundmass consists of a pilitic, intersertal or, less commonly, a diabasic aggregate of plagioclase laths, anhedral grains of pyroxene and magnetite, and commonly small amounts of glass. Commonly the glassand some of the pyroxene is chloritized. The feldspar laths range in composition from acid labradorite to medium andesine with basic andesine being the average composition. They pyroxene is usually augite and much less commonly hypersthene. Grains of pyroxene averaging less than 0.03 mm fill the interstices between the feldspar laths which average from 0.01 to 0.65 mm in length. The second generation plagioclase comprises from 25 to 40 per cent of the rock, the pyroxene from 15 to 25 per cent and the anhedral magnetite from 5 to about 12 percent. Fluxion structure aligning the phenocrysts and the second generation laths is usually present and is developed to a marked degree in a number of the thin sections studied.

Silver Star Granodiorite. The rock composing this body consists of a mass of granodiorite with subordinate amounts of augite diorite and quartz diorite developed near the periphery of the stock. Aplite dikes and hydrothermal rocks rich in quartz, tourmaline, and sericite are also developed locally within the mass.

The granodiorite is a light colored aggregate of white plagioclase sometimes tinged pink with the development of orthoclase, clear colorless quartz, and black to greenish biotite and hornblende crystals the color of which depends upon the degree to which chloritization has progressed. In most cases the minerals can be distinguished megascopically, the grain size often being as large as 6 x 9 mm.

Microscopically the rock exhibits a holocrystalline granitic texture with the minerals, both light and dark, not uncommonly aligned in a sub-trachitoid structure. In some instances the larger plagioclase crystals impart a sub-porphyritic appearance to the rock.

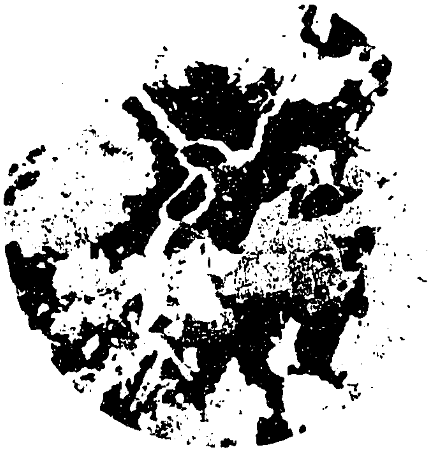
The plagioclase is hypidiomorphic, generally corroded and strongly zoned. The composition of the cores averages basic to medium andesine, each zone becoming richer in Ab to an outer zone of albiclase



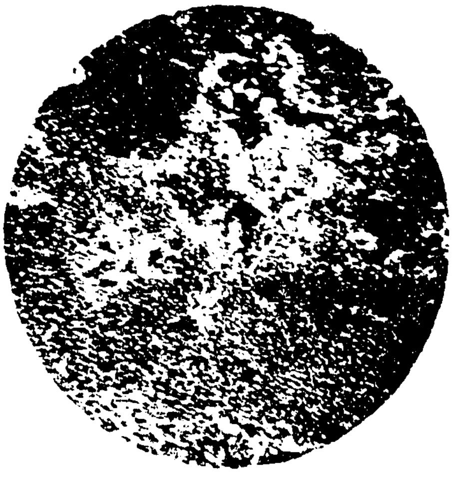
Porphyritic andesite from lower portion of Skamania series as exposed on Bluff Mtn.

Silicified Eagle Creek tuffs from saddle at the head of Silver Cr.

All photomicrographs 15x crossed nicols



Quartz - schorlite veinlet in grano-diorite from near the mouth of Summit Cr.



Hornfels developed from andesite near the contact with the granodiorite in Section 27 or, less commonly, albite. Many of these plagioclases have a final rim of orthoclase. This orthoclase commonly fills fractures developed in the plagioclases. Twinning developed in the plagioclase follows the albite, pericline, and Carlsbad laws with combinations of all three commonly found in a single individual. This plagioclase comprises about 55 percent of the rock.

10 to 25 percent of the rock consists of interstitial and anhedral orthoclase in some instances as clear as the quartz, which it closely resembles optically, but more generally "dusty" with sericite.

Clear anhedral quartz shares with the orthoclase the interstices between the earlier formed minerals. The two are commonly intergrown in a myrmekitic intergrowth showing contemporaniety of crystallization. The quartz granules average from 0.5 to 1.2 mm and make up from 10 to 25 percent of the rock.

The dark minerals may be uralitized pyroxene, or, more commonly hornblende or biotite with varying amounts of chlorite and secondary dusty magnetite. A little subhedral magnetite was developed early. These dark minerals are crowded into the interstices between the plagioclase feldspars and make up about 10 percent of the rock. The biotite where developed is a lustrous black variety with 2V estimated at about 5 or 6 degrees and is strongly pleochroic, the formula being X pale yellowish brown, Y reddish brown and Z very dark brown to black. Inclusions of apatite and of titanite are developed in the plagioclases and to a lesser extent in the quartz.

The more basic phases, as exposed at many places near the walls of the stock are characterized by more lath-like plagioclase crystals, little or no quartz and orthoclase, and larger amounts of pyroxene, usually augite. The plagioclase is ordinarily basic andesine. These more basic rocks make but a very small percentage of the total in the stock. Intermediate between these and the true granodiorite is a diorite very similar to the more basic diorite, but with 5 to 12 percent quartz and a little orthoclase. Note the photomicrographs of thin sections of each of these rock types on the accompanying plates.

The aplite dikes are composed almost entirely of quartz and pink orthoclase with small amounts of biotite and in some instances of sulfide minerals. Myrmekitic intergrowth is common and the orthoclase is commonly sericitized or even kaolinized to a considerable extent.

Metamorphic Rocks. The metamorphic rocks in this area are all products of thermal or hydrothermal processes accompanying the intrusion of the stock. The thermal metamorphism at places along the contacts between the stock and the andesites produces hornfelses of sugary-grained recrystallized feldspar, augite, and magnetite with considerable quartz being introduced in some instances. Where this action has been less severe at a distance from the contact, relicts of the original minerals remain and the hornfels is very poorly developed. At a greater distance, the effects become less marked until, at a distance varying from a few feet to several hundred, the only effect has been a propylitization of the andesites. This propylitization consists in the main of the development of epidote and chlorite within the andesites and the introduction of large amounts of pyrite and quartz. The replacement of the tuffs in the Eagle Creek formation by silica was mentioned previously.

Other hydrothermal effects, both within the intrusive and in the wall rocks, consist of (1) epithermal quartz-sulphide veins carrying low values in base metals and small amounts of gold, (2) quartz-tourmaline -sericite replacements occuring in shatter zones and as small veinlets in the granodiorite, and (3) silicification and orthoclasization of areas in the granodiorite, apparently after consolidation of the mass.

The genesis of the ore deposits within the area is being studied and reported in a separate paper by the writer's colleague, Mr. R.H.Howe.

The tourmaline - quartz replacements are shown to best advantage in the large shatter zone shown on the structure map as crossing sections 33 and 34. Solutions rich in boron and silica have bleached the granodiorite and produced a luxullianite rock consisting of quartz, schorlite, and sericite. In some instances the tourmaline aggregates make up 90 percent of the rock. Small veinlets of tourmaline in bleached and silicified portions of the granodiorite at the mouth of Summit Creek are shown in the accompanying photomicrograph. The tourmaline is of the schorlite variety; Nm being 1.66 and the pleochroic formula X pale brown, Z greenish-black, Basal sections show a very marked zonal growth.

The granodiorite in certain areas within the stock, such as in the north-east portion of section 8 and the north central portion of section 21 (in the south part of the area) appears pink in the hand specimen and has a dearth of ferromagnesianminerals. The original granodiorite, in these instances, shows evidence of having been replaced by orthoclase and quartz after consolidation of the granodiorite. Remains of some of the original minerals and structures of the normal granodiorite have been observed in a number of thin sections made from this altered rock. It is believed that this rock represents a result of orthoclasization after the main mass had consolidated, the potash and silica being introduced either by hot waters or by gaseous emanations.

Petrology of the Stock

Field observations and examination of about fifty selected thin sections from the stock shows a distinct gradation in the body from a quartz-free dark colored augite diorite occuring at places near the borders, to a granodiorite approaching a quartz monzonite in composition in the more central portions of the stock. No distinct zoning occurs and, in places, the more acid portions of the stock are in direct contact with the wall rocks, but, in a general way, it may be said that the dioritic phases are definitely border phenomena.

If the original magma at the time it was intruded had the composition of a quartz diorite it could form a series ranging from augite diorite near the borders to the quartz-orthoclase aplite dikes developed at a very late magmatic stage by the process of fractional crystallization. If, however, a magma with a composition essentially that of granite was intruded into a country rock consisting mainly of andesite by processes involving stoping and assimilation a basic border could also be produced.

Samples taken from the acid central portion in section 33 and from the wall phase in section 16 for chemical analysis resulted as follows:

	Acid phase	Basic phase
SiO_2	65.90	58.07
Al_2O_3	15.72	16.54
FeO	3.05	4.26
Fe_2O_3	1.11	2.47
TiO_2	.45	.61
MnO	.06	.17
CaO	4.78	7.32
MgO	2.39	4.94
K_2O	1.94	1.34
Na_2O	3.62	3.32
H_2O (-105 C)	.16	Nil
H_2O (-105 C)	.76	.70
CO_2	Nil	Nil
P_2O_5	.11	.12

F. H. Herdsman, analyst, Glasgow, Scotland.

These analyses were plotted on a diagram with the analyses of the Mount Stuart and Snoqualmie granodiorites, published by G.O.Smith (16),(17), an augite diorite from Bohemia, Oregon, and a granite from Nimrod Oregon, published by Buddington and Callaghan (5). All of these analyses are from intrusives of a nature similar to the Silver Star stock, in the same belt in the Cascade Mountains, and probably nearly of the same age. A fairly representative variation diagram for the Cascade intrusives of this type was obtained. The alkali - lime index for the series of analyses used in this diagram is 62.5 which compares with 61.6 reached for the Cascade intrusives of Oregon by Buddington and Callaghan (5). This number definitely places these rocks in the calcic group as defined by Peacock (13)

If the dioritic border be taken as an early roof or wall phase in the crystallization of the stock then the course of differentiation within the mass can be shown chemically by the diagram. The curves for the decreases in magnesia, iron, lime and alumina, as well as those for increasing potash and soda with increasing silica follow the same trends for the stock as for the whole Cascade region. This chemical change is shown mineralogically by the increase in the acidity of the feldspars from basic andesine in the dioritic border phases to albiclase and even orthoclase in the granodiorite, the development of relatively large amounts of free quartz in the more acid phases, and the change from the pyroxenes of the diorites to the smaller percentages of amphibole and biotite in the granodiorite. The feldspars are almost always zoned with the cores having the more basic composition. This fact shows that in all phases of the stock the early formed portion of the plagioclase crystals were removed from the reacting system by the formation of a more acid zone. As these basic cores were prevented from reacting with the remaining liquid an acid differentiate would thus be formed.

Xenoliths in all stages of assimilation were noted at many places near the borders of the stock. These range from angular blocks

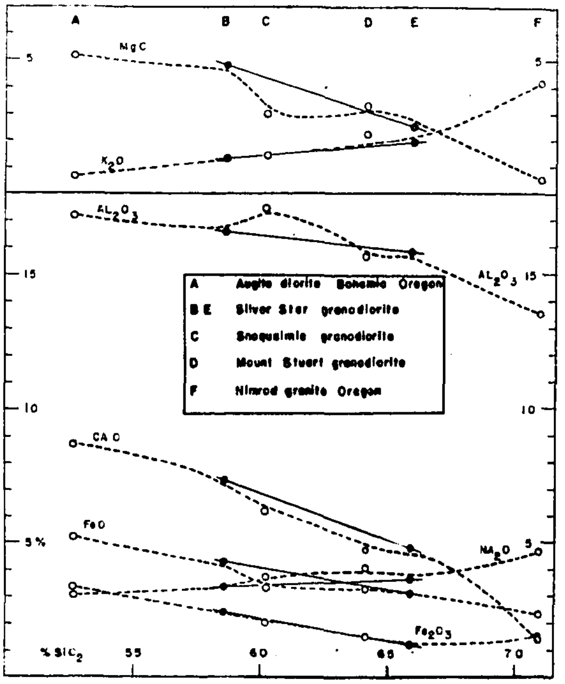


Fig. 2 Variation diagram of Cascade Intrusives

of fresh andesite to barely discernable ghosts made visible by concentrations of hornblende needles. The andesite clearly has been assimilated by reaction with the invading magma and the possibility exists that some of the border phases could be the result of contamination of a much more acid magma. Such contamination would not greatly affect the course of differentiation within the stock, however. (Bowen (3)

The xenoliths, of course, represent remains of stoped blocks of the country rock. They were found only in the lighter colored phases of the intrusives. If present in the darker phases, they were indistinguishable.

At many places the basic border of the intrusive is absent and the more acid phases are in sharp intrusive contact with the andesite wall rocks. It is believed that at these points portions of the roof, including the basic border, were stoped into the still liquid more acid differentiate and foundered.

Geologic Structure

An attempt was made to determine the mechanics of emplacement for this stock using some of Cloos' methods as outlined by Balk (2). Although a number of measurements were obtained, suitable exposures are so few and so many of these exposures, especially away from the walls, are of so nearly structureless rock, that the interpretation of these data should be taken as only suggestive. Although available data were taken from all exposures in the area, so much of the granodiorite is covered by talus that the structural observations are necessarily somewhat sketchy.

Elongation within the mass is shown in a few places by schlieren, and, less frequently, by a linear parallelism of mineral grains. The best developed of these lineal features occur near the walls and trend parallel or nearly parallel with the local trend of the contacts. The few observations obtained in the central portions of the mass show a more consistent east-north-east trend varying from north 60 east to north 80 east.

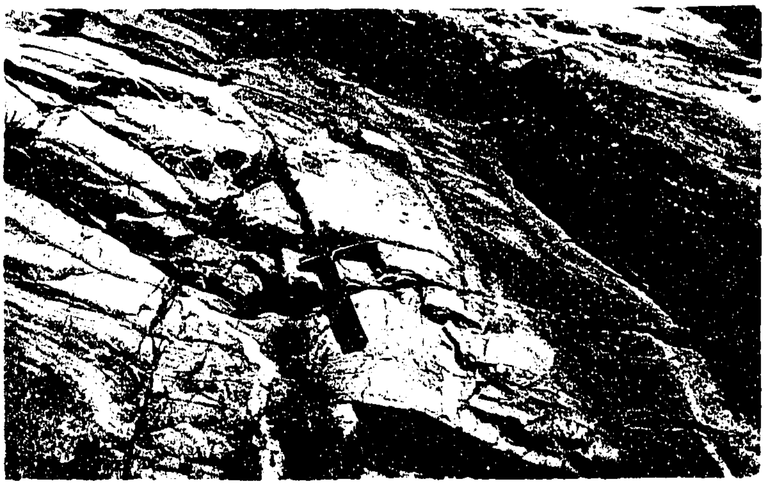
The following descriptions apply to the features illustrated on the accompanying map and are followed by a summation and interpretation.

Primary Flow Layers. In a few places along the borders of the mass some of the more resorbed xenoliths and their reaction minerals, principally hornblende, are drawn out in long streaks (schlieren) that are roughly parallel to the walls of the stock. These streaks, in places, form well developed flow layers the strike and dip of which can be measured, but in no case was the pitch of the elements within these streaks apparent. In the north-west corner of section 33 along the Yacolt-Hemlock road a well defined system of streaks and platey structures dips 76 degrees N30W, and in the north-east quarter of section 16 a similar system, less perfectly developed, dips 45 degrees S80E. In both cases, these flow layers dip at rather steep angles away from the stock and under the wall rocks.

In the interior of the stock poorly developed schlieren and elongated inclusions were noted just west of the center of section 4 in the bed of Copper Creek. These layers dip 20 degrees N10W. This last measurement was taken one-half mile east of the west wall of the stock.

Mineral Parallelism. In most of the exposures of the granodiorite the equidimensional character of the mineral grains precludes any development of mineral alignments. However, in a few places near the walls and near the flow layers mentioned above there exists a linear parallelism of mineral grains, both light and dark, but principally lines formed by the alignment of hornblende needles from the more resorbed xenoliths near the contacts. The general strikes of these lineal elements are shown on the map near the schlieren noted above and also near the center of section 8 and in the south-west quarter of section 21. In most cases no pitch or dip could be obtained for these linear elements although those in sections 8 and 16 seem to pitch to the south at high angles.

As was the case with the flow layers an inspection of the



A. Fault offsetting aplite dike near Last Chance Mine.

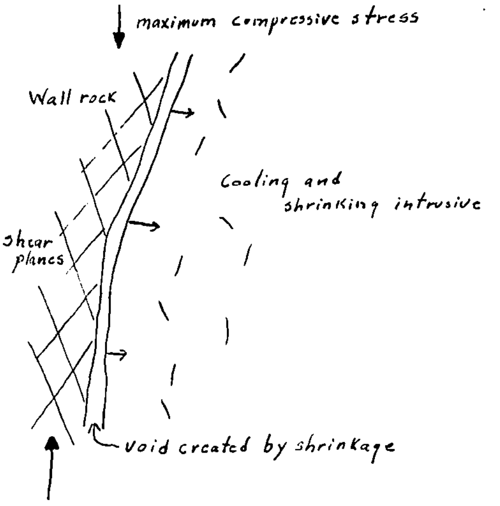
B. Joint systems in granodiorite near the center of section 4 map will show that two trends exist. Near the walls the strike of the mineral parallelism is roughly parallel to the walls, but in the more central portions of the stock the trend swings to east-north-east.

Joints. Wherever the granodiorite is exposed, in cliffs and in the stream beds, the joints are plentiful. The more persistent of the joint systems, both within the granodiorite and within the wall rocks, are shown on the accompanying map. Within the intrusive there are no extensive well defined systems of joints such as are found in many intrusives which were intruded under pressures great enough to greatly deform the wall rocks. Instead, the joints seem to be governed by purely local factors.

Not enough flow structure exists to designate any of the joint systems as "cross joints" but it is worthy of note that a weak general system of tension joints prevails. This system trends approximately parallel with the long axis of the intrusive. The joints in this system are usually vertical or high angle and are frequently filled by aplite dikes. Since they cross the flow lineations that exist in the central portions of the stock at rather high angles, and since they are followed by the aplitic dikes they are probably poorly developed cross joints. Near the borders where these joints follow the same trends as the flow structures, they would be classed as longitudinal joints. In any case, these high angle joints trending parallel with the wall of the stock indicate a weak doming.

Near the walls of the stock appear sets of gash fractures usually dipping into the intrusive at varying angles and commonly

A. Conjugate joint systems
on the north spur of
Bluff Mountain, Section 16.



B. Possible explanation for the joints
pictured above.

filled with aplite dikes. These fractures are attributed to friction between the wall rock and the moving mass of the intrusive.

Definite sets of conjugate joints exist (1) near the borders of the stock both in the granodiorite and in the country rock, (2) in the wall rocks at a considerable distance, usually from one-half to one and one-quarter miles from the contact, and (3) scattered within the intrusive mass.

Joint systems of the first type intersect at acute angles and are believed to be the result of frictional drag between the moving intrusive and the wall rocks. The conjugate joints of the second type intersect at right angles and are believed to be the result of shear due to an almost horizontal thrust away from the intrusive during emplacement. Conjugate systems of the third type within the granodiorite do not conform to any single system and are probably best assigned to cooling stresses. Some of these latter joints are actually faults of small displacement offsetting aplite dikes which fill previously formed longitudinal joints. Note the small fault on the accompanying picture.

In the north-west corner of section 17, and in the north-west portions of section 15 and adjoining portions of section 10 are systems of conjugate joints with a common strike and with dips of 60 degrees to each side. These joints are interpreted as shear planes developed in rigid brittle andesite. Under such conditions Hartmann's law may be applied to their analysis and the direction of maximum compressive stress would then be determined by a line normal to the line of intersection of the two joint planes and contained in the plane bisecting the acute dihedral angle between the joint planes. All of the conjugate shear systems were plotted stereographically after the method described by Bucher (4) and the direction of maximum stress plotted in space. The direction in azimuth and the angle of pitch were thus obtained. In the case of the conjugate joints with the common strike the direction of this force was vertical.

A possible explanation of these joint systems lies in the fact that when the intrusive cooled it would shrink away from the wall rocks. On the roof an adjustment could be made to this change of volume by keystone faulting, but along the walls the unsupported andesite would tend under its own weight to shear into the small voids created by the shrinking intrusive. Note the accompanying diagram.

Conclusions. The above data are believed to indicate that the stock was intruded along a line trending approximately N20E. The lack of serious deformation in the wall rocks and the lack of well defined joint systems within the mass of the stock suggest that doming and thrusting aside of the country rock was secondary to stoping in the processes of emplacement.

The swarms of xenoliths near the contacts many of which are almost completely resorbed are direct evidence of stoping and assimilation. The dark minerals, chiefly hornblende, and the more basic feldspars formed by the reaction of these xenoliths with the intrusive magma may have contributed to the basic border of the stock, but it is not believed to have been the sole cause.

The flow layers, where noted, tend to arch toward the center of the stock, the systems of steep joints trending parallel to the long axis of the stock can be interpreted as indicating a weak doming, but analysis of joint systems fails to produce any consistent results. It is believed that this relatively small and shallow intrusive was emplaced principally by stoping processes and that determination of the mechanics of emplacement by the methods of structural analysis as used by Cloos, Balk, and others can not be successfully applied to this stock or to like cases.

Physiography

As was mentioned under the heading of topography and as can be seen upon inspection of the accompanying panorama, the mapped area and its surroundings are characterized by a remarkable concordance of crests as viewed from any of the higher points within the region. This concordance, disregarding the few high volcanoes, persists throughout the Washington Cascades and has been well described from the vicinity of Mt. Rainier northward.

In the area under consideration the divides forming the skyline average close to 3700 feet A.T. with many ridges below this level and hence below the skyline and a few peaks rising several hundred feet above the general concordant skyline. Note the marked points on the accompanying panorama. As might well be expected, the elevations increase from the latitude of the Columbia River until in the vicinity of Mt. Rainier the average elevation of the divides is a little greater than 6000 feet A.T.

This even skyline or concordance of summits has long been thought of as representing a former peneplain being first called to attention by Russell (14) in connection with his work in the vicinity of Mt. Rainier. Russell wrote:

> As has been determined by Bailey Willis, the mountain (Mount Rainier) stands on a slanting peneplain, which consists of granites, schists, and coal bearing Tertiary rocks; that is, the region where Mount Rainier is situated was eroded during late Tertiary times until it was reduced to a plain practically at sea level. Such a plain is known among geographers as a peneplain. This peneplain was then upraised and tilted so as to slope gently westward. Since the plain was elevated it has been deeply dissected by erosion, and the land masses between the sunken stream channels have been worn into mountain forms. The general level of the summits which mark approximately the position of the tilted peneplain, in the region adjacent to Mount Rainier, on the north, is about 6,500 feet.

In the next few years both Willis and Smith worked in adjoining areas in the Cascades. Willis (19) described the Methow surface which was the equivalent of Russell's Cascade peneplain. Smith was at first skeptical about the peneplain hypothesis, but in 1903 he described a lowland in the Ellensburg - Yakima district which apparently beveled both the Yakima basalt and the Ellensburg gravels. Later (1904) Smith said that this surface was difficult to trace out of the region bordering the lower Yakima Valley.

Daly (10) was the first to take exception to the then generally accepted Cascade peneplain. He applied his principles of alpine sculpture to explain the accordance of crests and also objected to the short length of time given to post peneplain sculpture.

Buwalda (6) interpreted the features at Smith's type locality for the lowland surface as follows:

> The Yakima region is underlain by Columbia River basalts and overlying Ellensburg sediments, folded together into east-west

anticlinal ridges and much wider synclinal valleys.

The geomorphic history as interpreted by George Otis Smith in Professional Paper 19 included post-Ellensburg folding, Pliocene peneplanation, and further folding creating present day (hence second generation) ridges and valleys. Supposed peneplanation of the Cascade Range was dated from the Yakima area.

Evidence presented for peneplanation consisted of smooth supposedly beveled surfaces on crests and flanks of such basaltic ridges as Cleman Mountain and across both basalt and sediment at one locality, Kelly Hollow; and supposed intrenched meanders of Yakima River between Yakima and Ellensburg.

The writer's interpretation is that the smooth basaltic crests and flanks mapped by Smith on Plate 5 are not beveled but structural surfaces (dip slopes), locally lowered on the crests by recent stripping to an underlying basaltic layer. The supposed peneplain remnant at Kelly Hollow was cut across a small thickness of basalt in the present cycle by tributaries graded to the existing but slightly higher Wenas Creek. Smooth beveling surfaces on Ellensburg sediments in valleys are roughly graded to present drainage lines and commonly meet the basaltic dip slopes at sharp definite angles. The supposed meander pattern in Yakima Canyon may merely indicate structural control. If true meanders, they are as logically referable to the original surface of Ellensburg aggradation as to a postulated peneplane surface.

Present physiographic knowledge of the Yakima region points to a single cycle of post-lower Pliocene deformation and degradation, without peneplanation.

Coombs (9) presents a concise summary of previous work in the Washington Cascades and concludes that the "accordance (of crests) does not seem sufficiently striking to demand the introduction of the n+1 cycle."

Coombs further states:

> The writer prefers to account for the summit levels within the park as a constructional, rather than destructional, feature, and resulting from the outpouring and accumulation of volcanic material. This upland has subsequently undergone a minor amount of deformation in the form of gentle warping. Since the time of inception, it has been deeply dissected by the action of streams and ice, resulting in the present topography.

If within the mapped area and adjacent regions a surface be reconstructed from these concordant crests, that surface would be found to bevel the dipping lavas, and tuffs, and to have unroofed the Silver Star stock which must have cooled at a considerable depth. Pronounced erosion and beveling since the deposition of the lavas and the intrusion of the stock is thus indicated.

A question arises whether this accordant skyline represents a former near base level surface or could it have been produced during continued uplift and a maintenance of a relatively high relief.

In an area such as this, subjected to periodic igneous activity throughout most of the early and middle Tertiary periods and to regional uplift during the late Tertiary and Quaternary there would be a tendency to produce a plateau surface more or less dissected. During the early history when vulcanism was dominant each spasm of volcanic activity would tend to fill the valleys and low places much as the late intra-canyon flows have recently done. The higher ground, excepting occasional volcanoes, would be covered least or not at all, and would therefore, be subjected to almost continuous erosion. As the low places thus become filled and the higher areas worn down a surface of low relief would be produced in a relatively short time. Such a surface could have a relief, however, of hundreds of feet, could bevel the lavas and expose prelava or intrusive rocks and be in no true sense a peneplain.

With the lessening of vulcanism and the beginning of crustal movement in the area during Late Tertiary time the surface thus formed was elevated to somewhat more than the present heights of the divides and vigorous dissection begun. This uplift probably was continuous from early Pliocene until late Quaternary. Dissection of this continually rising surface by streams working headward from Columbia

River would be sufficient to account for the accordant crests, as viewed on the skyline, without any more erosion than would be accomplished at a stage of maturity in the first cycle.

The same results, of course, would occur if an old age surface developed on the lavas, tuffs and intrusive rocks solely by erosion were uplifted in the manner outlined above. It may be noteworthy, however, that nowhere in the Washington Cascades adjacent to the Columbia River are any remains other than even Skyline of an uplifted old age surface preserved. Any surface considered must be reconstructed from the accordant crests as seen on the skyline.

Problems Needing Attention

Before much of value can be written on the general history of the Cascade Mountains in southern Washington the following problems need detailed attention.

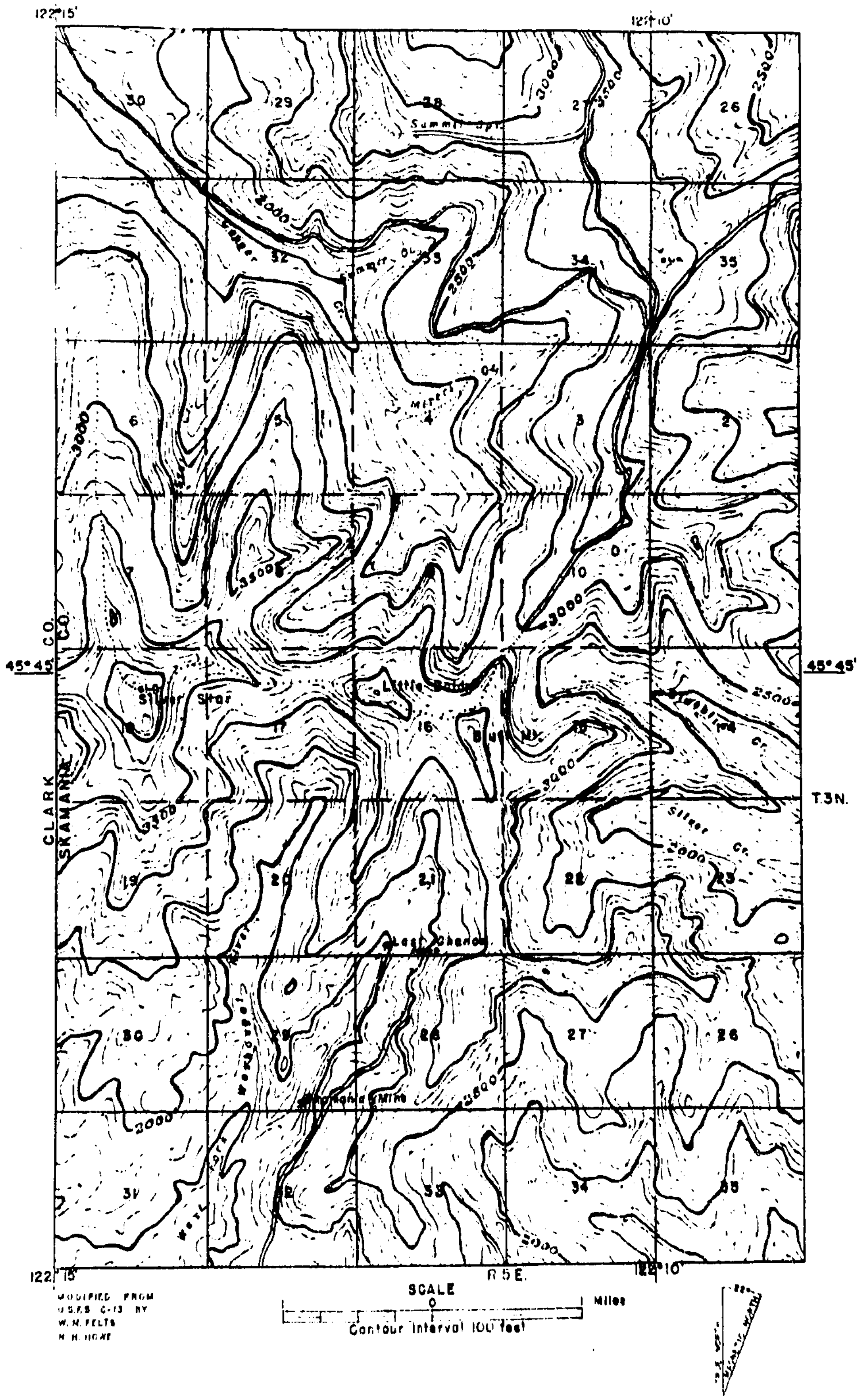
(1) Geological mapping of large areas within the range that are very poorly, if at all, known at the present time.

(2) Determination of the relationships existing between the marine strata in the southern extension of the Puget Trough and the lower pyroclastic material of the Western Cascades.

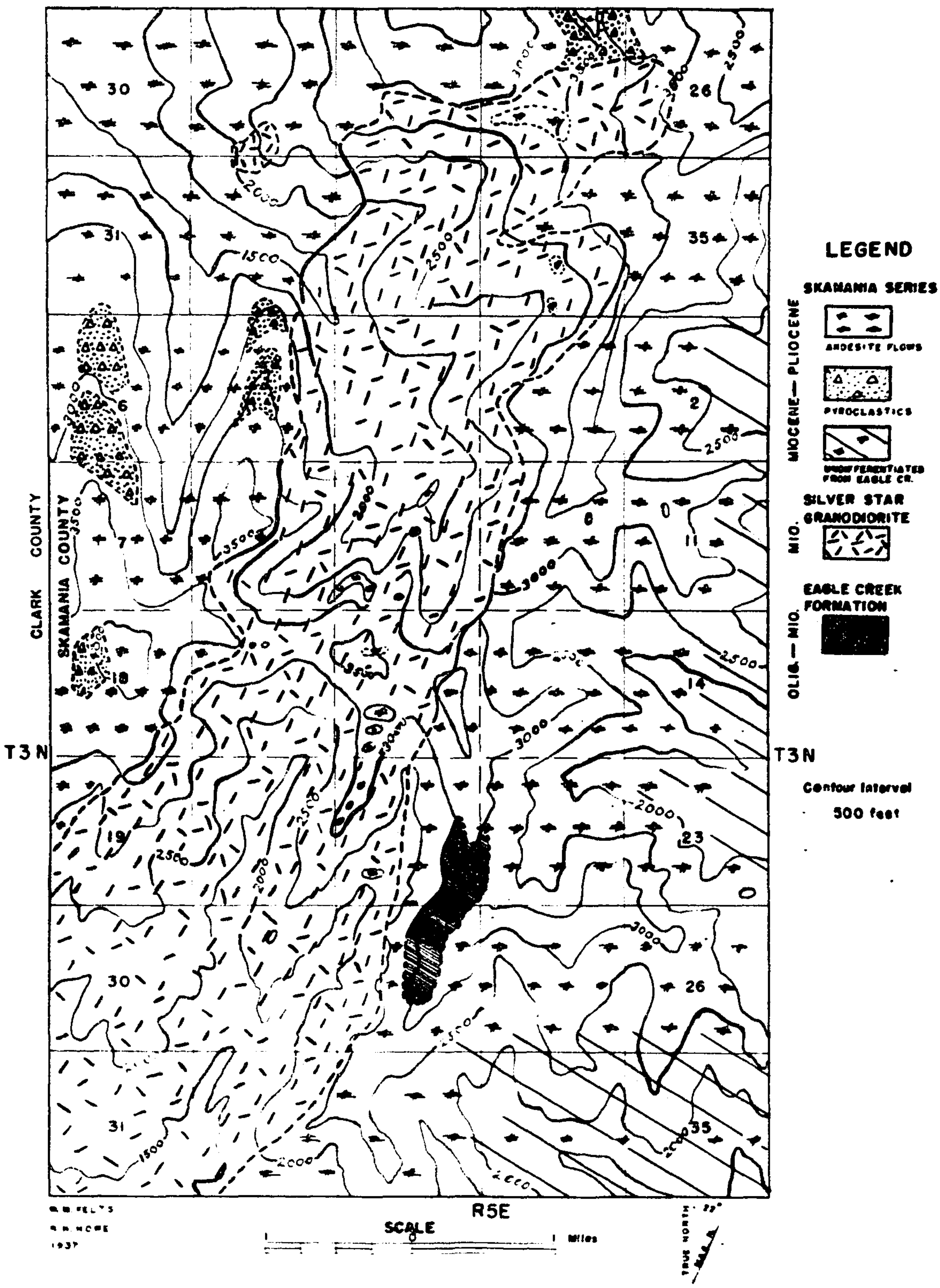
(3) Detailed mapping of the contact between the Columbia River basalts, exposed in the Columbia Gorge, and the Skamania andesites.

(4) Detailed paleobotanical studies of scattered floras known to exist in many places close to the area reported in this paper.

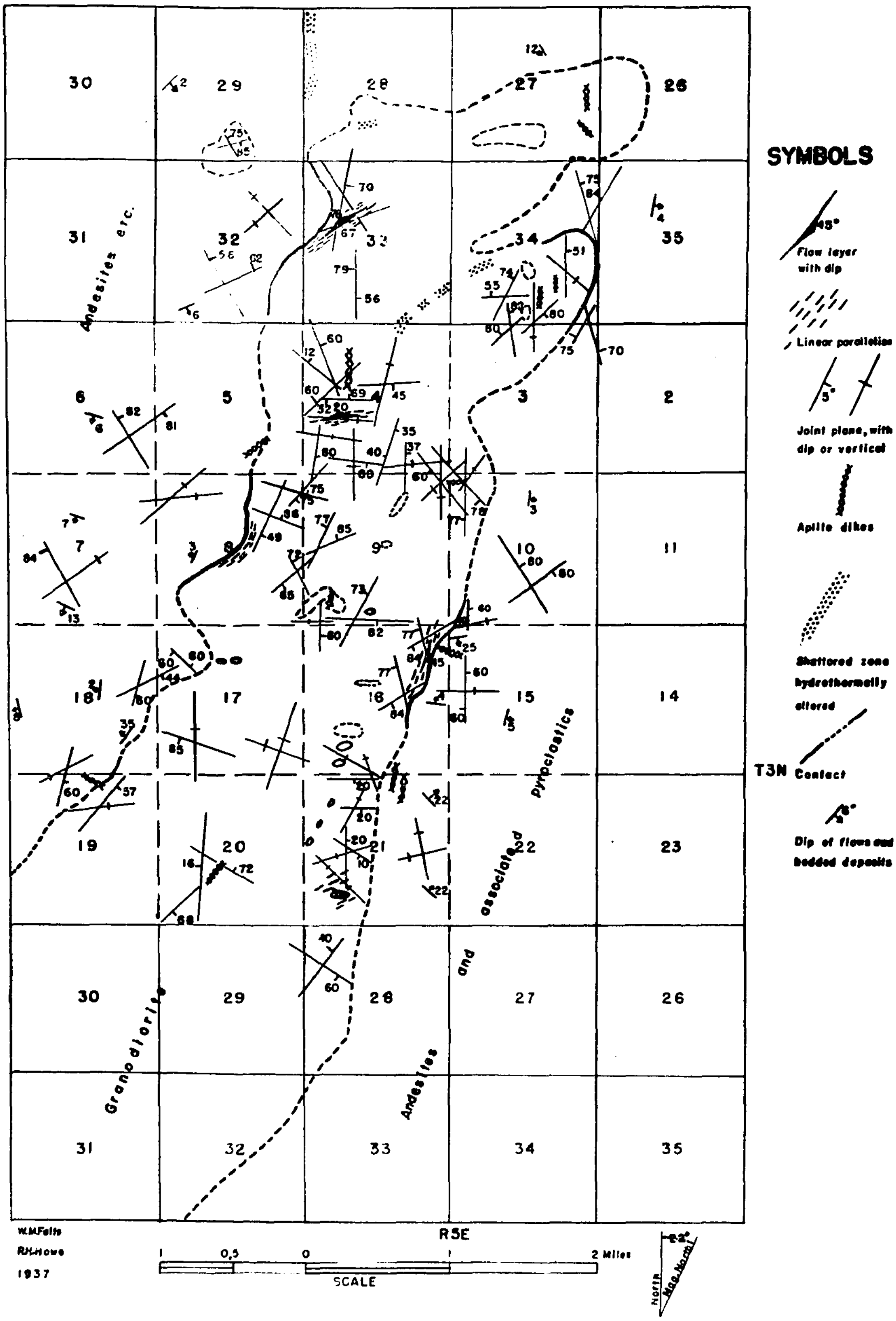
TOPOGRAPHY


122°15'
122°10'
Summit
Soapy Cr.
Miller
45°45'
CLARK CO.
SKAMANIA CO.
Little Baldy
Bull Mt.
Bluebird Cr.
Silver Cr.
T.3N.
Lost Chance Mine
R 5 E.
SCALE
Miles
Contour Interval 100 feet

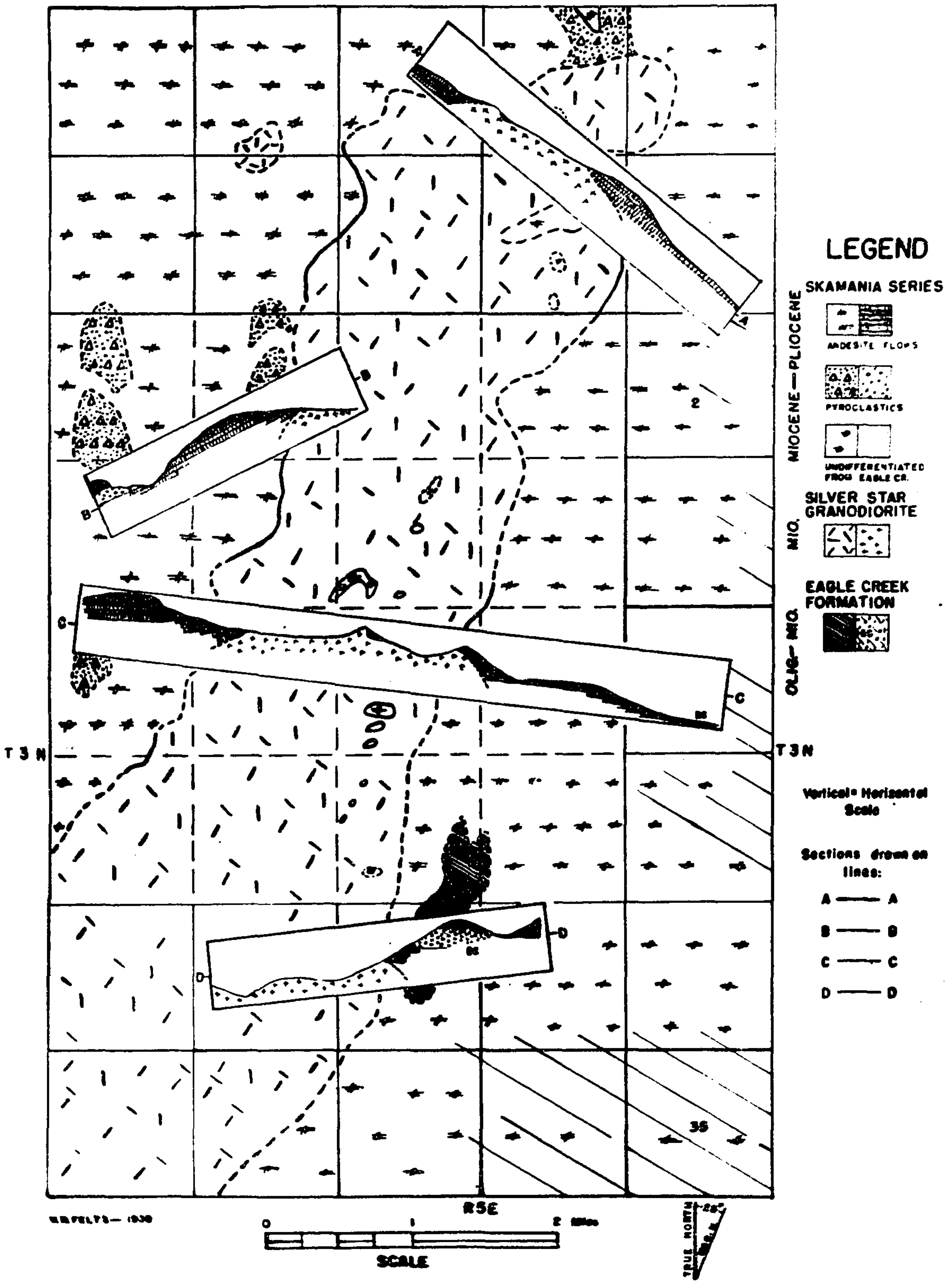
AREAL GEOLOGY



GEOLOGIC STRUCTURE



STRUCTURE SECTIONS



Bibliography

(1) Allen, J.E. "Contributions to the Structure, Stratigraphy, and Petrography of the Lower Columbia River Gorge" Univ. Ore. M.A. Thesis - 1932

(2) Balk, Robert "Structural Behavior of Igneous Rocks" Geol. Soc. Am. Mem. 5 - 1937

(3) Bowen, N.L. "The Evolution of the Igneous Rocks" Princeton Univ. Press - 1928

(4) Bucher, W.H. "The Mechanical Interpretation of Joints" Jour. Geol. Vol 28 pp 707 -730; Vol 29 pp 1 - 28, 1920 and 1921

(5) Buddington, A.F. and Callaghan, Eugene, "Dioritic Intrusive Rocks and Contact Metamorphism in the Cascade Range of Oregon" Am. Jour. Sci. 5 ser. Vol 31 pp 421 - 449 - June 1921.

(6) Buwalda, J. P. "Postulated Peneplanation in Central Washington" Proc. Geol. Soc. Am. p 331 - 1935 abst.

(7) Chaney, Ralph W. "The Flora of the Eagle Creek Formation" Chicago Univ. Walker Museum Contributions; Vol.2 No. 5 pp 115 181, 1920.

(8) Personal Communication - April 1938.

(9) Coombs, H.A. "The Geology of Mt. Rainier National Park" Univ. Washington Pub. in Geol. Vol.3 No. 2 pp 131-212-1936.

(10) Daly, R.A. "The Accordance of Summit Levels among Alpine Mountains" Jour. Geol. Vol. 13 no.1 pp 105 - 125 - 1905.

(11) "Geology of the North American Cordillera at the 49th Parallel." Geol. Surv. Canada Memoir 38 - 1912.

(12) Hodge, E.T. "Progress in Oregon Geology Since 1925" Northwest Science 6 - 44-53, June, 1932.

(13) Peacock, M.A. "Classification of Igneous Rock Series" Jour. Geol. Vol. 39 pp 54-67, 1931.

(14) Russell, I.C. "The Glaciers of Mt. Rainier" U.S.G.S. 18 Ann. Rpt. pt. 2, pp. 350-415, 1896.

(15) "A Preliminary Paper on the Geology of the Cascade Mountains in Northern Washington" U.S.G.S. 20th Ann Rpt pt.2 pp 83-210,1900.

(16) Smith, G.O. "Contributions to the Geology of Washington: The Geology and Physiography of Central Washington" U.S.G.S. Prof. Paper No. 19 pp 9-38 - 1903.

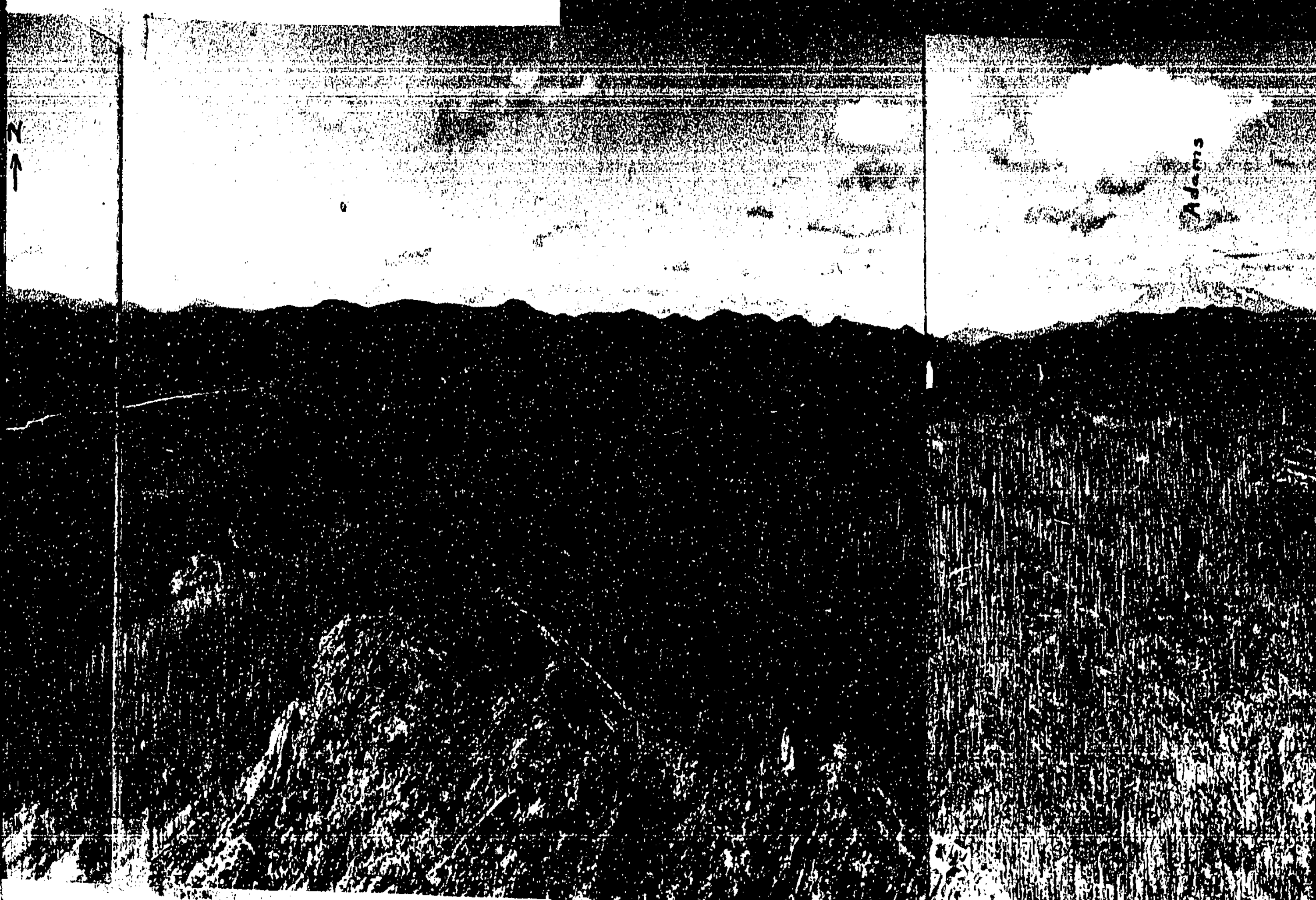
(17) Mount Stuart Folio U.S.G.S. Geol. Atlas 106 - 1904. and Calkins, F.C. "Snoqualmie Folio" U.S.G.S. Atlas 139 -1906.

(18) Warren, Walter "Tertiaries of the Washington Cascades" Pan. Am. Geologist Vol. 65 No. 4 pp 241 - 247 - 1936.

(19) Willis, Bailey, "The Physiography and Deformation of the Wenatchee-Chelan district, Cascade Range", U.S.G.S. Prof. Paper 19, pp 41-95 - 1903.

40

Panoramic Photograph from summit of Bluff Mountain


N
Adams


Adams