DIORITIC INTRUSIVE ROCKS AND CONTACT METAMORPHISM IN THE CASCADE RANGE IN OREGON.

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ABSTRACT.

A series of dioritic intrusive bodies penetrate Tertiary volcanic rocks and tend to be arranged in clusters within a narrow belt extending longitudinally through the Cascade Range of Oregon. The intrusive bodies range in greatest dimension from a few feet to two and one half miles. Most of the bodies are dikes, but there are numerous plugs and a few small stocks. They range from augite diorite to granite, and augite diorite and dacite porphyry are the most widespread varieties. Moderate orthoclasization of calcic or intermediate plagioclase is a common feature of almost all the intrusive bodies. A comparison of chemical analyses of the Tertiary intrusive rocks of the Cascade Range in Oregon with those of Tertiary intrusives in Utah and those of Mesozoic intrusives in the Sierra Nevada shows that the Oregon rocks are more closely related chemically to those of the Sierra Nevada than to those of Utah. Volcanic rocks surrounding the intrusive bodies have been modified to a variable extent in zones from a few inches to nearly one-half mile in width. In some places the original rock has been wholly reconstituted and changed to tourmaline hornfels.

CONTENTS.

INTRODUCTION.

The small dioritic intrusive bodies of the Cascade Range in Oregon have several features of general interest. They are distributed in a narrow belt through the western part of the range from Shellrock Mountain, on the Columbia River, to

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Sampson Creek, near the California line. Their age is not definitely known, but they appear to have been formed near the end of the Miocene epoch. They have a wide range in form, from long, narrow dikes to cylindrical plugs and small stocks as much as two and one-half miles long and one and one-half miles wide. The elongate bodies trend west or northwest. In several areas they are associated with quartz-sulphide veins which are believed to be related genetically to them. They range in texture from fine-grained rocks with a few scattered phenocrysts to rocks in which the abundance of phenocrysts produces a granitoid appearance. A very few are even-grained. The later intrusives are lighter-colored and more silicic than the earlier intrusives. The mineral composition appears to have been in part controlled by the early escape of volatile substances that caused the formation of pyroxenes rather than amphiboles and biotite in all but the largest body.

Contact or thermal metamorphism of the associated lava flows and tuffs has resulted in complete reconstitution in some places with the production of tourmaline hornfels. There is almost every gradation from such reconstituted rocks to those scarcely affected.

The field work upon which this paper is based was undertaken in 1930 and 1931 as a part of the study of the metalliferous mineral deposits of the Cascade Range in Oregon by the U. S. Geological Survey in Coöperation with the State Mining Board. The field work was of a reconnaissance nature except in the Bohemia district where moderately detailed work was done. This area is therefore regarded as the type example. The writers were associated in the field study of the Bohemia and North Santiam districts during the first season and were assisted by H. E. Wheeler. The work of the second season was carried on by Callaghan assisted by T. P. Thayer. The writers are indebted to Princeton University and to Prof. A. H. Phillips for chemical analyses and to James Gilluly, C. S. Ross, and B. H. Lane for critical reading of the manuscript.

GENERAL GEOLOGY.

The Cascade Range in Oregon is a deeply dissected region of volcanic rocks ranging in age from Eocene to Recent. It ranges in width from 30 to 70 miles and extends north into Washington and south into California. It has been separated into two geomorphic subprovinces, called "Western Cascades,"[2] to which the intrusives discussed in this paper are confined, and "High Cascades" (Fig. 1). The Western Cascades constitutes the western and larger part of the range. The High Cascades is a narrow strip along the east side of the range and contains numerous volcanic cones in various

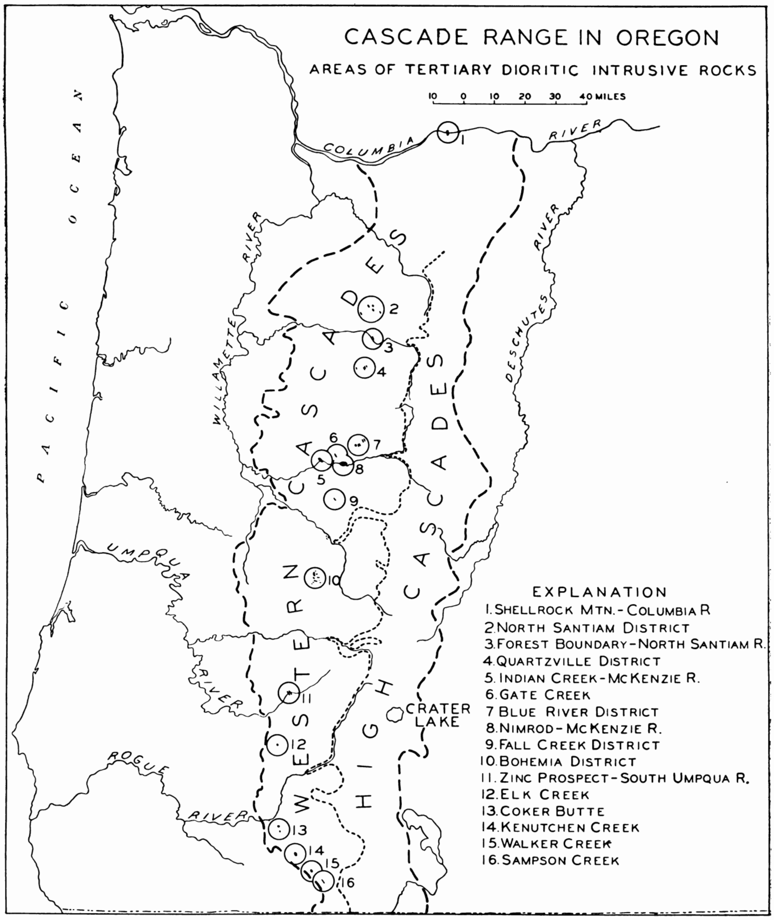

Fig. 1. Outline map showing distribution of dioritic intrusive rocks in the Cascade Range in Oregon.

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[2] Callaghan, Eugene: Some features of the volcanic sequence in the Cascade Range in Oregon: Am. Geophys. Union Trans. 14th Ann. Meeting, pp. 243-249, Nat. Research Council, 1933: Some aspects of the geology of the Cascade Range in Oregon [abstract]: Washington Acad. Sci. Jour., vol. 24, no. 4, pp. 190-191, 1934.

states of preservation. It is composed of younger lavas and is less dissected than the Western Cascades. Almost no original constructional surfaces are preserved in the Western Cascades, and the region is characterized by long, narrow ridges and valleys and differences of altitude ranging between 1,000 and 4,000 feet in the space of two or three miles. The stream pattern is dendritic.

The rocks of the Western Cascades are almost entirely of volcanic origin and include flows, tuffs, and volcanic breccias. The greater part of the Western Cascades is characterized by gray calcic andesites designated "labradorite andesites" (basaltic andesites), though basalts, augite andesites, and rhyolites do occur. Two areas characterized by black lavas, chiefly andesites, occur in the Rogue River Valley area and along the east side of the Willamette Valley. The bulk of these rocks appear to range in age from Eocene to Miocene, but possibly some rocks of Pliocene age are represented.

INTRUSIVE ROCKS.

General Features.

The intrusive bodies and the associated contact-metamorphic rocks occur in a belt extending through the center of the Western Cascades except toward the south in the Bear Creek Valley where they lie along the western margin of the range (Fig. 1). They occur as clusters of small bodies, as in the North Santiam, Quartzville, and Bohemia mining districts, or as isolated bodies, such as those on the North Santiam and McKenzie Rivers. Exposures of these rocks range in altitude from a few feet above sea level on the Columbia River and 740 feet on the McKenzie River to 5,400 feet in the Bohemia mining district.

Some of the dioritic intrusive bodies have been noted by other workers. In the Bohemia mining district Diller[3] found some of these rocks which he called "dacite porphyry." MacDonald[4] pointed out more clearly the occurrence of these rocks in the same area. Williams[5] described and mapped the Shellrock Mountain intrusive, which he called "diorite porphyry."

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[3] Diller, J. S.: The Bohemia mining region of western Oregon, with notes on the Blue River mining region and on the structure and age of the Cascade Range: U. S. Geol. Survey 20th Ann. Rept., pt. 3, pp. 11-12, 1900.

[4] MacDonald, D. F.: Notes on the Bohemia mining district, Oregon: U. S. Geol. Survey Bull. 380, p. 81, 1909.

[5] Williams, I. A.: The Columbia River gorge: its geologic history interpreted from the Columbia River highway: Mineral Resources of Oregon, vol. 2, no. 3, pp. 97-102, 1916.

Barnes and Butler[6] mapped the same area and found that the intrusive bodies extended northward into Washington. Campbell[7] described some features of the stocks at Nimrod and at Indian Creek on the McKenzie River. Tuck[8] described one of the stocks in the Blue River district. Piper[9] and Thayer[10] noted the intrusive at the forest boundary on the North Santiam River, and Thayer has described the Halls intrusive nearby. Waters[11] has pointed out the localities of the Tertiary intrusives in Oregon and Washington. They are also mentioned by Wells and Waters.[12]

The age of the intrusive bodies is not definitely known. They are probably all of about the same age, as their composition, structural features, trends, and relation to mineralization are similar throughout. The intrusive body at Shellrock Mountain[13] penetrates the Columbia River basalt, which is regarded by Hodge as lower Miocene.[14] The andesitic rocks traversed by the intrusives in such areas as the Bohemia mining district are believed to be of Miocene age, though no identifiable fossils have been found in them. The intrusive bodies are more nearly related chemically to the volcanic rocks of the Western Cascades than to those of the High Cascades. It seems probable from these bits of evidence that the dioritic intrusive bodies are of late Miocene age.

The dioritic intrusive bodies range in size from dikes a few feet wide to the stock at Nimrod, on the McKenzie River (No. 8, Fig. 1), which is roughly two and one-half miles long and one and one-half miles wide. Probably the typical average intrusive body is an elongate mass, slightly less than a

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[6] Barnes, F. F., and Butler, J. W.: Structure and stratigraphy of the Columbia River gorge and Cascade Mountains in the vicinity of Mount Hood (Oregon Univ. thesis), 1930.

[7] Campbell, Ian: A geologic reconnaissance of the McKenzie River section of the Oregon Cascades (Oregon Univ. thesis), 1923.

[8] Tuck, Ralph: The geology and ore deposits of the Blue River mining district (Oregon Univ. thesis), 1927.

[9] Piper, A. M.: Unpublished reports on water resources of Willamette Valley and dam sites, U. S. Geol. Survey.

[10] Thayer, T. P.: The general geology of the North Santiam River section of the Oregon Cascades. California Inst. Technology thesis, 1934.

[11] Waters, A. C.: Summary of the sedimentary, tectonic, igneous, and metalliferous history of Washington and Oregon: Ore deposits of the Western States (Lindgren volume), pp. 264-265, Am. Inst. Min. Met. Eng., 1933.

[12] Wells, F. G., and Waters, A. C.: Quicksilver deposits of southwestern Oregon: U. S. Geol. Survey Bull. 850, p. 26, 1934.

[13] Williams, I. A.: op. cit., p. 100. Barnes, F. F. and Butler, J. W.: op. cit.

[14] Hodge, E. T.: New evidence of the age of the John Day formation: Geol. Soc. American Bull., vol. 43, p. 701, 1932.

quarter of a mile wide and half to three-quarters of a mile long. There is almost every gradation in shape from long, thin dikes to cylindrical plugs (Fig. 2). There are not only many irregularities in the contacts of the bodies as shown in plan, but also irregularities in vertical cross section. The largest body in the Bohemia district (A, Fig. 2) appears to have a vertical contact on the west side, but the irregularities in the eastern contact indicate a sill-like or possibly laccolithic extension in that direction.

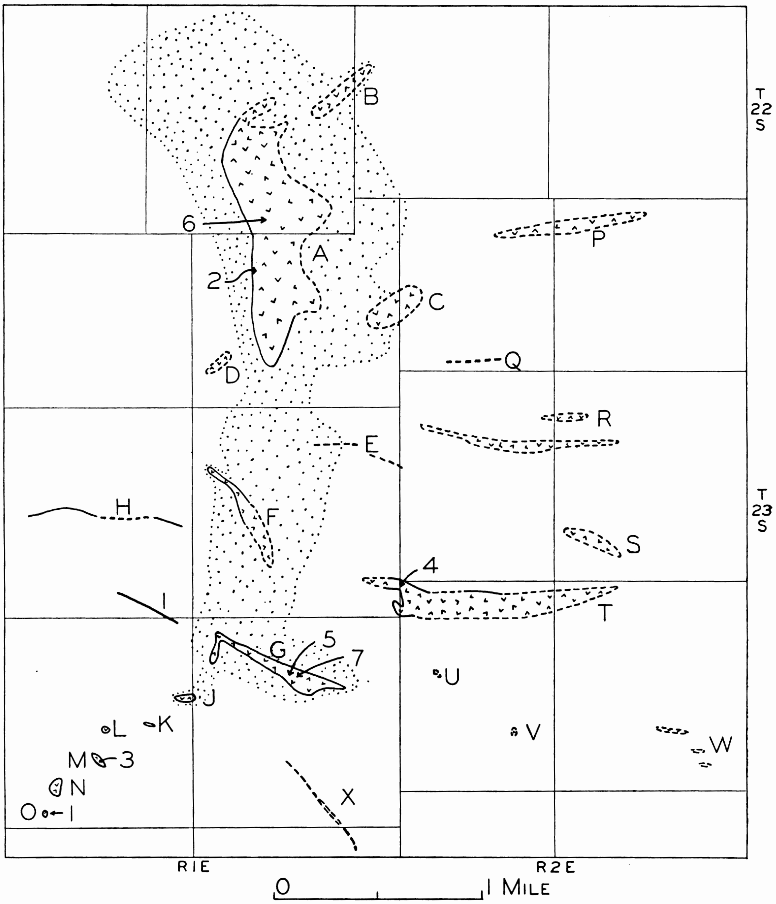

Fig. 2. Map showing dioritic intrusive bodies and principal area of contact metamorphism (stippled) in the Bohemia mining district. Numbers indicate the locations of analyzed samples.

It is believed that the sulphide mineralization in the Western Cascades was genetically related to the dioritic intrusive bodies.[15] All the larger mineralized areas are associated with a cluster of intrusive bodies. The veins are later than the intrusives and traverse them in many places. The trends of the veins are similar to those of the intrusives, indicating that similarly directed forces were operating during the emplacement of both intrusives and veins.

TABLE 1. Chemical analyses of representative types of dioritic intrusive bodies, Bohemia district and Nimrod, Lane County, Oregon.

	1	2	3	4	5	6	7	8
SiO_2	52.67	59.70	61.99	62.37	65.16	65.71	71.03	71.57
Al_2O_3	17.36	15.53	15.69	15.19	15.24	14.29	12.67	13.55
Fe_2O_3	3.37	3.57	2.96	2.13	2.08	2.44	2.03	1.55
FeO	5.14	4.07	2.85	3.38	3.04	2.85	1.58	2.28
MgO	5.06	3.16	2.76	2.78	2.22	2.15	1.29	.53
CaO	8.80	6.17	4.62	5.06	4.69	4.13	2.66	1.52
Na_2O	3.06	3.65	3.52	3.39	3.62	3.55	2.47	4.75
K_2O	.73	1.34	1.60	1.85	2.08	2.42	4.16	4.09
H_2O+	2.15	.98	1.83	1.90	.77	.82	.84	.13
H_2O-	.18	.03	.13	.11	.13	.11	.08	.02
CO_2	.09	....	.75	.32	.17	....	.05	....
TiO_2	1.13	1.13	.73	.82	.74	.81	.50	....
P_2O_5	.29	.25	.31	.24	.29	.20	.39	.03
MnO	.17	.17	.06	.11	.09	.18	.06	.03
Total	100.20	99.75	99.80	99.65	100.32	99.66	99.81	100.05

Norms.

Q	6.72	16.14	23.76	20.40	23.16	23.94	34.02	23.52
or	3.89	7.78	9.45	11.12	12.23	14.46	24.46	24.46
ab	25.68	30.92	29.34	28.82	30.39	29.87	20.96	40.35
an	31.97	21.96	16.40	20.57	19.18	15.85	10.56	3.34
C	....	....	2.24	....	....	....	.30	....
wo	3.94	3.36	....	.70	.58	1.51	....	1.74
en	12.70	7.90	6.90	7.00	5.60	5.40	3.20	1.30
fs	5.15	2.90	1.58	3.43	2.77	2.24	.53	2.90
mt	4.87	5.34	4.41	3.02	3.02	3.48	3.02	2.32
il	2.13	2.13	1.37	1.52	1.37	1.52	.91	....
ap	.67	.61	.74	.57	.67	.47	.91	....
cc	.20	....	1.70	.70	.40	....	....	....

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[15] Pardee, J. T.: Progress made in mineral survey of Oregon: U. S. Dept. Interior Press Mem. 50894, p. 8, March 2, 1931. Waters, A. C.: op. cit., pp. 264-265. Buddington, A. F., and Callaghan, Eugene: Metalliferous mineral deposits of the Cascade Range in Oregon: U. S. Geol. Survey Bull. —— (in preparation).

TABLE 1. Chemical analyses of representative types of dioritic intrusive bodies, Bohemia district and Nimrod, Lane County, Oregon—*Concluded.*

Approximate modes.

Quartz	1.0	19	1	0.5	....	18	....	31
Orthoclase	Trace	3	....	....	....	8	....	*a*37
Plagioclase	69	59.5	28.5	25.5	34.5	43.5	....	26
Augite, chlorite, etc.	26	....	3.5	9.5	7	....	....	....
Augite, hornblende, chlorite, etc.	....	14	....	....	....	9.5	....	....
Hypersthene	....	....	....	....	5.5	....	....	....
Biotite	....	....	....	....	....	....	....	3
Magnetite	3.5	4	1	1.5	2.5	2.5	....	3
Apatite	0.5	0.5	....	....	0.5	0.5	....	....
Micropegmatite	....	....	....	....	....	18.0	....	....
Groundmass	....	....	66	63	50.0	....	....	....

a Includes intergrowths with plagioclase on rims of plagioclase grains.

1. Augite diorite. Small plug, half a mile west of Peekaboo mine, sec. 14, T. 23 S., R. 1 E., Bohemia district (O, Fig. 2).
2. Porphyritic augite-quartz diorite. Border facies of small stock, Champion trail, 1,600 feet north of Golden Curry Creek, sec. 1, T. 23 S., R. 1 E., Bohemia district (A, Fig. 2).
3. Augite dacite porphyry. Small plug, southeast spur of Bohemia Mountain, sec. 14, T. 23 S., R. 1 E., Bohemia district (M, Fig. 2).
4. Augite granodiorite porphyry. Dike on trail to Grizzly Saddle, 300 yards west-southwest of Grizzly Peak, sec. 12, T. 23 S., R. 1 E., Bohemia district (T, Fig. 2).
5. Augite-hypersthene granodiorite porphyry. Core of dike on road to Champion Saddle, above Champion boarding house, sec. 13, T. 23 S., R. 1 E., Bohemia district (G, Fig. 2).
6. Augite granodiorite. Small stock, Champion Creek road, first creek crossing north of Golden Curry Creek, Bohemia district (A, Fig. 2).
7. Aplite. Small dike in porphyritic granodiorite dike, trail to Champion Saddle above Champion boarding house, Bohemia district (G, Fig. 2).
8. Granite. Stock at Nimrod, McKenzie River (8, Fig. 1).

Analyses 1, 5, 7 by T. Kameda; 2, 3, 4, 6 by R. B. Ellestad; 8 by A. H. Phillips.

PETROGRAPHY.

The intrusive rocks were studied and mapped by the writers in most detail in the Bohemia mining district, and all but one of the analyses given above represent rocks from this area. The detailed petrographic descriptions are therefore restricted to the analyzed specimens, but these are representative of the entire group.

Augite diorite.—The southernmost plug (O, Fig. 2) in the group on the southeast face of Bohemia Mountain is representative of the most calcic phase found in this group of rocks (1, Table 1). The rock, an augite diorite, is medium gray with a greenish hue. It is fine-grained and even-granular, the plagioclase grains ranging in general from 0.5 to 1 mm. in length with a few grains as long as 4 mm.

The plagioclase occurs as a mat of interlocking laths, and the augite as stubby euhedral crystals, some of which are twinned. The plagioclase is a sodic labradorite (about $Ab_{50}An_{50}$), which is slightly zoned. There is a little interstitial quartz and sparse orthoclase. Magnetite and ilmenite are disseminated throughout the rock as small grains or plates. Apatite and a few zircons are accessory minerals. The augite has been partly altered to uralite and in some places to chlorite. A network of threadlike replacement veinlets of orthoclase occurs in many of the plagioclase crystals.

Porphyritic augite-quartz diorite and dacite porphyry.—The porphyritic augite-quartz diorite and dacite porphyry form the border facies of the stocks and larger dikes and constitute the bulk of the smaller stocks and plugs. The contrast in texture between these rocks and the diorite is probably due to the more siliceous composition and consequent higher viscosity of their parent magma, particularly after release of the volatile constituents by their escape as a result of fracturing of the country rock during cooling.

The porphyritic augite-quartz diorite (2, Table 1) from the border facies of the small stock (A, Fig. 2) in the valley of Champion Creek is medium gray with a purplish hue due to the abundance of small phenocrysts of pale-purplish plagioclase. The structure is massive. In places this rock contains numerous very small reticulating veinlets of granodioritic composition, corresponding to the material forming the core of the stock.

The rock consists of a mat of plagioclase laths with interstitial quartz and subhedral grains of ferromagnesian minerals associated with numerous small phenocrysts of plagioclase (Fig. 3). Magnetite and ilmenite grains are common as accessory minerals, but apatite and zircon are much less abundant. Plagioclase phenocrysts, some of which show recurrent or oscillation zoning, are usually one to 3.5 mm. in length, whereas the plagioclase of the groundmass ranges between 0.3 and 0.6 mm. Most of the plagioclase is andesine ($Ab_{60}An_{40}$), but some of the grains are more calcic ($Ab_{50}An_{50}$). The larger plagioclase crystals contain a very little orthoclase in a network of thin replacement veinlets. Orthoclase also occurs in micrographic intergrowth with the interstitial quartz. The augite has been almost completely altered to uralite, and this in turn has been partly altered to chlorite. Small amounts of epidote occur in the rock.

The dacite porphyry (3, Table 1) is light gray with abundant small white plagioclase phenocrysts, a few black augite rods, and a very few quartz grains in a very fine-grained groundmass. The phenocrysts of andesine ($Ab_{60}An_{40}$) range between 1 and 5 mm. in length, and the materials of the groundmass range from 0.1 mm. to very minute grains. The augite has been almost wholly altered to uralite or to aggregates of chlorite and calcite with a little associated magnetite. The andesine crystals have been replaced by sericite to a slight extent. Some of the alteration may have been due to solutions that formed a vein near the outcrop from which the specimen was taken.

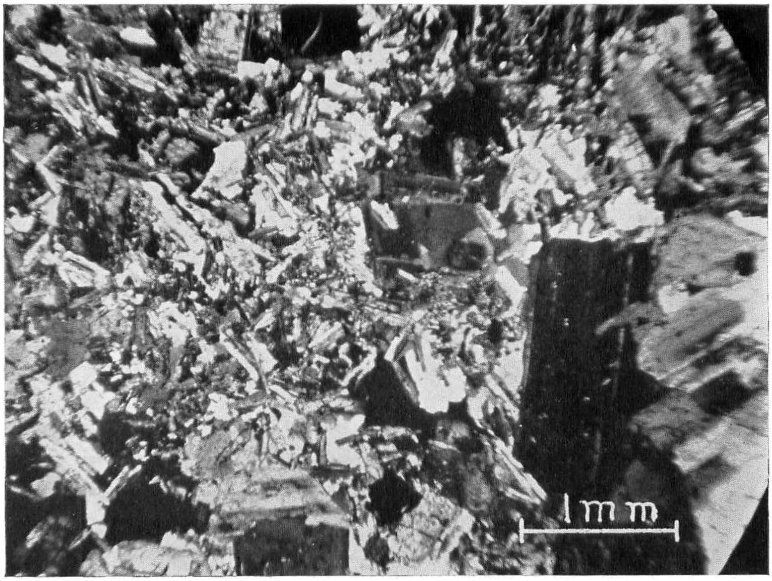

Fig. 3. Thin section of porphyritic augite-quartz diorite (column 2, Table 1) from border facies of small stock (A, fig. 2) in Bohemia district. Large phenocrysts and fairly coarse groundmass. This represents the coarser-grained facies of the dioritic intrusive bodies. Crossed nicols.

Granodiorite and granodiorite porphyry.—In the Bohemia district, granodiorite forms the core of the stock in the valley of Champion Creek (A, Fig. 2), and granodiorite porphyry forms the cores of all the larger dikes. Both facies contain abundant rounded inclusions of porphyritic augite-quartz diorite.

The granodiorite porphyry (4, Table 1) from the dike (T, Fig. 2) at the switchback on the trail to Grizzly Saddle is a light-gray rock of pale-purplish hue. Phenocrysts are so abundant that the rock has a granitoid appearance. The phenocrysts of andesine ($Ab_{60}An_{40}$) are 1 to 4 mm. in length. The groundmass is microgranitic, with a grain size of 0.1 to 0.2 mm., and consist of plagioclase, quartz, orthoclase, and a little augite. Euhedral phenocrysts of augite are commonly twinned. A little magnetite and apatite occur as disseminated small grains. The larger plagioclase crystals have been partly replaced by a network of very thin veinlets of orthoclase and contain epidote where these veinlets are abundant. The augite has been partly altered to chlorite and epidote, with calcite in a few places. No hornblende occurs in this specimen.

Granodiorite porphyry (5, Table 1) makes up the core of the large dike (G, Fig. 2) on the road 300 feet north of Champion Saddle. The rock is white flecked with black ferromagnesian crystals and contains numerous small inclusions of augite-quartz diorite averaging a quarter to half an inch in diameter. Phenocrysts are so abundant that the rock has a granitoid appearance. The phenocrysts are chiefly euhedral andesine ($Ab_{50}An_{50}$ to $Ab_{60}An_{40}$), with augite, which is commonly twinned, and hypersthene. The groundmass is microgranitic (Fig. 4), with an average grain size of 0.1 to 0.2 mm. Accessory minerals consist of a little disseminated magnetite, apatite, and a few minute grains of zircon. Many of the plagioclase crystals show recurrent zoning, and a few have a mottled appearance, possibly due to unmixing of a little orthoclase. The augite is unaltered, but the hypersthene in many places has been partly or wholly altered to chlorite.

The granodiorite (6, Table 1) from the core of the stock (A, Fig. 2), in the valley of Champion Creek, is a granitoid rock of pinkish hue, speckled with black. It contains a few small inclusions of dark-gray quartz diorite. It consists of euhedral andesine and augite grains, one to 2.5 mm. in length, with interstitial quartz, orthoclase, and micropegmatite. Magnetite, apatite, and a few minute zircon grains are accessory minerals. The andesine shows recurrent zoning and ranges between $Ab_{50}An_{50}$ and $Ab_{65}An_{35}$, with the latter variety the more abundant. Some of the andesine contains a network of thin orthoclase veinlets, and a few crystals are half replaced by orthoclase. Augite has been largely altered to fibrous hornblende but in places was altered to chlorite and more rarely to epidote.

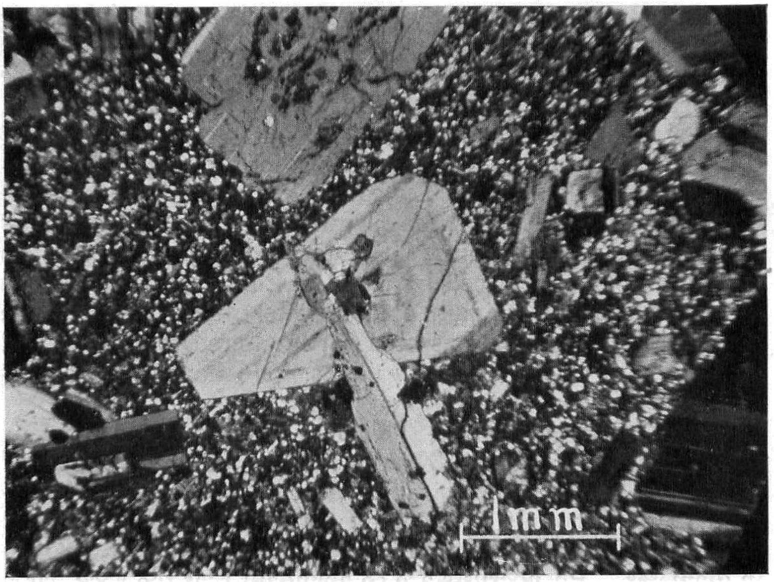

Fig. 4. Thin section of augite-hypersthene granodiorite porphyry (column 5, Table 1) from core of dike (G, fig. 2) at Champion mine, Bohemia district. Hypersthene phenocryst partly enclosed in plagioclase in center. Microgranitic groundmass. Crossed nicols.

Aplite.—Small aplite dikes or veins occur in the larger intrusive masses but were not found out in the country rock. Most of them are only a few inches in width and a few feet in length.

The analyzed sample of aplite (7, Table 1) came from a vein not over an inch wide in the granodiorite porphyry core of the dike 300 feet north of Champion Saddle (G, Fig. 2). The rock consists of oligoclase, quartz, and orthoclase with accessory magnetite, sparse hornblende, and veinlets of epidote and quartz. The average grain size is between 0.2 and 0.4 mm. The quartz and orthoclase occur in part in micrographic intergrowth. The plagioclase has been replaced by epidote to a very slight extent.

Granite.—The granite at Nimrod, on the McKenzie River (8, Table 1), is the largest intrusive body in the Cascade Range in Oregon and differs materially in composition from the other intrusive bodies. It is light to purplish gray, fine-grained, and even-granular. A few plagioclase phenocrysts are between 2 and 3 mm. long, but the average is 0.5 to 1 mm. for most of the feldspar and 0.2 to 0.5 mm. for most of the other constituents. The principal minerals are oligoclase, orthoclase, and quartz, with small amounts of biotite, magnetite, apatite, titanite, zircon, chlorite, epidote, and sericite. Oligoclase occurs as euhedral to subhedral grains, here and there containing veinlets of orthoclase and in many places partly replaced by orthoclase. Orthoclase occurs as interstitial material, borders, and partial replacement rims on the

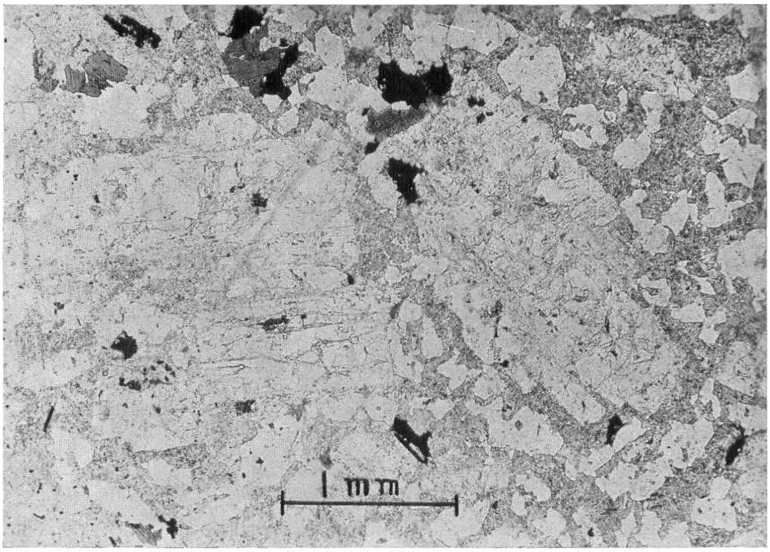

Fig. 5. Thin section of biotite granite at Nimrod on McKenzie River. Large oligoclase phenocrysts, clear quartz grains, dark gray biotite, and black magnetite in a dusty matrix of orthoclase. Orthoclase also partly replaces the oligoclase. Plain light.

plagioclase, and as euhedral to subhedral grains, which may be pseudomorphous after plagioclase (Fig. 5). It is highly charged with minute inclusions which distinguish it from the clear quartz and plagioclase. Under crossed nicols it is mottled, indicating remnants of intergrowths of plagioclase. Quartz grains are clear and equant but of irregular outline. Biotite is the only ferromagnesian mineral and occurs in small grains, some of which have been changed to chlorite. There is no indication of former pyroxene or hornblende. The amounts of chlorite, sericite, and epidote are variable. Some small cavities, 1 or 2 mm. in diameter, are lined with epidote.

The intrusive rocks in areas in the Cascade Range other than the Bohemia district and the Nimrod area are similar, both in texture and composition, to one of the rocks described above, though there are local differences, as might be expected. Most of the intrusives are small and more calcic than the large bodies in the Bohemia district and the Nimrod granite body, and are mostly porphyritic diorite or dacite porphyry. Varying proportions of orthoclase occur as interstitial material, veinlets, and cores in plagioclase in all these rocks.

The augite-hypersthene diorite of the Shellrock Mountain intrusive (1, Fig. 1) is composed chiefly of andesine, occurring both as phenocrysts (1 to 2 mm.) and groundmass (0.2 to 0.5 mm.), augite (0.2 to 0.6 mm.), hypersthene (0.2 to 1 mm.), and quartz (0.1 mm.). The augite is unaltered, but the hypersthene occurs as cores and remnants in pseudomorphs of uralite. Nearly a dozen small intrusive bodies were found in the North Santiam district (2, Fig. 1) scattered over an area of about 50 square miles. Most of them are dikes, but there are some small plugs, which are all made up of dacite porphyry. A larger body of quartz diorite of undetermined shape occurs at the Crown mine in the southeastern part of the area. The intrusive rocks as well as the country rocks are considerably altered and charged with epidote. The intrusive bodies on the North Santiam River, near the national-forest boundary (3, Fig. 1), were not studied by the writers. According to Thayer,[16] the largest body at Halls is a quartz diorite with phenocrysts of sodic andesine.

In the Quartzville district (4, Fig. 1) six dikes of dacite porphyry and one of porphyritic augite diorite were found. Float of a more even-granular rock was found in Galena Creek

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[16] Thayer, T. P.: op. cit.

near the outcrops of tourmaline hornfels. The body of augite diorite on the McKenzie River near Indian Creek (5, Fig. 1) is about 1,000 feet wide in the outcrop along the highway. It is somewhat coarser-grained than most of the other intrusive rocks in the Cascade Range and consists largely of euhedral calcic andesine phenocrysts as much as 4 mm. and mostly over 1 mm. in length and augite largely between 0.5 and 1 mm. in length. Smaller grains of augite and plagioclase make up a minor amount of interstitial groundmass. Near the northeast contact, the rock is finer-grained (0.5 to 2 mm.), contains sodic rather than calcic andesine, and contains more quartz and orthoclase. A small body of dacite porphyry with phenocrysts of both quartz and plagioclase was found on the old Gate Creek road (6, Fig. 1). Two groups of small intrusives were found in the Blue River district (7, Fig. 1), one in the vicinity of Gold Hill and another in the south fork of Tidbits Creek, two and a half miles to the northeast. A plug of porphyritic augite diorite on the north side of Gold Hill has apophyses containing more quartz than the main body. A dike of dacite porphyry and two dikes of porphyritic augite diorite are exposed on the ridge east of the plug. One dike of comparatively coarse diorite and two dikes of very fine-grained diorite occur in the Tidbits Creek area.

In the Fall Creek area (9, Fig. 1) two small dikes were found—a dacite porphyry on Portland Creek and an augite diorite at the Jumbo prospect about five miles to the southeast. Two dikes of considerably altered augite diorite, each about 150 feet wide and 200 feet apart, occur at the Zinc prospect (11, Fig. 1), on the South Umpqua River. A similar dike occurs 0.9 mile farther up the river. Residual boulders of augite diorite porphyry were found on Elk Creek (12, Fig. 1) near the divide between the Rogue and Umpqua Rivers. The rock consists of numerous large (1 to 5 mm. andesine phenocrysts in a groundmass of small (0.1 to 0.2 mm.) lath feldspars, augite, and magnetite with a little quartz and orthoclase.

Most of the intrusive rocks in the Bear Creek Valley occur in water-laid tuffs, arkoses, and conglomerates. Porphyritic augite diorite occurs in low hills near Whetstone Creek and at Coker Butte. A dike of hornblende-augite diorite occurs in a hill east of the upper part of Kenutchen Creek (14, Fig. 1). It is a fine-grained (0.5 to 1 mm.), medium-gray rock with black blotches of poikilitic and skeletal ilmenite from 1 to 3 mm. in width. The andesine is largely replaced by orthoclase, and hornblende (not fibrous uralite) is associated with augite in such a way as to indicate replacement of the augite. A little hypersthene and quartz are present. A body of nearly black augite-hypersthene diorite at least 200 feet wide occurs east of Ashland, at Walker Creek, (15, Fig. 1). It is probably the most calcic and least silicic of all the intrusives. It consists of labradorite (1 to 3 mm.) and both hypersthene and augite (0.5 to 1 mm.). A little orthoclase occurs as veinlets in the plagioclase, and there is a little interstitial quartz. The dike of dacite porphyry on Sampson Creek (16, Fig. 1) is the southernmost of the dioritic intrusive bodies known to the writers.

A few outcrops or indications of intrusives were found that are not shown on Fig. 1. Some residual boulders of porphyritic augite diorite were found on the Middle Fork of the Willamette River, about midway between localities five and ten (Fig. 1). A small outcrop was found on Frank Brice Creek, about six miles northwest of the Bohemia district (10, Fig. 1). Float was found on Clark Creek, five miles southwest of the Bohemia district.

Structural Features, Differentiation, and Late-Stage Alteration.

The structure of the volcanic rocks into which most of the dioritic rocks have been intruded is only imperfectly known. The flows along the western margin of the range dip mainly to the east or northeast south of the Santiam River and mainly to the west or northwest north of the river. In the Bohemia district they dip mainly to the east and northeast at angles as great as 30°, but in most of the areas the flows appear to be only gently folded. Some faults have been found, but the displacement is small on those faults for which it could be determined.

The outstanding structural feature of the intrusive bodies is the concentration of most of them in a belt through the center of the Western Cascades essentially parallel to the trend of the range. The cluster of intrusives in the Bohemia district follows this same trend, but the group in the vicinity of the McKenzie River and Blue River district (5, 6, 7, and 8, Fig. 1) trend more to the northeast. Those in the North Santiam district are widely scattered. Individual elongate bodies trend mainly to the northwest and west, as do the veins which are in or near many of the intrusive bodies. The regional alinement of the centers of intrusion naturally raises the question whether they indicate an axis of a continuous batholith at depth. If so, the country rocks do not show the intensely folded structure which is so often postulated as being produced before a major batholithic intrusion. The length of the batholith in Oregon would be 250 miles. Hodge[16a] has suggested that a batholith in this region has been active from pre-Cambrian to Recent.

Some minor structural features of the intrusives or adjoining rocks are of interest. Williams[17] and Barnes and Butler[18] state that the flows are tilted upward around the margin of the Shellrock Mountain intrusive, indicating that the emplacement of the stock was accompanied by doming of the flows. Similar tilting was observed on the north side of the Nimrod stock. The irregularities of the east contact of the stock in the Bohemia district (A, Fig. 2) suggest that it is roughly accordant with the flows, which dip to the east, and may have a laccolithic extension in that direction. Rounded dark fragments appear in some of the intrusive bodies, particularly in the stock in the Bohemia district, but they appear to be parts of an earlier differentiate rather than fragments of country rock. Apophyses of the intrusive bodies invade dark border facies or contact rocks. No linear parallelism or platy foliation was observed.

No evidence of differentiation in place was noted, and the different intrusive rocks are believed to have resulted from the differentiation of a large deep-seated magma body before intrusion. The narrow dikes and small plugs each contain only one kind of rock, either dacite porphyry or pyroxene diorite or pyroxene-quartz diorite. The composite character of the larger masses appears to be due to successive intermittent intrusions of the products of differentiation, in part along the same general lines of fracturing. In general, the augite diorite or augite-quartz diorite was the earliest differentiate and was followed by granodiorite porphyry and lastly by granodiorite, or, as in the Nimrod intrusive, by biotite granite. In the smaller masses the early differentiate sealed the fissure, but in the larger masses the early differentiate was brecciated and invaded by the more siliceous differentiate. In

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[16a] Hodge, E. T.: Oregon batholiths: Northwest Science, vol. 7, p. 36, 1933.
[17] Williams, I. A.: op. cit., p. 100.
[18] Barnes, F. F., and Butler, J. W.: op. cit.

some places the early differentiate, if present, was completely removed so that the more siliceous rock lies directly against the country. A small amount of aplite represents the final phase, and no lamprophyres were observed.

A notable feature of these intrusive bodies is the dominance of pyroxene, chiefly augite, over hornblende and biotite in all except the Nimrod granite stock. Biotite and hornblende are likewise uncommon in the flows of the Western Cascades. Biotite occurs in a rhyolite on the west margin of the range near the intrusive on Elk Creek (12, Fig. 1), and hornblende occurs in some rhyolites, particularly in the North Santiam district. The chemical analyses of the intrusive rocks are very similar to those of diorites and granodiorites characterized by hornblende and biotite in other areas.

The explanation for this mineralogic difference is probably to be sought in the conditions of emplacement and crystallization of the intrusive bodies. The formation of hornblende and mica is commonly attributed[19] in major part to the volatile components of the magma, and this appears to be true of the Cascade intrusive rocks. If small masses of magma were emplaced in narrow chambers in rocks, such as relatively porous bedded flows and tuffs at shallow depths, they would cool quickly and lose their contained volatile components, crystallizing directly as pyroxene rocks rather than as hornblende or hornblende and biotite facies. The entire course of crystallization is thought to have occurred in place, as the phenocrysts of plagioclase are little if any more calcic than the plagioclase of the groundmass, and the texture is fine-grained.

In most of the intrusives the principal primary magmatic minerals—plagioclase, augite, hypersthene, quartz, and magnetite or ilmenite—were commonly followed by later minerals, including orthoclase, uralite, epidote, chlorite, sericite, carbonate, quartz, pyrite, leucoxene, and clay minerals. Orthoclase occurs as replacement veinlets in plagioclase in all thin sections examined. Normally in the diorites there is only a little, but in a diorite from Kenutchen Creek the andesine is

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[19] Iddings, J. P.: Igneous rocks, vol. 1, pp. 132-134, 140, New York, 1909. Vogt, J. H. L.: The physical chemistry of the crystallization and magmatic differentiation of igneous rocks: Jour. Geology, vol. 30, pp. 659-672, 1922. Niggli, Paul: Homogeneous equilibria in magmatic melts and their bearing on the processes of igneous rock-formation: Faraday Soc. Trans., vol. 20, pt. 3, p. 435, 1925. Gilluly, James: Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 55, 57, 1932.

largely replaced by orthoclase. With increasing proportions of SiO_2 and K_2O, the orthoclase tended to replace a larger part of the plagioclase and to become more abundant as interstitial material in the groundmass. In the Nimrod sodic granite orthoclase makes up a large part of the interstitial material and forms intergrowths with plagioclase in the margins of the plagioclase grains. It is regarded as a late magmatic mineral. A similar orthoclasization, described by Gillson,[20] occurred at Pioche, Nev., where a primary gabbro has been changed to a rock of quartz monzonitic character. The alteration is ascribed by Gillson to reaction with potash-bearing emanations from below during the magmatic stage. Orthoclasization is also thought to have occurred in the solid rock locally. Hypersthene is more susceptible to alteration than augite and changes to uralite or chlorite. Uralite also appears to be a late magmatic mineral. The other alteration minerals are largely hydrothermal, but there was overlapping of processes and minerals produced by very late magmatic solutions, contact-metamorphic solutions, vein solutions, and supergene solutions from pyritized or otherwise mineralized rock.

Comparisons with Other Groups of Rocks.

Both chemically and mineralogically the intrusive rocks of the Western Cascades of Oregon accord very well with other rocks of the Pacific petrographic province in which they are located geographically. The variation diagram (Fig. 6) compares the Tertiary intrusive rocks of the Cascade Range with Tertiary intrusives of Utah and Washington and Mesozoic intrusives of the Sierra Nevada. The "smoothed" curves are based on seven analyses of the Oregon rocks (small circles) made for the writers, on 12 analyses of the Utah rocks, and 42 analyses of the Sierra Nevada rocks, largely from Washington's[21] tables.

This diagram shows that the granodiorite of the Snoqualmie batholith in the Cascade Range of Washington, which is probably of about the same age as the Oregon rocks, is very similar to them chemically. It is higher in Al_2O_3 and lower in Fe_2O_3 than the Oregon rocks, but the relative proportions of the

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[20] Gillson, J. L.: Petrography of the Pioche district, Nevada: U. S. Geol. Survey Prof. Paper 158, pp. 79-86, 1929.

[21] Washington, H. S.: Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99, 1917.

alkalies are almost the same. The Oregon rocks are very similar to the Mesozoic intrusives of the Sierra Nevada,

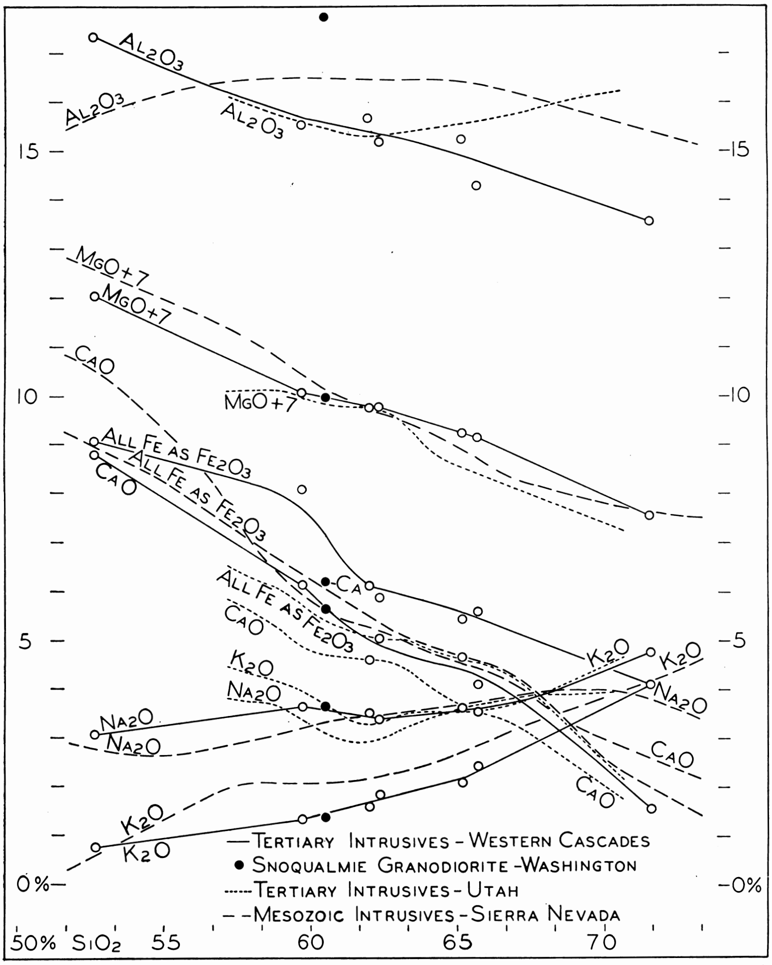

Fig. 6. Variation diagram of Tertiary intrusive rocks of the Western Cascades of Oregon, early Tertiary intrusives of Utah, and Mesozoic intrusives of the Sierra Nevada.

especially in the intermediate group (55 to 65 per cent SiO_2). The only marked differences are the relatively higher proportion of Al_2O_3 and slightly higher K_2O in the Mesozoic rocks and the higher proportion of Fe_2O_3 in the Cascade rocks. The

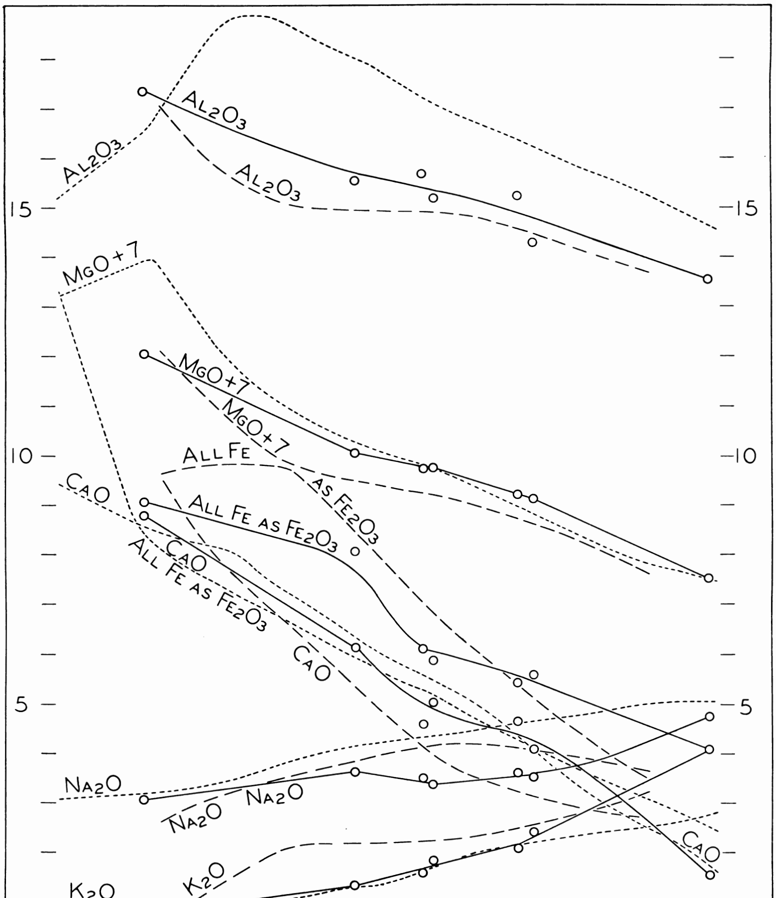

Fig. 7. Variation diagram of Tertiary intrusive rocks of Western Cascades of Oregon, associated lavas, and later lavas of the High Cascades.

alkali-lime index[22] of the Sierra Nevada rocks, deduced from this diagram, is 60.8, as against 61.6 for the Cascade intrusives. The Tertiary intrusive rocks of the Cascade Range differ

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[22] Peacock, M. A.: Classification of igneous rock series: Jour. Geology, vol. 39, pp. 54-67, 1931.

sharply from the Tertiary intrusive rocks of Utah. In the intermediate group the proportion of alkalies is much higher in the Utah rocks, and the relative quantities of K_2O and Na_2O are reversed. The iron oxides and CaO are lower in the Utah rocks. These comparisons show that the Tertiary intrusives of the Western Cascades are more closely related chemically to Mesozoic intrusives of the Pacific province than to Tertiary intrusives of the Utah region.

Another variation diagram (Fig. 7) was constructed in order to compare the dioritic intrusive rocks of the Western Cascades with the lavas of the Western Cascades and of the High Cascades. The diagram is based upon six analyses of rocks of the Western Cascades[23] and 22 analyses of lavas and pumice of the High Cascades,[24] 15 of them from the Crater Lake area. The volcanic rocks of the High Cascades differ from those of the Western Cascades in having a higher proportion of Al_2O_3 and lower Fe_2O_3. The relative proportions of Fe_2O_3 and CaO are reversed in the intermediate group (55 to 65 per cent SiO_2). The alkali-lime index of the lavas of the Western Cascades is 59, as against 61.3 for those of the High Cascades. In most of the differences the intrusive rocks more closely resemble the associated rocks of the Western Cascades than those of the High Cascades, but this does not necessarily demonstrate that they are also related in age and source.

CONTACT-METAMORPHIC ROCKS.

General Features.

Aureoles of contact or thermally metamorphosed country rock occur around all the dioritic intrusive bodies. In a few places metamorphic rocks were found without an adjacent outcrop of intrusive rocks. The width of the zone in which the contact effects may be readily observed ranges from a few inches to over 2,000 feet (Fig. 2). The effects range

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[23] Callaghan, Eugene: Some features of the volcanic sequence in the Cascade Range in Oregon: Am. Geophys. Union Trans. 14th Ann. Meeting, p. 246, Nat. Research Council, 1933.

[24] Hague, Arnold, and Iddings, J. P.: Notes on the volcanoes of northern California, Oregon, and Washington Territory: This Journal, 3d ser., vol. 26, p. 225, 1883. Washington, H. S.: op. cit. Williams, Howel: Mount Thielsen, a dissected Cascade volcano: California Univ., Dept. Geol. Sci., Bull., vol. 23, p. 212, 1933. Callaghan, Eugene: op. cit., p. 248. Moore, B. N.: Deposits of possible nuée ardente origin in the Crater Lake region, Ore.: Jour. Geology, vol. 42, pp. 262-263, 1934.

from the development of spots of new minerals, or of disseminated pyrite in an otherwise normal flow or tuff to complete reconstitution and obliteration of original structures and minerals. No evidence of simple melting or vitrification was observed. All the effects appear to have been brought about by solutions emanating from the intrusive aided by the heat supplied by that body. The principal effect was silicification, which was accompanied by the formation of one or more of the minerals, tourmaline, sericite, albite, epidote, chlorite, specular hematite, magnetite, and pyrite. In some places the rocks are bleached, particularly in the tourmalinized zones, but in most places they are dark gray or black and have a flinty appearance. The term "hornfels" is used for these rocks, and varieties are qualified by the names of characteristic metamorphic minerals.

Various structures and textures occur in the contact rocks. They are mostly very fine-grained, compact, and flinty in appearance. Quartz commonly occurs as a fine-grained aggregate, but coarse quartz with terminal faces lines cavities in tourmaline hornfels in the North Santiam district. Tourmaline lines fractures, as shown in Fig. 8, or occurs in rosettes or spherulitic masses as much as an inch in diameter. Veinlets of magnetite occur very near the contact at the north end of the stock (A, Fig. 2) in the Bohemia district. Nodules of contact minerals are common in flows and tuffs that are only slightly metamorphosed and otherwise retain their original appearance. Nodules of chlorite and magnetite, some of the latter in a peculiar hour-glass structure, occur in tuff in the North Santiam district. Nodules of friable specularite surrounded by epidote occur in tuff in the Blue River district. Some nodules in andesite in the Bohemia district consist chiefly of epidote with a little albite, hematite, and magnetite. No shear structures were observed.

PETROGRAPHY.

Tourmaline hornfels.—The tourmaline hornfels is regarded as representing the most intense effect of contact metamorphism. It occurs in the Bohemia district along the Cross vein above the Champion mill (about halfway between localities F and G, Fig. 2) and in masses as much as 40 feet in width on the northeast side of the intrusive at the Champion mine (G, Fig. 2). It occurs in the valley of the Little North

Santiam River near Stony Creek, in the North Santiam district, and near the head of Galena Creek, in the southern part of the Quartzville district.

The rock (Fig. 8) consists of angular black masses of tourmaline 0.1 to 2 cm. in diameter in a dense white groundmass of microcrystalline quartz. Most of the tourmaline aggregates are from 1 to 4 mm. in diameter. As a rule they consist of a mat of black tourmaline needles (schorlite) associated with a little cherty quartz. Some of the tourmaline aggregates have a growth of tourmaline needles on the surface. In places there are spherulites of tourmaline. The individual grains of quartz average less than 0.01 mm. in diameter. They have

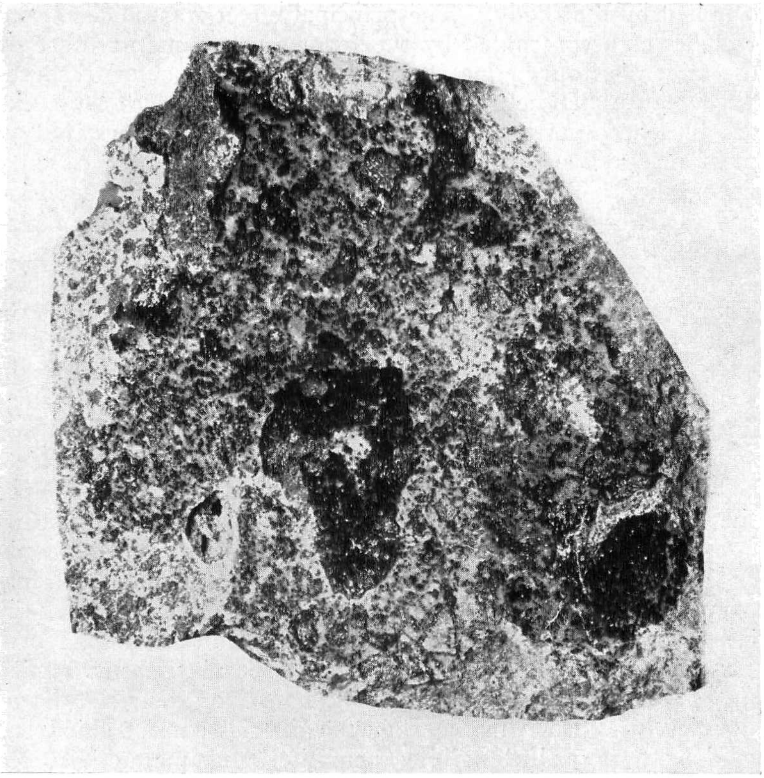

Fig. 8. Contact-metamorphic tourmaline hornfels from Champion mine, Bohemia district (north side of G, fig. 2). Dark areas of tourmaline in matrix of very fine grained quartz. Natural size.

sutured boundaries, lack definite boundary lines, and for the most part have wavy extinction. In places the quartz shows a microconcretionary or microcolloform structure. A few small angular aggregates of quartz have a slightly coarser (0.03 mm.) texture and in places contain a few sheafs of tourmaline. A little pyrite occurs here and there and is later than the tourmaline.

A rhyolite (Fig. 9) from the Champion road near Helena No. 2 camp (east side of F, Fig. 2) shows partial replacement by tourmaline which has worked outward from intersecting fractures that are lined with cherty quartz. Complete replacement followed by brecciation and emplacement of quartz would produce a rock having the appearance of that described above. Selective replacement of a tuff would also produce the brecciated appearance.

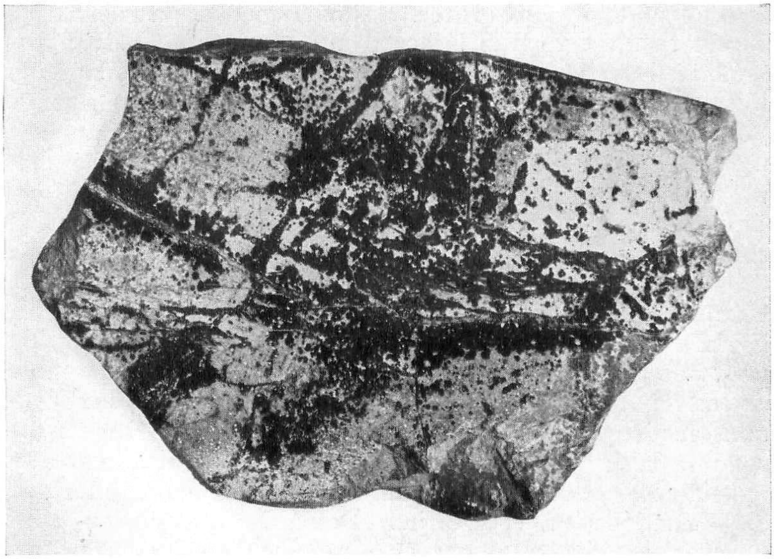

Fig. 9. Rhyolite partly replaced by tourmaline along a network of fractures. Cherty quartz forms thin facings of fractures. Bohemia district. Reduced one-fourth.

Epidote-tourmaline hornfels.—The epidote-tourmaline hornfels occurs at the Champion mine (north side of G, Fig. 2), in the Bohemia district, and at the Crown mine in the North Santiam district. It is a contact-metamorphosed greenish tuff containing knots of the metamorphic minerals and disseminated titaniferous magnetite, chlorite, epidote, and sericite. The nodules are 2 to 4 mm. in diameter and consist of epidote with black tourmaline in the center. In one specimen pyrite occurs in the outer zone of the nodule and is followed successively toward the center by chlorite, sericite, epidote, and tourmaline. Fractures are lined with epidote or less commonly with magnetite. Pyrite was found to occur along the center of one magnetite veinlet. A few pyrite nodules occur.

Another facies of hornfels is similar to that just described, except that the rock is bleached and contains abundant disseminated pyrite accompanied by sericite. Some fractures in this rock are lined with a colorless magnesium tourmaline (dravite), and nodules of the same minerals occur. The needles of dravite appear to have formed as a result of alteration of schorlite.

Tourmaline-specularite-sericite hornfels.—The hornfels characterized by tourmaline, specularite, and sericite occurs in the Bohemia district on the Champion road southwest of the Champion mill (north of the west end of the intrusive at G, Fig. 2). It consists chiefly of quartz and sericite and varying proportions of the original magmatic minerals. In the more extensively metamorphosed part the rock is bleached and contains moderately abundantly tourmaline knots. In a shear zone the rock is almost completely altered to sericite and contains a few nodules of tourmaline and numerous nodules and disseminations of specularite. Fractures are dusted with specularite plates, which appear to be later than the tourmaline. Pyrite is disseminated through the rock and fills fractures as well.

Epidote-chlorite hornfels.—The most common rock in the outer part of the aureole of contact metamorphisms, particularly that in the Bohemia district (Fig. 2), is epidote-chlorite hornfels. It is particularly well exposed along the Champion road northwest of the stock (A, Fig. 2). The greater part of the rock retains its original magmatic minerals with comparatively little alteration but contains nodules of epidote and chlorite with centers of magnetite or pyrite. The minerals of the nodules are extremely fine-grained. Some contain orthoclase or albite, possibly some more calcic plagioclase, and quartz. The nodules range from an eighth of an inch to an inch in diameter, but they are predominantly small. The outermost zone contains nodules of pyrite with a little chlorite.

Siliceous hornfels.—The term "siliceous hornfels" is used to include flinty medium- or dark-gray rocks that occur at the contacts of many of the small intrusives and are in many places only a few feet wide. They consist chiefly of varying amounts of quartz and remnants of magmatic minerals. They generally contain sericite and disseminated pyrite. Magnetite occurs in some of them.

METAMORPHIC PROCESSES.

In general, the intensity of contact metamorphism is a function of distance from the outcrop of the intrusive body. However, this is not entirely true, as a glance at the map of the Bohemia district (Fig. 2) will show. Some of the most thoroughly metamorphosed rocks occur between the stock (A, Fig. 2) and the dike (G, Fig. 2). Furthermore, some of the highly metamorphosed rocks occur in veinlike masses at a distance from the known outcrop of intrusive rock, and in a few places they are followed by quartz-sulphide veins.[25] They suggest a connecting link between the high-temperature contact metamorphism and the lower-temperature veins. More significantly, perhaps, they indicate that the changes were effected by hot solutions rather than by direct heat from the magma.

The formation of such highly metamorphosed yet extremely fine-grained rocks as the tourmaline hornfels may be interpreted as resulting from the chemical activity of solutions that rose rapidly at high temperature along a favorable fractured zone. As these rocks were probably formed within 2,000 feet of the surface, the resultant low pressure and initial high temperature of the solutions would warrant the surmise that their formation was in part accomplished by precipitation through distillation, in part by pneumatolysis, and in part by quick chilling through contact and reaction with relatively cold country rock. The coarser quartz of the sulphide veins was probably formed after the country rocks were already warmed up, by solutions at a lower temperature and not subject to so sharp a change in temperature or so sudden precipitation.

The combination of tourmaline and fine-grained quartz or jasperoid has been noted in other areas. The Dartmoor gran-

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[25] Buddington, A. F.: High-temperature mineral associations at shallow to moderate depths: Econ. Geology, vol. 30, pp. 219-221, 1935.

ite[26] in places has been moderately tourmalinized under conditions favorable to the genesis of opal or chalcedony, which subsequently transformed to quartz. It seems probable that the cherty quartz of the tourmaline hornfels in the Cascade Range may have been originally deposited in colloidal form also. Gilluly[27] has observed in the southern portion of the Oquirrh Mountains, Utah, hornfelses of contact-metamorphic origin adjacent to small intrusive bodies, and widespread jasperoid bodies replacing limestone along fissures and bedding surfaces without direct relations to exposed masses. These jasperoid masses he interprets as formed by deposition of colloidal silica, accompanied by tourmaline, apatite, zircon, and calcite.

REGIONAL ALTERATION.

The volcanic rocks of the Western Cascades are altered in many areas far beyond the zones of obvious contact metamorphism. Tuffs are greenish, rhyolites are altered almost everywhere, and the intermediate andesites commonly contain chlorite, sericite, epidote, and carbonate. The more calcic rocks are less altered in most places and are generally fairly fresh outside the mining districts or mineralized areas.

The most common minerals developed in these rocks are carbonate, zeolites, chlorite, clay minerals, quartz, pyrite, sericite, and epidote. The zeolites, probably chiefly thomsonite and stilbite, occur along the western part of the Western Cascades, particularly in the lower part of the valley of the McKenzie River. The other minerals may be found almost anywhere in the Western Cascades. Epidote seems to be largely restricted to areas that contain dioritic intrusive rocks.

In a broad way there are several processes by which these minerals could be formed. Some could be formed at the time of volcanic extrusion, either by contact of hot rocks with bodies of water or wet soil, or by reactions within the hot rocks with escaping gases. There might be solfataric action during volcanism. Alteration subsequent to volcanism would be brought about by the heat and fluids escaping from intrusive bodies aided by a general rise in the geothermal gradient over

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[26] Brammall, A., and Harwood, H. F.: The temperature range of formation for tourmaline, rutile, brookite, and anatase in the Dartmoor granite: Mineralog. Mag., vol. 36, pp. 216-217, 1927.

[27] Gilluly, James: Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 97-101, 1932.

a large area. A slightly later process is that which accompanied the emplacement of the quartz-sulphide vein minerals. Zones of altered rocks similar to those in the mining districts and having in many places the usual trends of the veins occur outside the mining districts. Finally, there are the supergene effects of weathering and the oxidation of sulphide minerals, chiefly pyrite, which releases sulphuric acid, a very effective agent in alteration.

It seems probable that the greater part of this regional alteration took place immediately after the emplacement of the intrusive rocks, which was accompanied by a rise in the geothermal gradient over a very large area. It may be regarded as a widespread contact metamorphism, but it grades imperceptibly into the alteration that accompanied the formation of the veins. Smith and Calkins[28] noted similar conditions in the Snoqualmie area and arrived at the same conclusion as to processes involved.

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[28] Smith, G. O., and Calkins, F. C.: U. S. Geol. Survey Geol. Atlas, Snoqualmie folio No. 139, p. 10, 1906.

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