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Department of Conservation and Development
JACK V. ROGERS, Director

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SHELDON L. GLOVER, Supervisor

Report of Investigations
No. 17

PERLITE

AND OTHER VOLCANIC GLASS OCCURRENCES IN WASHINGTON

By
MARSHALL T. HUNTTING

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FOREWORD

The desirability of investigating the perlite resources of Washington became increasingly evident during the past two or three years as interest mounted in this industrial material. Perlite itself is not new, but its use in industry is a recent development that has, with excellent reason, attracted widespread attention. Although one or two brief references to perlite in Washington may be found in geologic literature, and a small number of rock samples that proved upon investigation to be perlite had been found in the state, no information was available on occurrences. In fact, only one example of the material had been described as to location, and for this deposit nothing was known of physical characteristics or whether a minable amount existed. The investigation, therefore, was begun as a prospecting project to ascertain whether perlite could be included among the industrial mineral resources of the state.

The results obtained were disappointing, despite the fact that some fourteen occurrences were found. Apparently, the geologic conditions that gave rise to the extensive Oregon deposits were not duplicated in Washington. Here the rock occurs in relatively small amount and, in general, its expandability is not the equal of ordinarily acceptable industrial material. It is believed, however, that this report, giving, as it does, information on occurrences of various other glassy rocks as well as those that are perlitic, is a useful contribution to the available literature on the industrial minerals of Washington.

SHELDON L. GLOVER, Supervisor,
Division of Mines and Geology.

June 1, 1949.

PERLITE AND OTHER VOLCANIC GLASS OCCURRENCES IN WASHINGTON

By MARSHALL T. HUNTTING

INTRODUCTION

Perlite was recognized in Washington at least as long ago as 1901, when a deposit at Wenatchee was noted by two geologists[1] of the United States Geological Survey, but it was not until many years later that the rock was considered to be of more than only scientific interest. Recent developments, however, have proved expanded perlite to have useful qualities which give it considerable value as a material of commerce. Its light weight and its excellent heat insulating and sound deadening properties in particular are responsible for its rapidly increasing demand in the building trades. It was only natural that the current interest in pumice as a building material would lead to a demand for perlite, since perlite has many of the same uses and in some respects is far superior to pumice. Pumice occurrences in Washington are described in detail by Carithers,[2] but perlite in the State has been referred to only very briefly in the literature.[3][4] No Washington perlite deposit has been developed commercially; however, some of the deposits described in this report may have future commercial value, and other deposits not now known undoubtedly will be found. Most of the known perlite occurring in Washington is perlitic vitrophyre; it is unlikely that this can be used in competition with higher grade perlite until there are developed low-cost methods of separating the non-expandable crystalline material from the perlitic glass.

FIELD WORK

The field work for this report was done intermittently through the summer and fall of 1947, and in January and August 1948. Previous to the time of the field work only one occurrence of perlite in the state was known to the Division of Mines and Geology, but the existence of other deposits was suspected.

A rock and mineral identification service has been maintained by the Division and its predecessor agencies for many years, and

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[1] Smith, G. O., and Calkins, F. C., A geological reconnaissance across the Cascade Range near the forty-ninth parallel: U. S. Geol. Survey Bull. 235, pp. 31, 55-57, 1904.

[2] Carithers, Ward, Pumice and pumicite occurrences of Washington: Washington Div. Mines and Geology Rept. Inv. 15, 78 pp., 1946.

[3] Smith, G. O., and Calkins, F. C., op. cit.

[4] Chappell, W. M., Geology of the Wenatchee quadrangle, Washington: Univ. Washington Doctor's Thesis (unpublished), pp. 123-129, 1936.

since 1927 a record has been kept of all samples examined. Upon checking through this record, 7 samples of perlite and 24 samples of other volcanic glasses from the state were found to have been sent in for identification. Tracing these samples back to their senders and then back to the deposits from which they came consumed a large part of the time spent in the field. Two of the perlite occurrences and several of the other volcanic glass occurrences were found in this manner.

Field examination of the deposits was largely of a reconnaissance nature, the purpose being to discover those deposits which might yield perlite in commercial quantities. Thirty samples from twenty-four deposits were collected for laboratory examination. Preliminary tests on these indicated the need for additional study of larger samples, consequently a 500-pound sample from one deposit and a 900-pound sample from another were taken to a commercial perlite-expanding plant for further testing.

More detailed examination of the areas adjacent to the deposits herein described and further prospecting of the rhyolite- and andesite-covered areas in the state should disclose more and possibly better deposits than are now known.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the wholehearted cooperation of property owners and interested parties. Among those especially deserving of mention are Mr. J. J. Keegan, who supplied a large sample for pilot-plant testing; and Mr. Garfield Olsen, General Manager, Mr. Thomas Ildstad, Logging Superintendent, and members of the engineering staff, White River Lumber Co., who furnished maps, gave valuable field assistance, and supplied a large sample for pilot-plant testing. For information about several volcanic glass occurrences, the writer is indebted to Mr. A. M. Ritchie, Geologist, State of Washington Department of Highways.

Thanks are due Mr. F. W. Libbey, Director, Oregon Department of Geology and Mineral Industries, and to members of his staff, for cooperation and valuable suggestions during the early part of the investigation. Special mention should be made of the cordial and generous assistance contributed by Mr. Elko Zoradi, General Manager, Dantore Products Division, Dant and Russell, Inc., and by Mr. Paul Schmidt, Plant Superintendent of this Company, who interrupted operation of their commercial perlite-expanding plant at St. Helens, Oregon, to make pilot plant-scale tests on the large samples. Laboratory equipment of the University of Washington School of Mineral Engineering was generously made available for preparing the two samples for the pilot-plant tests. The U. S. Bureau of Mines Northwest Experiment Station, Seattle, kindly furnished a chemical analysis of one of the perlites.

The writer is indebted to Mr. Sheldon L. Glover, Supervisor, Division of Mines and Geology, for counsel and aid in the preparation of this report.

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PERLITE

GENERAL DESCRIPTION

Definitions of perlite vary widely, some writers using structure only as the defining feature, others combining structure and chemical composition, and still others using combined water as the distinguishing characteristic. For the purposes of this report, the least restrictive definition will be used: Perlite is a volcanic glass having a concentric, shelly structure and usually a notable percentage of water. Obsidian, pitchstone, and basaltic glass are other varieties of volcanic glasses; and vitrophyre, pumice, pumicite, and some tuffs are rocks which are predominantly volcanic glass.

The color of perlite is commonly in shades of gray to black but ranges through shades of green, brown, and red. The distinctive perlitic structure is the result of shrinkage cracks formed during solidification and cooling of the glass. The cracks, which may be either microscopic or visible to the unaided eye, result in onion-

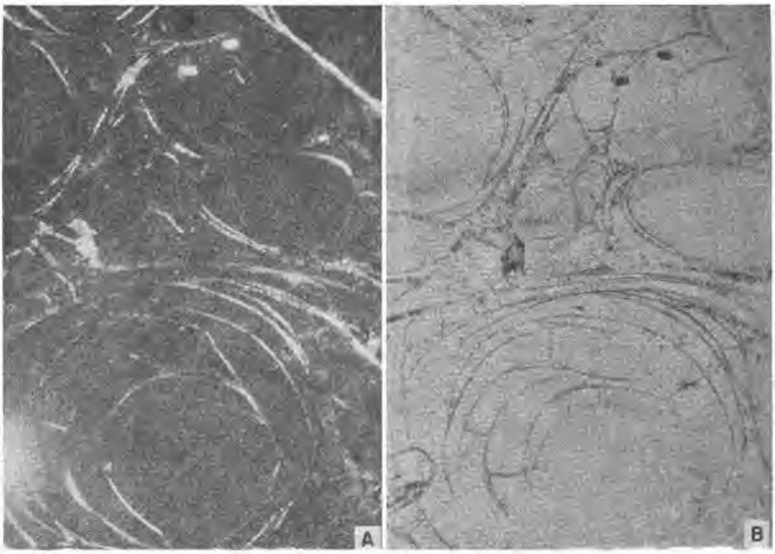

FIGURE 1.—Photomicrographs showing perlite structure in perlite from Divide deposit, White River area. (X 50) A. Crossed nicols. B. Plane polarized light.

like, concentric shells or "pearls" (fig. 1, above), and less commonly splintery or granular textures. Specific gravity ranges from 2.23 to 2.39 and averages 2.346, and index of refraction ranges from 1.488 to 1.506, the average being 1.497.[1] Perlite is commonly rhyolitic in composition, but andesitic and dacitic perlites are not uncommon. It contains from 2 to 5 percent of combined water, about 3 percent being the average. Combined water, expressed in analyses as H_2O+, is that which is driven off at above 110° C. Pitchstone has 5 to 10 percent combined water, and obsidian and basaltic glass generally have less than 1 percent.

[1] George, W. O., The relation of the physical properties of natural glasses to their chemical composition: Jour. Geology, vol. 32, no. 5, p. 368, 1924.

Analyses of crystalline volcanic rocks and their glassy equivalents

	Crystalline volcanic rocks				Glassy volcanic rocks							
	Rhyolite	Dacite	Andesite	Basalt	Perlite	Perlite, rhyolitic	Perlite, dacitic	Perlite, andesitic	Obsidian	Pitchstone	Basaltic glass	Basaltic glass
	A	B	C	D	E	F	G	H	I	J	K	L
SiO_2	72.62	66.91	59.59	49.06	72.71	74.73	69.56	65.13	73.84	70.19	51.78	50.10
Al_2O_3	13.77	16.62	17.31	15.70	11.81	10.82	15.65	15.73	13.00	12.37	16.10	15.62
Fe_2O_3	1.29	2.44	3.33	5.38	2.37	2.46	1.24	2.24	1.82	1.45	4.68	1.54
FeO	0.90	1.33	3.13	6.37		0.58	0.91	1.86	0.79	0.81	7.50	12.07
MgO	0.38	1.22	2.75	6.17	0.36	0.20	0.82	1.49	0.49	0.91	5.00	3.34
CaO	1.43	3.27	5.80	8.95	1.63	0.80	2.52	3.62	1.52	1.43	7.64	8.92
Na_2O	3.55	4.13	3.58	3.11	n.d.	2.68	4.09	2.93	3.82	3.03	3.79	2.40
K_2O	4.09	2.50	2.04	1.52	n.d.	4.40	2.19	3.96	3.92	3.57	1.51	1.94
H_2O-	1.53	1.13	1.26	1.62	5.27	0.27	n.d.	0.52	0.53	6.48	n.d.	1.70
H_2O+						2.94	2.92	1.91			1.22	
TiO_2	0.25	0.33	0.77	1.36	n.d.	0.12	n.d.	0.58	0.14	0.07	1.13	1.63
MnO	0.12	0.04	0.18	0.31	n d.	0.03	n.d.	tr.	0.07	0.02	0.16	0.54
P_2O_5	0.07	0.08	0.26	0.45	n.d.	0.12	0.13	0.23	0.01	0.03	0.26	0.05
NiO	....	....	....	....	....	....	....	0.07	....	....	....	....
FeS_2	....	....	....	....	....	....	....	....	0.02	....	....	....
Total	100.00	100.00	100.00	100.00	94.14	100.15	100.03	100.27	99.97	100.36	100.00	99.85

A. Rhyolite, average of 64 analyses. Daly, R. A., Average composition of igneous rock types: Am. Acad. Arts Sci. Proc., vol. 45, no. 7, p. 219, 1910.
B. Dacite, average of 30 analyses. Daly, R. A., idem, p. 223.
C. Andesite, average of 87 analyses. Daly, R. A., idem, p. 223.
D. Basalt, average of 198 analyses. Daly, R. A., idem, p. 224.
E. Perlite, Washington State, average of 5 analyses. This report, pp. 35, 48.
F. Perlite, rhyolitic, New Zealand. Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99, p. 73, 1917.
G. Perlite, dacitic, Colombia. Washington, H. S., idem, p. 231.
H. Perlite, andesitic, Eureka, Nevada. Hague, Arnold, Geology of the Eureka district, Nevada: U. S. Geol. Survey Monograph 20, p. 264, 1892.
I. Obsidian, average of 41 analyses. Johannsen, Albert, A descriptive petrography of the igneous rocks, vol. 2, p. 278, 1932.
J. Pitchstone, average of 18 analyses. Johannsen, Albert, idem, p. 281.
K. Basaltic glass, average of 8 analyses. Washington, H. S., op. cit.
L. Basaltic glass, Washington State, average of 2 analyses. Peacock, M. A., and Fuller, R. E., Chlorophaeite, sideromelane, and palagonite from the Columbia River Plateau: Am. Mineralogist, vol. 13, no. 7, pp. 363, 371. See also this report, pp. 70, 74.

THERMAL EXPANSION

When heated rapidly to about 1,700° F. (930° C.), perlite "pops," or suddenly expands, to a cellular glass which is equivalent to naturally produced pumice. Rapid heating to its softening temperature (incipient fusion) allows the glass to expand by intumescence, but slow heating releases the combined water by decrepitation, without any appreciable expansion of most glasses. The optimum expansion temperatures for various glasses vary with their water content and also with their content of silica, the alkalies, lime, iron, alumina, and other constituents; the temperatures ranging between the approximate limits of 1,400° and 2,200° F. Depending upon the composition of the original material and conditions under which it is expanded, perlite will increase in volume to as much as 10 times or more, specimens from Nevada being reported[1] to expand 30 to 1. The expanded material weighs from 2 to 20 pounds per cubic foot. For most commercial uses perlite which has been expanded to 6 or 7 times its original volume and weighs 10 to 12 pounds per cubic foot is most satisfactory. An early report by Kôzu[2] of thermal-expansion experiments on volcanic glasses from Japan showed that, at least under the conditions of those experiments, not only perlite but obsidian, pitchstone, and basaltic glass also can be made to expand explosively at high temperatures. United States Bureau of Mines investigators[3] found that the water in perlite in excess of about 1.2 percent is loosely held and easily removable, and they concluded that probably only the more firmly held water content below 1.2 percent is effective in the expansion of perlite upon heating.

It has been noted that water content of the volcanic glasses is not the only factor which governs their thermal expansion. Page[4] found that some glasses having less than 2 percent moisture expand nearly twice as much as others with nearly 4 percent. However, under different heating conditions his results might have been very different or even reversed. It is possible, also, that fluids other than water may be in solution with the volcanic glasses and be responsible, in part at least, for their rapid expansion at high temperatures. Gas and liquid bubbles of microscopic size are common as inclusions in rock-forming minerals, the most abundant gas being hydrogen,[5,6]

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① Hastings, E. F., Perlite: Arizona Dept. Min. Resources, p. 17, 1947.

② Kôzu, S., Thermal studies of obsidian, pitchstone, and perlite from Japan: Tôhoku Imp. Univ. Sci. Repts., vol. 3, no. 3, pp. 225-238, 1929.

③ King, E. G., Todd, S. S., and Kelley, K. K., Perlite: Thermal data and energy required for expansion: U. S. Bur. Mines Rept. Inv. 4394, p. 13, 1948.

④ Page, C. E., Pres., Volcalite Co., El Monte, Calif., personal communication, 1947.

⑤ Prof. Tildon, Royal Soc. London Proc., vol. 59, p. 223, 1896, and vol. 60, p. 453, 1897.

⑥ Chamberlain, R. T., Contributions to cosmogony and the fundamental problems of geology; the gases in rocks: Carnegie Inst. Wash. Pub. no. 106, 80 pp., 1908.

followed by carbon dioxide, then carbon monoxide. The most abundant liquid in the inclusions is water,[1] in many cases associated with dissolved salts and gases. Carbon dioxide may be in solution in water or may occur alone as a liquid. Although fluids in inclusions are not abundant in perlite, it is entirely possible that the same fluids may be present in a combined state. Barus[2] has demonstrated that ordinary soft glass will take up a large volume of water when heated with water to a high temperature in a closed bomb and cooled under pressure. This glass, with its dissolved water, when heated in air swelled enormously, lost water, and formed a pumice-like product, thus illustrating experimentally what may be the conditions under which perlite is formed in nature.

The following is quoted from King: [3]

> Perlite is a rock, not a mineral, and therefore is variable in chemical composition within a wide range. Composition of separate deposits differ, and there is variation even within the same deposit. These variations in chemical composition strongly affect the softening point or viscosity at a given temperature, the type and degree of expansion, the size of the bubbles, the wall thickness between bubbles, and the porosity of the resulting product, as well as other physical properties of the expanded material. To date, very little fundamental research has been concluded upon these and other important variables affecting the control of the processing of perlite. The most that can be said at this time is that, in general, a perlite rock containing more than 74 percent silica, more than 12 percent alumina, less than 5 percent combined alkalis (sodium and potassium oxides) and less than 2 percent total water, will usually require over 2000° fahrenheit expansion temperature and a relatively long time (on the order of many seconds rather than fractions of a second) in the hot zone, and will tend to yield a relatively heavy but structurally strong and minutely vesicular product. Likewise, a perlite in the range of 70 percent silica, less than 14 percent alumina, more than 8 percent combined alkalis, with appreciable calcium, iron, and manganese oxides (3 or 4 percent combined), and with more than 3 percent total water, will usually expand in a temperature range between 1300° and 1700° fahrenheit. It will also tend to yield a relatively lightweight coarsely vesicular and friable product, and will require a relatively short time contact at maximum temperature (a fraction of a second to a second or two).
>
> The foregoing rough variations in silica, alumina, alkali, and water content represent the practical range in analyses of expanding obsidians. Higher silica plus alumina and lower alkali content obsidians are too viscous at practical furnace temperatures to expand properly. More basic glasses (silica content much lower than 70 percent, and higher alkali, lime, magnesia, and iron content than the above range) are too fluid near the softening point to retain the bubbles of expanding gas, and result in a product too coarsely vesicular.

[1] Giekie, A., Textbook of geology, vol. 1, p. 143, London, MacMillan Co., 1903.
[2] Barus, Carl, Am. Jour. Sci., 4th Ser., vol. 9, p. 161, 1900.
[3] King, C. R., Pumice and perlite as industrial materials in California: California Jour. Mines and Geology, vol. 44, no. 3, pp. 311-312, 1948.

One of the most important variables in raw perlite is the amount and type of contained water or gas. The force which causes a cellular structure in expanded perlite is expansion of contained water vapor or other gas. The effect of contained water upon viscosity at elevated temperatures is marked. Some expanding obsidians contain less than 0.2 percent total ignition loss (including water) but will expand satisfactorily at furnace temperatures above 2200° fahrenheit. The expanding agent in some of these cases may be gases other than water vapor, but not necessarily so. Even 0.1 percent of combined water is theoretically ample to give several hundred percent volumetric expansion at about 2000° fahrenheit. Little is known about the physical or chemical state of the water in obsidians. Some of it is undoubtedly loosely bound or in simple solution. Some of it is tightly bound in chemical combination, and probably some of it is not in the rock in the form of water at all, but in the form of an acid radical. Until careful thermal analyses of obsidians are made, no real understanding of these problems is possible.

ORIGIN

The experimental work of Barus,[1] combined with the observed field relations at the perlite deposits in Washington and other states indicates that perlite has formed where siliceous water-bearing magmas have cooled rapidly under pressure. In order for such a magma to have cooled rapidly it must have been at or near the surface, but if it cooled rapidly as a surface flow at atmospheric pressure probably most of the dissolved water would have been lost and pumice would have been the product. Thus, by elimination, the most favorable places geologically for perlite to form would be in near-surface volcanic necks, feeder dikes, and sills. Allen[2] describes perlite overlying water-laid tuff beds near a volcanic plug at the Lady Frances mine in eastern Oregon and states that this relationship is common among perlite deposits elsewhere. The stratigraphic relationships and the silicification and alteration of the volcanic breccia and portions of the perlite suggest to him that the extrusions may have occurred beneath lakes of considerable depth. Such an origin would have supplied the rapid cooling and the necessary pressure for perlite to form, and the interaction of hot lava and the surrounding waters may have been responsible for the silicification and alteration of the perlite and adjacent rocks.

The viscous lavas of acidic and intermediate composition are most favorable for the formation of glass, thus most perlite has the composition of rhyolite, but dacitic and andesitic perlites are not uncommon. The table on page 12 gives analyses of several perlites and other volcanic glasses as well as some volcanic flow-rocks. Un-

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① Barus, Carl, op. cit., p. 161.

② Allen, J. E., Perlite deposits near the Deschutes River, southern Wasco County, Oregon: Oregon Dept. Geol. and Min. Ind. Short Paper 16, p. 9, 1946.

fortunately, the more basic lava, basalt, which is so widespread in Washington, is rarely perlitic. A further limitation is imposed by the fact that volcanic glasses readily alter to rocks which do not have the expansion qualities of fresh perlite. As a consequence, little perlite older than Tertiary is known. Volcanic glass alters by devitrification to minutely crystalline rock with microfelsitic or microspherulitic texture. This devitrification, according to Johannsen,[1] results from pressure applied to glassy rock. The crystals are more stable under pressure than is their glassy equivalent, because they occupy less volume and have higher specific gravity than the glass. A second variety of alteration to which perlite appears to be unusually susceptible gives bentonitic clay as a product. This clay-mineral development generally is accompanied by silicification, which produces agate-filled nodules ("thunder eggs") and irregular seams and masses of chalcedony.

AIDS TO PROSPECTORS

Perlite is of volcanic origin, so obviously prospecting should be limited to areas where volcanic rocks are exposed. These rocks are abundant and widely distributed over the entire state, as shown by the geologic map of Washington;[2] however, most of those mapped are basalts and so are unfavorable to the occurrence of perlite. This rules out nearly the whole southeastern quarter of the state and the area south and west of Puget Sound. Some of the volcanic rocks in the northern row of counties in eastern Washington are rhyolites and andesites and may be found to have perlitic phases, but most of these rocks are too old geologically to be likely sources of perlite. Lavas of acidic and intermediate composition extruded during Tertiary to Recent times are found mostly in the Cascade Mountains and their foothills. The area underlain by these rocks is outlined on the map (fig. 2) on page 17. The prospector should be on the lookout for the vents or feeder dikes through which acidic lavas rose, since most perlite deposits occur either in or immediately adjacent to these features. The frequent close association of tuff and agglomerate with perlite suggests the advisability of examining rather carefully areas in which these rocks are known, if other conditions are favorable. The hobbyists who collect agates and similar rocks and minerals for polishing have long prized the eastern

[1] Johannsen, Albert, A descriptive petrography of the igneous rocks, vol. 1, p. 9, University of Chicago Press, 1939.

[2] Culver, H. E., The geology of Washington, pt. 1, General features of Washington geology—with accompanying preliminary geologic map of the state: Washington Div. Geology Bull. 32, 1936.

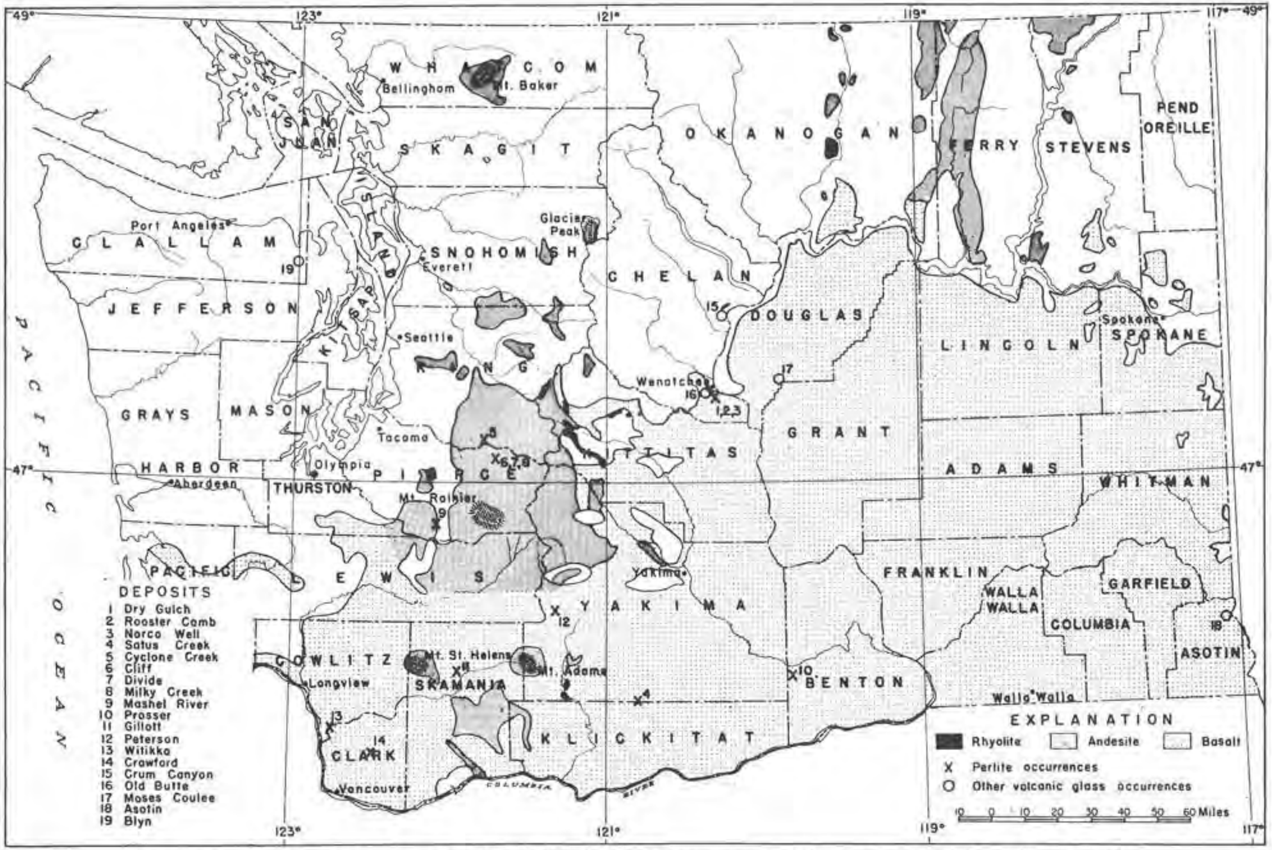

FIGURE 2.—Map of Washington showing volcanic glass occurrences and areas covered by volcanic rocks.

Oregon colorful geodes and agate-filled nodules, known commonly as "thunder eggs," and it has been noted[1] that these are almost invariably associated with perlite. This association was the basis for the suggestion that hobbyists use perlite outcrops as clues in their search for thunder eggs. Conversely, the prospector looking for perlite should watch for geodes and quartz-filled nodules (see fig. 3) in acidic lavas as a favorable indication of perlite occurrence.

FIGURE 3.—Nodules in andesite. Some of the nodules are hollow and some are filled with chalcedony.

UTILIZATION

Expanded perlite is a comparatively new product entering a highly competitive field in which several other mineral products are already established, but because of marked advantages it has already partially replaced some of the competing materials and is supplementing others.

Perlite rock as mined is being used at present only after being crushed to sand-size and heat-expanded to lightweight, frothy glass particles, but unexpanded perlite may prove to be suitable also as raw material for mineral-wool production, for ceramic glazes, and for other purposes. To date the chief use for expanded perlite is as aggregate for building plaster, where its light weight is a distinct advantage over ordinary plaster sand, and its ease of application is an advantage over exfoliated vermiculite, which is similarly used. The applied perlite plaster is superior in that it has a high modulus of elasticity and is resistant to cracking, the plaster will take nails without chipping, its light weight allows savings in reinforcing steel

[1] Agates with perlite: The Mineralogist, vol. 15, no. 12, p. 640, 1947.

in large buildings, it is a thermal insulant, and it has acoustical properties otherwise obtainable only by special installation for that express purpose.

Perlite is sold as ready-mixed acoustical plaster, for which use it is admirably suited, and at least one plant is experimentally producing acoustical tile using perlite as its chief constituent. Other uses for perlite in the building trades are as aggregate for monolithic concrete work, for building blocks using portland cement or other binders, for wallboard panels, and for mortar. Perlite aggregate weighing 6 to 16 pounds per cubic foot gives concrete weighing 40 to 65 pounds per cubic foot, as compared with pumice aggregate weighing 30 to 60 pounds per cubic foot giving concrete weighing 60 to 90 pounds per cubic foot, and with ordinary sand and gravel aggregate weighing 90 to 130 pounds per cubic foot giving concrete weighing 130 to 150 pounds per cubic foot.

Perlite is well suited for loose-fill insulation. It is inert, does not draw water from the air, does not deteriorate when damp, does not settle, is easily handled, and has a low thermal conductivity (K) factor.[1] Its K factor ranges from 0.20 for perlite weighing 2½ pounds per cubic foot to 0.56 for 13-pound material. This compares with K factors of 0.5 to 1.0 for pumice, 0.26 to 0.4 for mineral wool, and 0.4 to 0.5 for wood shavings.

Perlite is used as a rooting medium for cuttings and young plants in nurseries, and may be useful as a soil conditioner to lighten clay soils. It could be used in the field of hydroponics to make beds in which dilute water solutions of plant foods are used to raise garden flowers and vegetables without the use of soil.

The absorbent qualities of perlite make it suitable for cleaning oily floors and for use as chicken-house litter. Fine or crushed perlite is used as an abrasive and polishing agent. Other uses are as molding sand, filter aids, and as fillers.

There is a wide range in the thermal conductivities, bulk specific gravities, size gradations, and mechanical strengths of expanded perlites; and the uses to which any given perlite may be put depend upon those variables. The physical properties of expanded perlite depend not only upon the method of processing but also upon the properties of the raw material. The bibliography on page 9 gives references to detailed reports on uses, physical property tests, and processing techniques.

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[1] K = thermal conductivity in British thermal units transmitted per hour through 1 square foot of material, per inch of thickness, at a temperature gradient of 1° F.

TESTS

An effort was made to develop simple laboratory tests which would indicate whether or not a given specimen of perlite when heated would expand to produce a salable product. In order for this testing program to be complete it would be necessary to supplement the laboratory tests with additional tests on larger samples of the same rocks, made in commercial-size perlite-expanding furnaces. As large-scale tests were made on samples from only two deposits, any evaluation of the laboratory tests must be made largely on a theoretical basis. This is not undesirable though, as identical laboratory-test results will be evaluated differently by various people. For example, one investigator[1] found that perlite containing about 4 per cent combined water (expressed in rock analyses as H_2O+) produced the most satisfactory expanded product; whereas another investigator[2] found that some rocks containing less than 2 percent combined water gave almost double the expansion of perlite having 4 percent combined water; and a third investigator[3] found that, at least under laboratory conditions, some obsidians having less than one-half of 1 percent combined water, and even some basaltic glasses, when heated would expand to many times their original volumes. Similarly, laboratory-test results given in the table on pages 26 and 27 show that three of the volcanic glasses from Washington, although containing less than one-half of 1 percent combined water, expanded under laboratory test conditions as well as or better than most of the perlites, which varied from 1¼ percent to 6 percent combined water.

For the purpose of this report, 30 rock samples were tested in the Division of Mines and Geology laboratory, the results appearing in the table on pages 26 and 27; and 2 large samples were tested in a commercial perlite-expanding furnace described on page 36. Results of 7 chemical analyses made by other laboratories are recorded on pages 35, 48, 70, and 74. Laboratory tests were made on 16 perlite samples, 10 samples of non-perlitic volcanic glasses, and 4 samples of igneous rocks other than glasses. Characteristics determined by laboratory tests and recorded in the table on pages 26 and 27 include:

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[1] Dantore Products Division, Dant and Russell, Inc., in Allen, J. E., Perlite deposits near the Deschutes River, southern Wasco County, Oregon: Oregon Dept. Geol. and Min. Ind. Short Paper 16, p. 12, 1946.

[2] Page, C. E., Pres., Volcalite Co., El Monte, Calif., Personal communication, 1947.

[3] Kôzu, S., Thermal studies of obsidian, pitchstone, and perlite from Japan: Tôhoku Imp. Univ. Sci. Repts., vol. 3, no. 3, pp. 225-238, 1929.

1. Water content
   a. Hygroscopic water (H_2O-)
   b. Combined water (H_2O+)
2. Specific gravity
3. Index of refraction
4. Color of crushed fragments
5. Fused color
6. Slow-heating characteristics
   a. Expansion
   b. Degree of fusion
   c. Color after heating
7. Silica content
   a. By analysis
   b. Indicated by specific gravity
   c. Indicated by index of refraction
8. Expansion at 1,850° F.

WATER CONTENT

Loss on ignition, determined for each of the 30 samples, was reported as percent of water—a procedure which is accurate enough for this purpose, since carbon dioxide and other gases would be present in only very small quantities in these rocks. Ignition loss at 110° C. was recorded as H_2O-, and at 850° C. as H_2O+. The combined water (H_2O+) is of significance in determining the expansibility of a volcanic glass, as discussed on pages 13 and 15. Hygroscopic water (H_2O-) present in a rock in quantities greater than 1 percent may indicate alteration by weathering or hydrothermal solutions; however, this is not universally true. The hygroscopic water content of a volcanic glass does not appear to have much bearing upon its expansion qualities.

To determine the hygroscopic water, a weighed sample (about 0.6 gram) of rock, crushed and screened to minus 10 mesh-plus 100 mesh, was kept in a drying oven at 110° C. for 3 hours, then was cooled in a dessicator and weighed. The loss in weight was recorded as H_2O-. To determine combined water, the same sample was again heated for 3 hours in the furnace, this time at 850° C., then was cooled in a dessicator and weighed. The additional loss in weight was recorded as H_2O+.

For most of the perlite samples tested, hygroscopic water was less than 0.75 percent. The smallest percentage found was 0.04, in the Peterson sample, which contained a large amount of non-glassy rock; and 1.32, the largest percentage of hygroscopic water found in the perlites, was in the Norco sample, a rock which is strongly hydrothermally altered. The Asotin basaltic glass had 2.13 percent H_2O-, and it is also considerably altered. Combined water in the perlites ranged from 1.24 percent in the Peterson sample to 6.17 percent in the Mashel River perlite. Combined water in the nonperlitic glasses ranged from none in the Marshall sample to 8.41 percent in the Crum (1,b) sample. The Marshall rock is basaltic glass; it actually gained, rather than lost, weight when heated for 3 hours at 850° C. An analysis of a duplicate sample of the rock showed a similar anomalous result. A satisfactory explanation for this peculiar feature has not yet been offered.

In general, the glasses with high content of combined water have low indices of refraction and specific gravities, and those with low water content have high refractive indices and specific gravities.

Specific Gravity

The specific gravities of 29 samples were determined on a Jolly balance, and the values were found to range between 2.13 and 2.87. Figure 4 on page 23 shows a curve relating specific gravity to combined water content of the glasses. On the graph, several of the points do not closely fit the curve, but of the three points farthest from the curve, two represent samples which contain large amounts of glass which has altered to clay minerals and thereby do not have the specific gravity of fresh glass. The third erratic point represents the Satus perlite; this is very vesicular, so the specific gravity of the glass is undoubtedly considerably higher than that of the rock as a whole.

After studying a large number of natural glasses, George[1] found that several chemical constituents had definite relations to the specific gravity of the rocks. He found silica to have the widest range and greatest significance, followed by iron oxides, lime, magnesia, potash, and water. With increasing specific gravity, percentages of silica, potash, and water decrease, and percentages of iron oxides, lime, and magnesia increase. Tests of the Washington volcanic glasses confirm George's conclusions with respect to the relation of specific gravity to water content, in that those glasses with high specific gravity contain little combined water, and those with lower specific gravity have a higher water content. Too few of the rocks were chemically analyzed to relate the other chemical constituents to specific gravity.

[1] George, W. O., The relation of the physical properties of natural glasses to their chemical composition: Jour. Geology, vol. 32, no. 5, pp. 362-363, 1924.

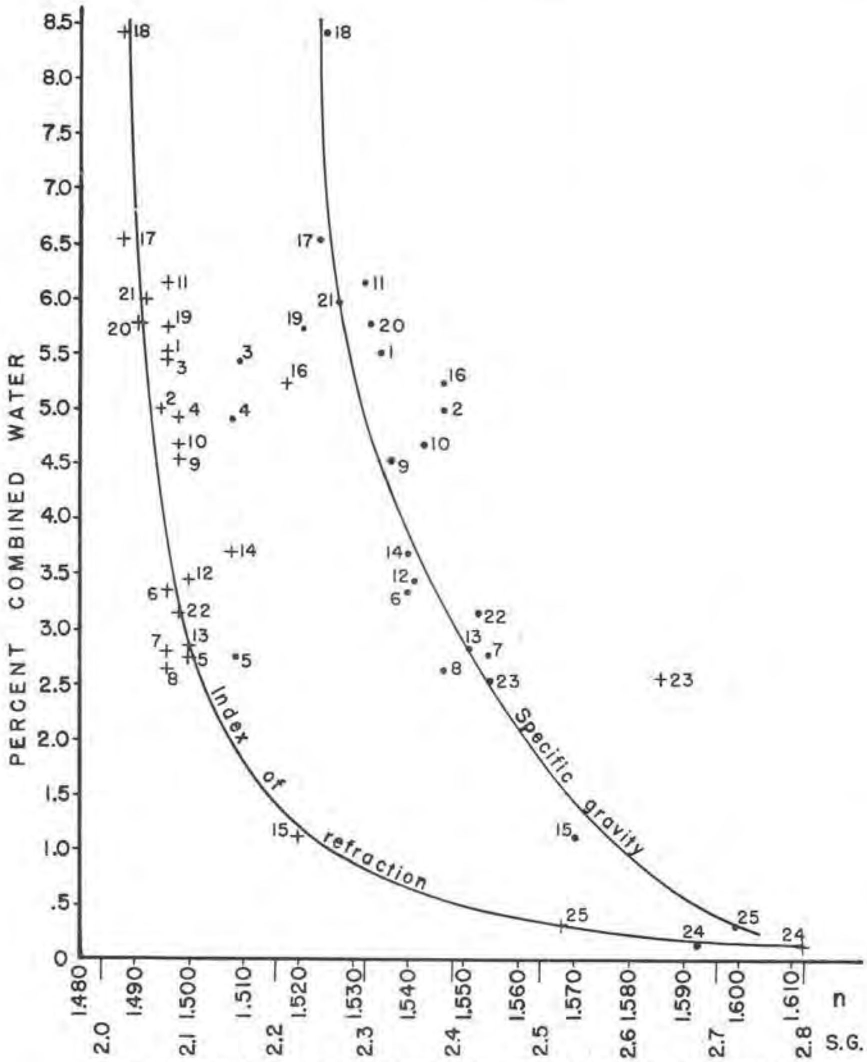

FIGURE 4.—Graph relating combined-water content of volcanic glasses to specific gravity and index of refraction.

Index of Refraction

Indices of refraction were determined with a petrographic microscope, using immersion oils, on crushed fragments of each of the 30 samples. Indices range from 1.488, for some of the Crum Canyon glass, to 1.612 for the Blyn basaltic glass. The Crum Canyon glass, having an index of 1.488, contained 8.41 percent combined water—the highest of all tested; and the Blyn glass, with an index of 1.612, contained only 0.16 percent combined water. This relationship between index of refraction and combined-water content holds for all the rocks tested except for two variants. These were the Asotin and Witikka samples, each of which has a higher index of refraction than its water content indicates. Figure 4, page 23, shows a curve relating index of refraction to combined-water content of Washington volcanic glasses.

George[1] concluded that the index of refraction of natural glass is closely related to the silica, iron oxide, magnesia, lime, and potash contents of the glass, and showed these relationships by curves. The curve relating silica to index of refraction is especially significant and has been widely quoted by various authors. For a discussion of this relationship as it applies to Washington volcanic glasses see page 27.

Color of Crushed Fragments

While crushed fragments of a volcanic glass were being examined under the microscope to determine the refractive index of the material, the color of the glass was noted and recorded in the table in the column headed "color of fragments." Most of the glasses are colorless when viewed as small fragments but may be quite dark colored in large masses. In general, the more acidic glasses are colorless, while the basaltic glasses are dark brown to opaque.

Fused Color

Some of the volcanic glasses may be suitable as raw material for mineral wool manufacture. Color of mineral wool ranges from white to black, white being in greatest demand. In order to determine the color which would result from use of various Washington volcanic glasses, 17 samples were fused with an ordinary welder's acetylene torch. Most of the samples fused to an opaque black color and would produce black mineral wool. A few samples fused to a mixture of colorless and black glass, which probably would give black mineral wool. The two samples of Crum Canyon glass which were

[1] George, W. O., op. cit., pp. 365-366.

tested gave a clear colorless glass and should produce white mineral wool. Some of the colorless glass appeared white because of abundant included bubbles.

Slow-Heating Characteristics

Samples of the glasses, crushed and screened to minus 10 mesh-plus 100 mesh, were placed in a laboratory electric muffle furnace at room temperature and slowly heated to 1,850° F. The furnace temperature at 30 minutes was 1,300° F., at 60 minutes 1,650° F., at 90 minutes 1,800° F., and at 120 minutes 1,850° F. The purpose of this test was to determine the amount of expansion, degree of fusion, and color resulting from a relatively slow temperature increase. Although most perlite expands or "pops" only when heated very rapidly, some of the glasses were found to expand considerably under the slow-heating conditions. The expansion is recorded as the ratio of the unexpanded to expanded volume of the rock. The figure 1.0 therefore indicates no expansion. The column headed "fusion" shows the amount of fusion noted at the end of the test. The fusion, in increasing order, is expressed by the terms: none, slight, little, moderate, much, and complete. This affords a rough measure of the temperatures necessary to melt the various glasses.

Silica Content

The silica content of glass influences the temperature at which it melts and its viscosity when molten. These and other factors affect the expansion characteristics of perlite and determine the furnace conditions necessary to produce commercially usable expanded perlite.

The table on pages 26 and 27 shows a comparison of the silica content of the Washington volcanic glasses as determined by analyses and as indicated by their measured specific gravities and indices of refraction using George's[1] curves. Chemical analyses made by the United States Bureau of Mines and a private laboratory are quoted on pages 35 and 48. For the five samples analyzed the silica content ranged between 68.06 and 81.34 percent. It has been proven by George[2] that the silica content of natural glass can be reliably estimated by measuring either the specific gravity or the index of refraction of the glass. His curve relating silica to specific gravity shows that glasses having specific gravities ranging from 2.1 to 3.0 will have silica contents from 75 to 45 percent respectively. Of the four Washington glasses which can be compared with this curve,

[1] George, W. O., op. cit., pp. 362, 365.
[2] George, W. O., op. cit., pp. 353-371.

Properties of Washington perlites and

Locality	Water content		Specific gravity	Index of refraction	Color of crushed fragments	Silica content percent		
	H_2O-	H_2O+				By analysis	By specific gravity	By refraction index
Perlite								
Dry Gulch (1)	0.64	5.52	2.32	1.496	colorless	....	71	73
Dry Gulch (2)	0.71	5.00	2.39	1.495	colorless	72.6	68	73
Rooster Comb	0.61	5.44	2.16	1.496	colorless	....	74	73
Norco Well	1.32	4.92	2.15	1.498	light brown	....	74	73
Satus Creek	0.34	2.74	2.13	1.500	colorless	....	74	72
Cyclone Creek (1)	0.27	3.36	2.35	1.496	colorless	81.34	69	73
Cyclone Creek (2)	0.24	2.79	2.44	1.496	colorless	....	66	73
Cyclone Creek (3)	0.35	2.66	2.39	1.496	colorless	....	68	73
Divide	0.23	4.56	2.33	1.498	brown	68.82	70	73
Milky Creek	0.45	4.09	2.37	1.498	colorless	72.74	69	73
Mashel River	0.67	6.17	2.30	1.496	colorless	....	71	73
Prosser (1)	0.10	3.47	2.36	1.500	dark brown	....	69	72
Prosser (2)	0.11	2.84	2.42	1.500	med. brown	....	67	72
Gillott	1.25	3.70	2.35	1.508	dark brown	....	69	69
Peterson	0.04	1.24	2.55	1.520	dark brown	....	60	63
Witikka	1.01	5.28	2.39	1.518	dark brown	....	68	63
Other volcanic glass								
Crum Canyon (1,a)	0.56	6.55	2.25	1.488	colorless	....	72	76
Crum Canyon (1,b)	0.73	8.41	2.26	1.488	colorless	....	72	76
Crum Canyon (3,a)	1.11	5.72	2.23	1.496	colorless	....	73	73
Crum Canyon (3,b)	1.06	5.78	2.31	1.491	colorless	....	71	75
Crum Canyon (4)	0.66	6.00	2.27	1.492	colorless	....	72	74
Old Butte (1)	1.52	3.16	2.43	1.498	light brown	....	67	73
Asotin	2.13	2.68	2.44	1.586	light brown	....	66	49
Blyn	0.42	0.16	2.67	1.612	med. brown	....	55	47
Hanmer	0.18	0.37	2.72	1.568	med. brown	....	53	52
Marshall	0.05	-0.47	2.87	1.610	med. brown	....	48	47
Other volcanic rock								
Old Butte (2)	1.84	0.40	2.46	....	....	....	65	....
Hyak	0.07	1.47	2.57	....	....	....	59	....
Randle	0.19	1.76	2.57	....	....	....	59	....
Ruth Creek	0.08	0.49	2.54	....	....	....	61	....

other volcanic glasses and rocks

Fused color	Slow-heating characteristics			Expanded volume ("popped" at 1,850° F.) ÷ unexpanded volume (average of 3 tests)						
	Expansion ratio 1:	Fusion	Color	15 sec.	30 sec.	1 min.	2 min.	3 min.	4 min.	No.
Perlite										
....	1.2	much	red	1.8	1.8	2.0	2.2	2.1	1.8	1
colorless, black........	1.4	much	red	1.6	1.9	2.1	2.1	2.1	2.1	2
....	1.4	much	red	2.4	2.7	3.0	2.6	2.6	2.5	3
....	1.0	none	yellow-brown	1.2	1.4	1.4	1.5	1.3	1.3	4
colorless, black........	1.0	none	brown	2.6	2.8	2.3	2.3	2.2	2.1	5
colorless, black........	1.0	none	red	1.4	1.4	1.5	1.6	1.5	1.5	6
....	1.0	slight	brown	1.5	1.5	1.6	1.5	1.6	1.6	7
....	1.1	slight	brown	1.4	1.5	1.5	1.5	1.5	1.4	8
colorless, black........	1.1	slight	brown	*1.1	1.2	1.3	1.3	1.3	1.1	9
....	1.2	none	brown	*1.1	1.3	1.3	1.3	1.1	1.2	10
colorless, black........	1.5	moderate	red	2.1	2.5	2.3	2.0	1.9	1.8	11
....	1.4	moderate	black	2.2	2.4	2.3	1.9	1.7	1.6	12
colorless, black........	1.1	much	black	*1.3	1.3	1.4	1.4	1.4	1.5	13
black....................	1.3	complete	red-brown	1.7	2.0	2.0	1.9	2.0	2.0	14
black....................	1.4	complete	red-brown	1.6	1.7	1.8	1.8	1.6	1.5	15
black....................	1.2	complete	black	1.4	1.5	1.5	1.3	1.3	1.2	16
Other volcanic glass										
....	1.0	none	white	1.3	1.4	1.5	1.4	1.4	1.5	17
colorless................	1.0	none	white	*1.3	1.3	1.3	1.3	1.4	1.4	18
....	1.0	little	white	1.5	1.6	1.6	1.6	1.6	1.5	19
....	1.0	none	white	1.6	1.8	1.8	1.7	1.7	1.7	20
colorless................	1.0	little	white	1.4	1.5	1.6	1.5	1.5	1.5	21
black....................	1.2	moderate	brown	*1.1	1.1	1.1	1.1	1.3	1.1	22
black....................	0.9	little	red	*1.0	1.0	0.9	1.0	1.0	1.0	23
....	1.4	moderate	red-brown	*1.9	2.0	1.8	1.9	2.1	1.9	24
black....................	1.6	moderate	black	*1.7	1.6	1.5	1.5	1.5	1.5	25
black....................	1.0	none	black	2.2	2.1	2.3	2.4	2.4	2.3	26
Other volcanic rock										
....	1.0	none	brown	*1.0	1.0	1.1	1.0	1.0	1.1	27
....	1.0	none	white	*1.0	1.0	1.0	1.0	1.1	1.1	28
black....................	1.1	none	black	*1.1	1.1	1.1	1.1	1.0	1.1	29
black....................	1.2	none	black	*1.1	1.1	1.1	1.1	1.1	1.1	30

* One test only.

three fall either on the curve or close to it, as can be seen by plotting the figures in the columns under the heading "silica content percent" on page 26. The fourth sample, from the Cyclone Creek deposit, has a specific gravity which indicates 69 percent silica, but the analysis shows 81.34 percent silica. This and other evidence indicate that the chemical analysis may be in error.

George's curve relating silica to index of refraction shows that glasses ranging in refractive index from 1.49 to 1.62 may be expected to contain from 75 to 47 percent silica, respectively. Of the four Washington perlites which can be compared with this curve, the actual silica contents of two correspond to within 1 percent of the value indicated by the curve. In the other two samples, the variation in one case is 3.18 percent and in the other, 9.34 percent. This last, large variation probably is the result of an erroneous chemical analysis.

Expansion at 1,850° F.

In an effort to develop a single test by which volcanic glass can be evaluated as a raw material for "popping" to make expanded perlite, 30 samples of volcanic rocks from Washington were introduced into a laboratory electric muffle furnace at 1,850° F. The conditions of the test were made to conform as closely as possible to those maintained in commercial perlite-expanding furnaces, but because so many of the latter conditions could not be duplicated, the results of the laboratory test could not be expected to duplicate commercial plant results. For example, a perlite which expanded to 7 times its original volume when treated in a commercial furnace expanded to only 2.4 times its original volume when treated in the laboratory furnace. The laboratory furnace-expansion test gives an indication, though, of which glasses warrant further testing.

The procedure used for the test was as follows: The sample was crushed and screened to minus 10 mesh-plus 100 mesh. A 30-milliliter porcelain Coors crucible was put in the muffle of a small electric furnace maintained at 1,850° F. (1,010° C.). After the crucible had come up to heat, the furnace door was opened, a measured volume (½ milliliter) of crushed rock was poured into the crucible, and the door was quickly closed. The sample was kept in the furnace a given length of time, then was cooled and its volume was measured. The increase in volume was recorded as the quotient of the expanded volume divided by the unexpanded volume. Separate samples from each deposit were tested in the furnace at 1,850° F. for 15 seconds, 30 seconds, 1, 2, 3, and 4 minutes, to determine the heating time necessary to obtain maximum expansion. The glass from the Hanmer deposit was tested also at 5 and 10 seconds, the maximum expansion being found at 10 seconds. Each test was run in triplicate (with the exception of those marked with an asterisk), and the quotients of volume increase recorded in the table on pages 26 and 27 are the average for the three tests.

OCCURRENCES

Wenatchee Area Occurrences

General Statement

Perlitic volcanic glass from two localities south of Wenatchee, Chelan County, was described in 1904 by Smith and Calkins,[1] and the same material was described in more detail in 1936 by Chappell.[2] The two deposits, here called the Dry Gulch and the Rooster Comb deposits, are within half a mile of each other, and both are near the northeastern end of the ridge between Dry Gulch and Squillchuck Canyon. The existence of a third occurrence was established early in 1934, when the Washington State Division of Geology discovered perlitic rhyolite in cuttings from the Norco No. 1 oil and gas test well then being drilled by the Northwest Oil Research Corporation on Wenatchee Heights, 1½ miles southeast of the Rooster Comb perlite deposit. Examination of the Wenatchee area by the writer in 1947 did not disclose further occurrences of perlite, but igneous rock having an unusually glassy groundmass was found at Old Butte, about 1¼ miles northwest of the Dry Gulch deposit. Topographically prominent crags at Squaw Saddle, ½ mile southeast of Old Butte, and at Castle Peak, 1 mile northwest of Old Butte, are made up of igneous rocks which Chappell[3] considered to be intrusive. Portions of these he found by thin section study to be more or less glassy. Thus, in the vicinity of Wenatchee there are three known occurrences of perlite, and at least three small masses of igneous rocks which have nonperlitic glassy phases.

Geography

The perlite deposits and the three igneous rock masses having nonperlitic glassy phases lie in a nearly straight line which trends N. 35° W. diagonally across the center of Township 22 North, Range 20 East. The town of Wenatchee is in the north-central part of the same township and is on the west bank of the Columbia River at an altitude of 750 feet. At Wenatchee the Columbia Valley floor rises gently in a width of 1½ miles from the river to the ends of several parallel ridges which separate northeastward-flowing small tributary streams. These ridges rise abruptly to an average altitude of 2,000 feet, or approximately 1,000 feet above the level of the adjacent

[1] Smith, G. O., and Calkins, F. C., A geological reconnaissance across the Cascade Range near the forty-ninth parallel: U. S. Geol. Survey Bull. 235, pp. 31, 55-56, 1904.

[2] Chappell, W. M., Geology of the Wenatchee quadrangle, Washington: Univ. Washington Doctor's Thesis (unpublished), pp. 123-129, 1936.

[3] Chappell, W. M., op. cit., pp. 123-129.

valley floor. The ridges and intervening streams and valleys, from southeast to northwest, are Stemilt Creek, Wenatchee Heights, Squillchuck Creek, Rooster Comb, Dry Gulch, Squaw Saddle and Old Butte, Canyon Number Two, Castle Peak, and Canyon Number One. The area is well served by graveled or paved roads. The area is devoid of timber, and water for mining or quarrying is not plentiful.

Geology

Rocks of four different formations cover the 25-square-mile area (fig. 5, p. 31) within which the Wenatchee perlite deposits occur. These include Swauk continental sedimentary rocks; Middle Eocene intrusive rhyolite, dacite, andesite, and basalt; Yakima basalt flows; and alluvium.

SWAUK FORMATION

The oldest rocks are those of the Swauk formation. This was regarded to be Eocene in age by F. H. Knowlton [Russell, 1900],[1] [Smith, 1904][2] on the basis of admittedly inadequate fossil evidence. Later work, as summarized by Lupher,[3] indicates that at least part of the formation may be Cretaceous. It includes moderately to well consolidated arkosic to highly quartzose sandstones, pebble conglomerates, and shales, all of continental origin. The beds are gently to moderately folded, dips being generally less than 60°. The axes of the folds trend northwestward. In several places the formation contains elongated zones, 100 feet or more wide, where secondary silica has been added by solutions probably originating in the magma that was responsible for the associated intrusive bodies. One of these silicified zones is prominently exposed in Rooster Comb ridge between Squillchuck Creek and Dry Gulch. This dike-like body, 200 to 800 feet thick, is Swauk sandstone thoroughly impregnated with secondary quartz and cut by a network of small quartz stringers. Original textures have been almost completely destroyed, thus giving rise to the names "rhyolite dike" or "aplite dike" commonly applied to the body.

EOCENE INTRUSIVES

Intruded into the Swauk formation are dikes, sills, necks, and possibly small laccoliths, the rocks of which range from basalt through andesite to dacite and rhyolite porphyry. These rocks are characteristically light colored and porphyritic, phenocrysts of

[1] Russell, I. C., Preliminary paper on the geology of the Cascade Mountains in northern Washington: U. S. Geol. Survey 20th Ann. Rept., pt. 2, p. 123, 1900.

[2] Smith, G. O., U. S. Geol. Survey Geol. Atlas, Mount Stuart folio (no. 106), p. 5, 1904.

[3] Lupher, R. L., Stratigraphic aspects of the Blewett-Cle Elum iron ore zone, Chelan and Kittitas Counties, Washington: Washington Div. Geology Rept. Inv. 11, p. 8, 1944.

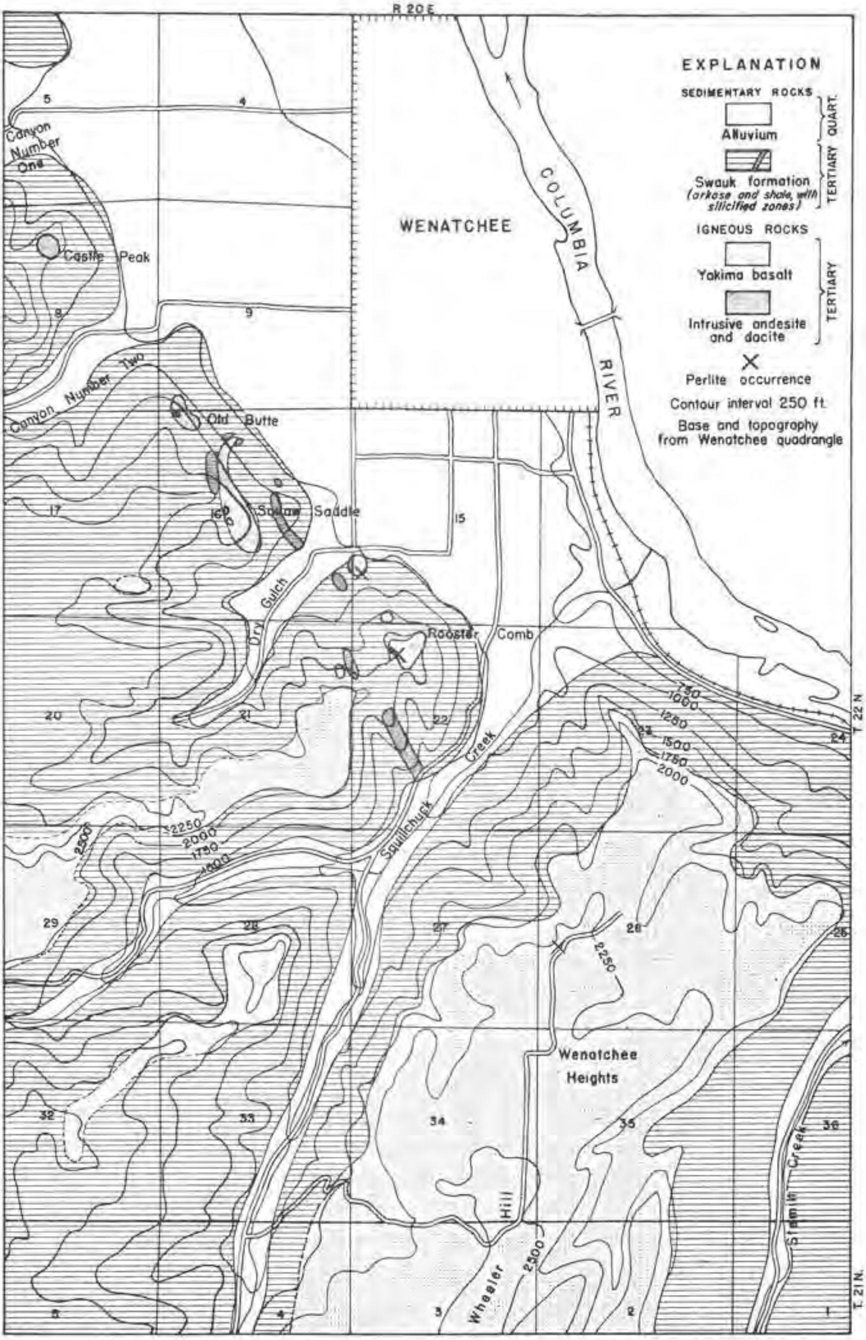

FIGURE 5.—Geologic map of the Wenatchee perlite area.

plagioclase feldspar and mafic minerals being abundant. The sills and dikes are less than 100 feet thick and are exposed for lengths as much as ½ mile. They are basaltic in composition, so are too basic to be probable sources of perlite; consequently they were examined only cursorily by the writer. The larger intrusive bodies may include both laccoliths and necks or feeders for surface lava flows, but the flows which they may have furnished are nowhere exposed. These bodies of igneous rock make up the unexposed mass encountered in the Norco well on Wenatchee Heights, the low domelike body at the mouth of Dry Gulch, and the rugged crags known as Castle Peak, Old Butte, Squaw Saddle, and Rooster Comb. Of these, the intrusive body forming Squaw Saddle is the largest, being 700 feet wide and ½ mile long. All the other bodies are less than 1,000 feet in their greatest exposed dimension. They all lie along or near the axis of a northwest-trending anticline in the Swauk beds. The rocks of the necks differ from those of the dikes and sills in that they are more acid in composition, have more-or-less glassy groundmass, and some have perlitic glass phases. They are andesite, rhyolite, and dacite porphyry. At Squaw Saddle the rock is severely hydrothermally altered; it is also altered, but to a lesser extent, at Old Butte and at the Norco well; but elsewhere the rock is only slightly altered.

The intrusive rocks are younger than the Lower Eocene or Cretaceous Swauk formation and older than the overlying Yakima basalt. Chappell[①] concluded that they were of Middle Eocene age.

YAKIMA BASALT

The Yakima basalt, of Miocene age, unconformably overlies the Swauk and intrusive rocks as essentially flat flows. The only known perlite occurrence overlain by basalt in this area is the one encountered in the Norco well on Wenatchee Heights, where the basalt is 336 feet thick. Elsewhere in the mapped area the basalt is lacking or ranges from a few feet to 600 feet in thickness.

ALLUVIUM

Recent alluvium floors the broad valley of the Columbia River and its narrow tributary valleys. Most of the hills in the area are thinly covered by soil.

Dry Gulch

Blue-gray perlite is exposed on the south side of a dome-shaped hill which rises 150 feet above valley level at the place where Dry Gulch opens out into the Columbia Valley. The dome is at the south end of Miller Street, at the toe of the slope which rises to form the

① Chappell, W. M., op. cit.

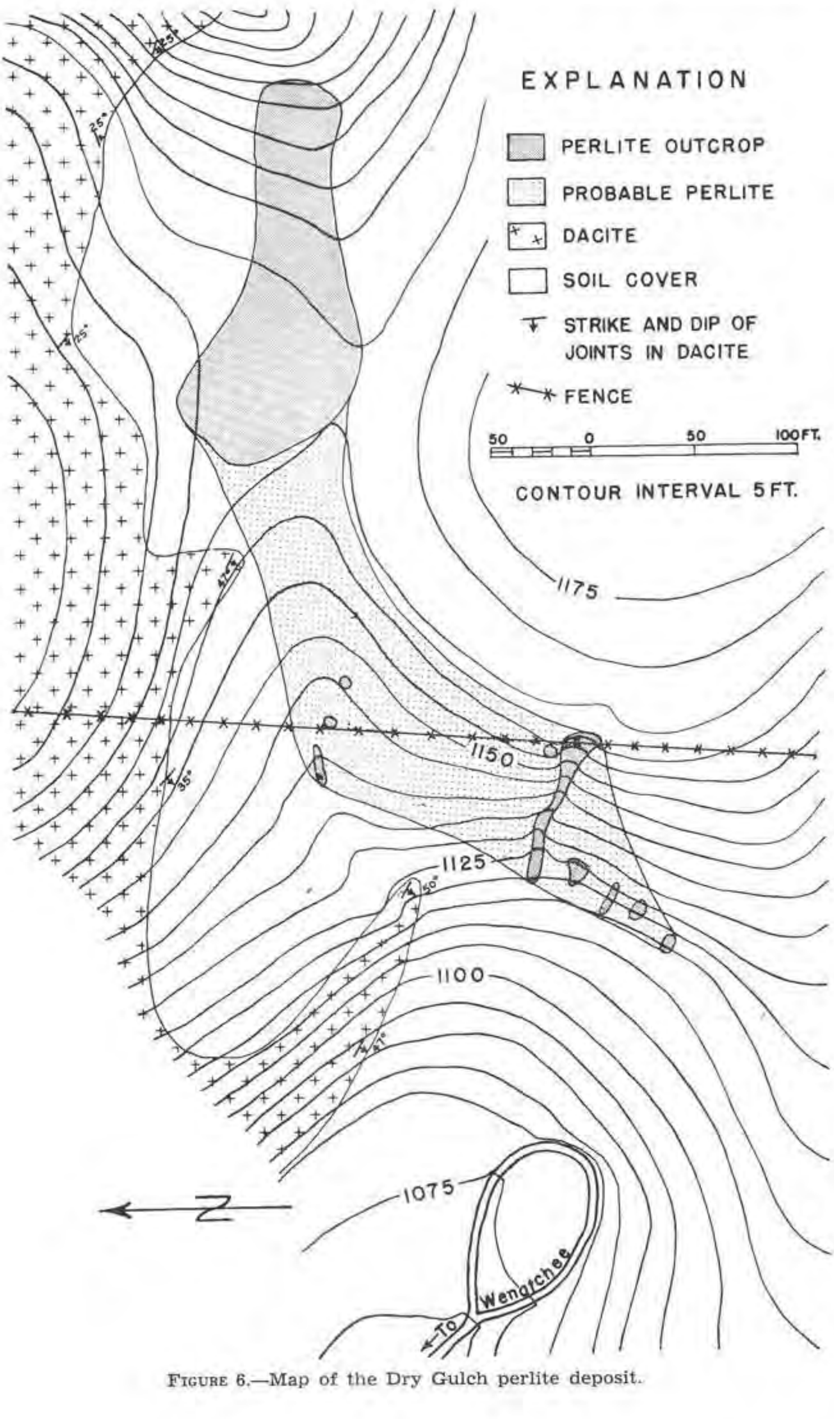

FIGURE 6.—Map of the Dry Gulch perlite deposit.

divide between Dry Gulch and Squillchuck Creek. The line between secs. 15 and 16, (22-20E)[1] cuts across the western tip of the deposit, leaving a small portion in the NE¼SE¼SE¼ sec. 16 and the rest in the NW¼SW¼SW¼ sec. 15. The part in sec. 16 is owned by J. J. Keegan of Wenatchee, and the mineral rights on the part in sec. 15 are leased by Keegan from the owner.

In the saddle between the dome and the hill which rises to the southeast to Rooster Comb ridge, perlite is naturally exposed over an area 40 to 70 feet wide and 175 feet long (fig. 6, p. 33). Other natural exposures and a series of shallow open cuts extend 300 feet farther southwestward, showing a maximum width of 75 feet of perlite. The altitude at the lowest exposure is 1,113 feet and at the highest, 1,172 feet, a difference of 59 feet. Soil a few inches to 2 feet thick covers more than half of the area presumed to be underlain by perlite. Although the deposit is fairly well exposed there is little to indicate the actual shape and attitude of the perlite body, but its relationship to the adjacent dome-like body of dacite porphyry suggests that it is tabular and dips perhaps 20° to the southeast. Assuming this to be true, the thickness of the body is about 20 feet. However, faint banding in the perlite at the west end of the deposit strikes N. 45° E. and dips 70° SE., which indicates a much steeper dip and consequently greater thickness, approximately 50 feet. In either case, the indicated tonnage above the level of the lowest exposure is on the order of 75,000 tons, but the steeper dip would be much more favorable for quarry operation. A few shallow drill holes properly placed should disclose the actual dip and thickness of the body.

The rock in the dome-like body of which the perlite is a border phase has been variously called soda-rhyolite and dacite porphyry. It has a pronounced lamination roughly parallel to the surfaces of the dome, causing it to separate into thin, rough slabs of light-colored rock. It is porphyritic and contains quartz, feldspar, and a few biotite crystals in a dense groundmass.

Smith and Calkins[2] report that a thin section showed both the quartz and feldspars to be extremely corroded. The feldspar crystals show very irregular outlines and have abundant glass inclusions. They are all plagioclase, and some are identified as albite. On the basis of the phenocrysts, the rock is named soda-rhyolite. A more detailed petrographic report on the rock of the Dry Gulch intrusive body is made by Chappell,[3] who calls it biotite-dacite porphyry.

[1] Township 22 North, Range 20 East, W. M.

[2] Smith, G. O., and Calkins, F. C., A geological reconnaissance across the Cascade Range near the forty-ninth parallel: U. S. Geol. Survey Bull. 235, p. 56, 1904.

[3] Chappell, W. M., op. cit., pp. 123-129.

He describes a thin section of the perlite which is adjacent to the southeast margin of the intrusive body as being largely glass which has the characteristic perlitic cracks and contains numerous aligned longulites and a few globulites. He finds phenocrysts of clear quartz and plagioclase (An_{27}) make up less than 10 percent of the rock, and the remainder is glass, the index of refraction of which is 1.495.

In a thin section of the perlite examined by the writer many of the phenocrysts are completely crushed, and they make up nearly 20 percent of the rock rather than the previously reported 10 percent. Hornblende and biotite occur sparingly as phenocrysts.

A partial analysis and test results supplied by the owner show that the perlite contains 0.56 percent moisture, and 5.14 percent combined water, and has an expanded weight of 35.8 pounds per cubic foot.

Analysis of Dry Gulch perlite
by courtesy of the
United States Bureau of Mines, Northwest Experiment Station, Seattle.

Ignition loss, 1,000° C.	4.3
SiO_2	72.6
Fe_2O_3	1.5
Al_2O_3	13.2
TiO_2	0.3
CaO	1.1
MgO	0.1
K_2O, Na_2O (by difference)	6.9
Total	100.0

In order to test the expansion qualities of the perlite on a pilot-plant scale, a representative sample was taken across the 75-foot width of the deposit near its western end. After crushing, screening to pass 10 mesh screen, and drying, the sample weighed 815 pounds and had a volume of 10.7 cubic feet. A screen analysis of this sample is given below.

Screen analysis of crushed perlite

U. S. standard screen mesh	Percent (by weight) retained on screen
10	0.0
30	57.5
80	32.5
100	2.9
pan	7.1
	100.0

The sample was run through the perlite expansion furnace of Dantore Products Division, Dant and Russell, Inc., at St. Helens, Oregon. This expansion plant is described by Allen[1] as follows:

> At the St. Helens pilot plant, the perlite is expanded in a 4- by 8-foot specially designed kiln,[2] fired by four gas burners to temperatures ranging from 1,500° to 2,500° F. The sized perlite is raised by a small 20-foot bucket elevator to a 3- by 4-foot storage cone, and is fed into the kiln, which rotates at 8 r.p.m., above and about 1 foot ahead of the burners. The system operates at a vacuum of from .4 to .8 inches of water, this being maintained by an automatically regulated steam jet directed upwards in the exhaust stack. The expanded perlite is drawn from the furnace into a downdraft box where the coarse material is removed; thence into a cyclone six feet in diameter, where the fines are collected, thence into a 10-foot cyclone which catches any remaining dust.

The plant produces two end products—fine and coarse expanded perlite—which may be saved. Since the above description was written the plant has been altered so that the raw perlite is first dried in a rotary gas-fired kiln before going to the expansion kiln. During the run in which the Dry Gulch perlite was tested, the furnace was operated at 1,750° F. (950° C.).

Results of the pilot-plant test of the Dry Gulch perlite indicate the material not to be of commercial quality, at least not under the conditions of the test. Only 56 percent by weight of the material which entered the furnace was recovered in the sacker at the end of the plant. The other 44 percent was lost, partially by accumulation on the inner surfaces of the furnace and cyclones, and partially by passing out the exhaust stack. Presumably this loss would be somewhat lower on long continuous runs, but so large a loss on even a short run indicates that either the raw perlite had poor expansion qualities or the optimum expansion conditions for this particular material were not maintained in the furnace. Probably both factors contributed to the loss.

Of the expanded perlite produced, the percentage of fines was unduly large, being 21 percent by volume and 23 percent by weight. This may have been the result of the characteristics of the raw perlite or of improper plant operation for this material, and it certainly was aggravated by feeding into the furnace raw material from which all the fines had not been previously removed. It is important to the successful operation of the plant that there be no minus 100 mesh material in the feed, but the raw perlite for this test contained 7 percent of minus 100 mesh material, which for lack of facilities was not removed.

[1] Allen, J. E., Perlite deposits near the Deschutes River, southern Wasco County, Oregon: Oregon Dept. Geol. and Min. Industries G. M. I. Short Paper No. 16, pp. 10, 12, 1946.

[2] Patent applied for.

Fines produced in the expanded product of this test weighed 106½ pounds and had a volume of 3 cubic feet, which is an average of 35 pounds per cubic foot. Coarse expanded perlite produced weighed 349 pounds and had a volume of 11 cubic feet, which is an average of 32 pounds per cubic foot.

Screen analysis of expanded Dry Gulch perlite

U. S. standard screen mesh	Coarse Percent (by weight) retained on screen	Fine Percent (by weight) retained on screen
14	0.2	0.0
20	5.6	0.1
35	21.0	0.2
45	27.2	1.4
60	23.0	8.2
100	15.0	36.8
150	4.0	19.3
200	1.6	12.2
pan	2.4	21.8
	100.0	100.0

The expanded Dry Gulch perlite is light-buff colored, which is objectionable, as the buyers are being educated to demand pure-white material. The individual expanded grains are strong and not easily crushed—a point in their favor—but many grains are only slightly or not in the least expanded, which increases the weight of the product and detracts from its value. Visual and microscopic examination of the unexpanded Dry Gulch perlite disclose approximately 20 percent of nonexpandable material in the form of mineral grains. These mineral grains went through the plant and came out with the expanded perlite, adding considerably to its weight and contributing to its objectionable color.

Although the pilot-plant test indicates the Dry Gulch perlite to have poor expansion qualities, further testing might prove it to be usable. As a guide to further testing the following suggestions are submitted: (1) Remove the nonexpandable material from the raw perlite before it is put into the furnace, (2) remove the minus 100 mesh material from the raw perlite before it is tested, (3) test the perlite at various furnace temperatures, (4) allow the perlite to remain in the furnace for various lengths of time, and (5) test the perlite in furnaces of various designs.

Results of laboratory tests made on duplicate samples of Dry Gulch perlite are shown in the table on pages 26 and 27. The sample designated "Dry Gulch (1)" is a cut from the large sample tested in the commercial perlite expansion furnace, and the one designated "Dry

Gulch (2)" is an independent sample taken from the same part of the Dry Gulch deposit. The location from which the samples were taken is indicated on the map on page 33.

Rooster Comb

Blue-gray perlite similar to that of the Dry Gulch deposit occurs at the south edge of the crag known locally as the Rooster Comb. The crest of the crag is at the northeastern end of the divide between Dry Gulch and Squillchuck Creek, 1,953 feet in altitude, 1,000 feet above the level of the valley and the nearest road. Perlite is exposed naturally in an area only 8 feet square at an altitude of 1,900 feet, 100 feet southwest of the crest, and perlite also shows on the dump of a shallow caved open cut 1,750 feet in altitude, about 600 feet due south of the crest. Probably the perlite on the dump came from the open cut, but because of caving this is not definitely known. The natural exposure and the open cut are near the SE. corner of the NW¼NW¼ sec. 22, (22-20E). This location is just 0.5 mile in a S. 24° E. direction from the Dry Gulch perlite deposit and 750 feet higher in elevation. A thin mantle of soil effectively masks the relationships among the perlite, the dacite of Rooster Comb crag, and the intruded Swauk sedimentary rocks. Smith and Calkins[1] called the rock of Rooster Comb rhyolite, and considered it to be extrusive, but there is no clear evidence to indicate the rock to be extrusive, and its similarity to the undoubtedly intrusive Dry Gulch body makes more plausible an intrusive origin.

The perlite is bordered on the north and south by laminated, flow-brecciated dacite, but 50 feet southwest of the exposure is a thin vertical bed of Swauk conglomerate which trends N. 50° W., and 900 feet east of the exposure is an outcrop of Swauk sandstone which strikes N. 75° W. and dips 30° NE.

The perlite undoubtedly is a phase of the dacite which encloses it. Megascopically it is similar in every respect to that at Dry Gulch. Chappell[2] reported a thin section to be similar except for the presence of numerous microspherulites in the Rooster Comb rock. A thin section was made of the perlite from the dump of the open cut and showed this rock to be highly altered by silicification which started along the perlitic cracks and progressed outward until only about one-third of the rock was left as remnant cores of glass. The rounded glass cores are surrounded by secondary quartz, and abundant crushed grains of rounded quartz and corroded plagioclase and a few biotite flakes are scattered through the rock.

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[1] Smith, G. O., and Calkins, F. C., A geological reconnaissance across the Cascade Range near the forty-ninth parallel: U. S. Geol. Survey Bull. 235, p. 31, 1904.

[2] Chappell, W. M., Geology of the Wenatchee quadrangle, Washington: Univ. Washington Doctor's Thesis (unpublished), pp. 123-129, 1936.

Laboratory tests indicate that the perlite from the 8-foot exposure expands to greater volume than the perlite from Dry Gulch; in fact, the Rooster Comb perlite expanded better in the laboratory furnace than did any other Washington material tested.

Norco Well

Perlite was found in 1934 in cuttings from the Norco No. 1 well of the Northwest Oil Research Corporation of Wenatchee. The well was being drilled as a test for gas and/or oil near the center of the NW¼SW¼ sec. 26, (22-20E). The collar of the well is 2,300 feet in altitude, at the edge of the Wenatchee Heights plateau. Eight miles of paved road leads from the well down Squillchuck Valley to Wenatchee. The well is 1¾ miles southeast of the Rooster Comb perlite, and is in a direct line with the northwest-trending axis of the anticline in Swauk sandstone along which are the Dry Gulch and Rooster Comb perlite deposits and the igneous bodies of Squaw Saddle, Old Butte, and Castle Peak.

The well passed through 3 feet of soil, 336 feet of Yakima basalt, 339 feet of Swauk shale and sandstone, 256 feet of rhyolite (177 feet of which was perlitic), and then 3,969 additional feet of Swauk sandstone, shale, and conglomerate. The bottom of the well was still in the Swauk formation when drilling ceased. The following is a composite log of the well compiled from the driller's log and the Washington Division of Geology's description of cuttings:

Norco well log

Description	From (feet)	To (feet)
Clay	0	3
Basalt	3	339
Shale; some sandstone	339	475
Sandstone; some shale	475	678
Rhyolite porphyry, somewhat altered	678	711
Rhyolite, devitrified, perlitic	711	719
Rhyolite, altered, soft	719	738
Rhyolite porphyry, hard	738	762
Rhyolite	762	765
Rhyolite, altered, perlitic	765	787
Rhyolite, devitrified, perlitic	787	821
Rhyolite, perlitic	821	900
Rhyolite, perlitic; some sandstone	900	923
Rhyolite, perlitic; much sandstone	923	934
Tuff (?); little rhyolite	934	940
Sandstone	940	946
Sandstone and shale (possibly some tuff)	946	960
Sandstone	960	995
Sandstone, shale, conglomerate	995	4,903

As shown by the log the drill penetrated 8 feet of perlite near the top and 169 feet of perlite in the lower part of the 256-foot thick rhyolite body.

The form and structure of this igneous body is unknown. No rhyolite has been found cropping out in the vicinity of the well, but it might occur near the surface and be masked by a soil cover. If the rhyolite is a sill, as appears likely, it might be possible by means of a detailed structural study of the area to predict where an extension of the body could be expected to occur at or near the surface.

Thin sections of samples from depths of 715, 800, and 815 feet show the rock to be devitrified perlitic rhyolite in which 5 percent consists of phenocrysts of quartz and feldspars. More-or-less rounded quartz grains as much as 1 millimeter in diameter show corrosion borders, and angular grains of orthoclase and plagioclase are highly kaolinized. The whole rock shows considerable recrystallization or possibly cementation by silica.

Laboratory tests on samples of the drill cuttings from the depth interval of 830 to 880 feet do not show very encouraging results (see pages 26 and 27), but this may be due in part to dilution of the samples by cavings at the time of drilling.

Satus Creek Occurrence

Geography

A perlite specimen sent in September 1937 to the Division of Geology for identification was said by the sender to have been found at the head of the South Fork of Satus Creek, in north-central Klickitat County. The deposit, examined in 1947, is on the east bank of the stream at an altitude of 4,700 feet, in the SW¼ sec. 9, (6-16E). This is on the Yakima Indian Reservation about 1½ miles north of Indian Rock.

The occurrence may be reached from Toppenish via Satus Ranger Station by 19 miles of paved highway (U. S. 97), 20½ miles of very poor dirt road, and 2 miles of trail. Should the deposit be worked commercially a new road would be required, probably following down Satus Creek (eastward) for 9 miles to U. S. 97. From there, Goldendale, the nearest railroad connection, is 20 miles to the southwest. An alternate route, involving 5 miles of new construction, would be up Satus Creek and over the Simcoe Mountain divide, to connect with a county road which leads directly southward 12 miles to Goldendale.

The deposit is near the center of the Simcoe Mountains, but the topography is not especially rugged. The highest peaks are not over

6,000 feet in elevation, and the relief in general is less than 1,500 feet. Satus Creek has a gradient of about 55 feet per mile in its upper reaches. More than adequate supplies of timber and water are available for mine or quarry use.

Geology

The soil cover is so continuous that no rock is exposed within a quarter of a mile of the Satus Creek perlite exposure. As shown on the state geologic map,[1] more than 80 percent of the area within a 15-mile radius of the deposit is underlain by Miocene volcanic rock, which here is Yakima basalt. The remainder is covered by material mapped as Quaternary continental sediments. Not mapped but showing in cuts along the Goldendale-Toppenish highway in sec. 30, (5-17E) are red-stained quartzitic gravels, mentioned in reports by several writers, and described in greatest detail by Warren.[2] He used the name Hood River conglomerate, in conformity with the usage of Buwalda and Moore[3]. This is a deeply weathered, moderately well indurated fluvial conglomerate which rests conformably, or nearly so, on Yakima basalt and was deformed with the latter. It is contemporaneous with the Dalles and Ellensburg formations, which fact, combined with fossil evidence, dates the conglomerate as late Miocene or early Pliocene. Overlying the conglomerate is porphyritic basalt. Little is known of this rock, but a thin flow is exposed at the surface and in cuts along about a mile of the Goldendale-Toppenish highway about 8½ miles south of Satus Pass. Warren[4] mentions this rock and calls it andesite, stating that it overlies Hood River conglomerate in the area west of the conglomerate outcrops. Although the rock in the road cuts south of Satus Pass appears megascopically to be andesite and the large feldspar phenocrysts are andesine (An_{42}), most of the feldspar is present as small crystals in the ground mass of the rock and has the properties of labradorite (An_{62}), so the rock should be classified as basalt. This is also in accord with the observed abundance of olivine (some of which has altered to iddingsite) occurring as euhedral phenocrysts and as smaller irregular grains in the groundmass. This rock may be interbedded with the late Miocene or early Pliocene Hood River conglomerate, as Warren implies, or it may be much younger and correlative with the Quaternary lavas of Mount Adams to the west.

[1] Culver, H. E., The geology of Washington, pt. 1. General features of Washington geology—with accompanying preliminary geologic map of the state: Washington Div. Geology Bull. 32, 1936.

[2] Warren, C. R., The Hood River conglomerate in Washington: Am. Jour. Sci., vol. 239, no. 2, p. 106, 1941.

[3] Buwalda, J. P., and Moore, B. N., Age of the "Satsop" and the Dalles formations of Oregon and Washington: Science, vol. 66, p. 236, 1927.

[4] Warren, C. R., op. cit., p. 117.

The perlite body at the head of Satus Creek possibly marks the site of a vent through which this lava reached the surface. If this be true, careful mapping and search of the area covered by the younger flow should disclose other vents and possibly other perlite deposits.

Deposit

The Satus Creek perlite deposit comprises a small and very inconspicuous knob of rock exposed for 30 feet along the east bank of the stream. The rock barely protrudes through the soil cover and is exposed for only about 50 feet up the 35° slope. A very small ridge extends up the hill from the uppermost edge of the exposure, and it is likely that shallow trenches in this ridge would expose more perlite.

Aligned and flattened vesicles and parallel phenocrysts cause a a vertical banding which trends approximately E-W and is indicative of flow structure. The rock as a whole is light-gray colored and has a peculiar brilliant sheen, apparently resulting from refraction of light by the thin onion-like layers of perlite. In part the exposed mass is very vesicular, individual vesicles less than 1 millimeter in diameter being so numerous as to give the rock a pumiceous structure.

A thin section of the rock shows about 15 percent brown spherulites and feldspar phenocrysts in a groundmass of colorless glass that has very well developed perlitic cracks. The feldspar is entirely unaltered orthoclase, in rounded crystals. A few fresh anhedral grains of augite are present, but no quartz or plagioclase.

Results of laboratory tests made on Satus Creek perlite are shown in the table on pages 26 and 27.

White River Area Occurrences

General Statement

During the course of alunite investigations in 1940 Mr. John W. Melrose, then on the staff of the Division of Mines and Mining, found an occurrence of volcanic glass 10 miles east of Enumclaw, in Pierce County. Similar rock, in two places in the same area, was recognized as perlite by Mr. Tom Ildstad, Logging Superintendent, White River Lumber Co.; and two other occurrences were reported by Mr. R. E. Ljungdahl, an employee of the same company. Several additional occurrences were found during the investigation of the area by the writer. Of these various occurrences, four or five appear to be possibly large enough to be of commercial interest, but none responded well to preliminary tests of heat-expansion qualities. The others are smaller bodies that occur within a large area of landslide and surface slump, where no continuity could be expected.

In most places the perlite does not crop out but is exposed in railroad cuts; however, the area is presently being logged, and as logging-railroad and truck-road grades are extended beyond the area examined, new deposits may be discovered.

Geography

The perlite deposits are in the White River drainage, on the western flank of the Cascade Mountains, 20 miles north of the summit of Mount Rainier and about 40 miles east of Tacoma. In its surface characteristics, the region is typified by high ridges separating the narrow valleys of the principal rivers, and by branching ridges sloping toward the main streams and separating the smaller tributaries. The gradient of the White River here is about 50 feet per mile, and in the perlite area the river flows through a terraced valley bottom about a quarter of a mile wide.

The perlite deposits lie in a 6½-mile line (fig. 7, p. 44) which begins on the south slope of Grass Mountain, crosses White River, and continues southward in the hills which lie between Clearwater River and the West Fork of White River. Farthest north of the four deposits, and the only one on the north side of the White River, is the Cyclone Creek deposit, a little more than 1 mile northeast of the woods office and camp of the White River Lumber Co. About 3 miles southwest and across the river is the Cliff deposit, ¾ mile south of this is the Divide deposit, and 2½ miles still farther south is the Milky Creek deposit. The perlite body lowest in altitude is at 2,500 feet, and the highest, at 4,000 feet; White River here is at 1,400 feet.

Near the river is the Naches Pass highway (U. S. 410), by which it is 12 miles west to the Northern Pacific and the Chicago, Milwaukee, St. Paul and Pacific Railroads at Enumclaw. A logging railroad extends from Enumclaw up the river into the perlite area, one of the deposits being exposed in a railroad cut beside trackage which was in use in 1947, and other deposits being exposed in cuts in abandoned railroad grades which are now being maintained as truck roads. With the exception of the Milky Creek deposit, all the perlite deposits in the area are directly adjacent to either a railroad or good graveled truck roads. Timber and water are amply available for mining or quarry uses.

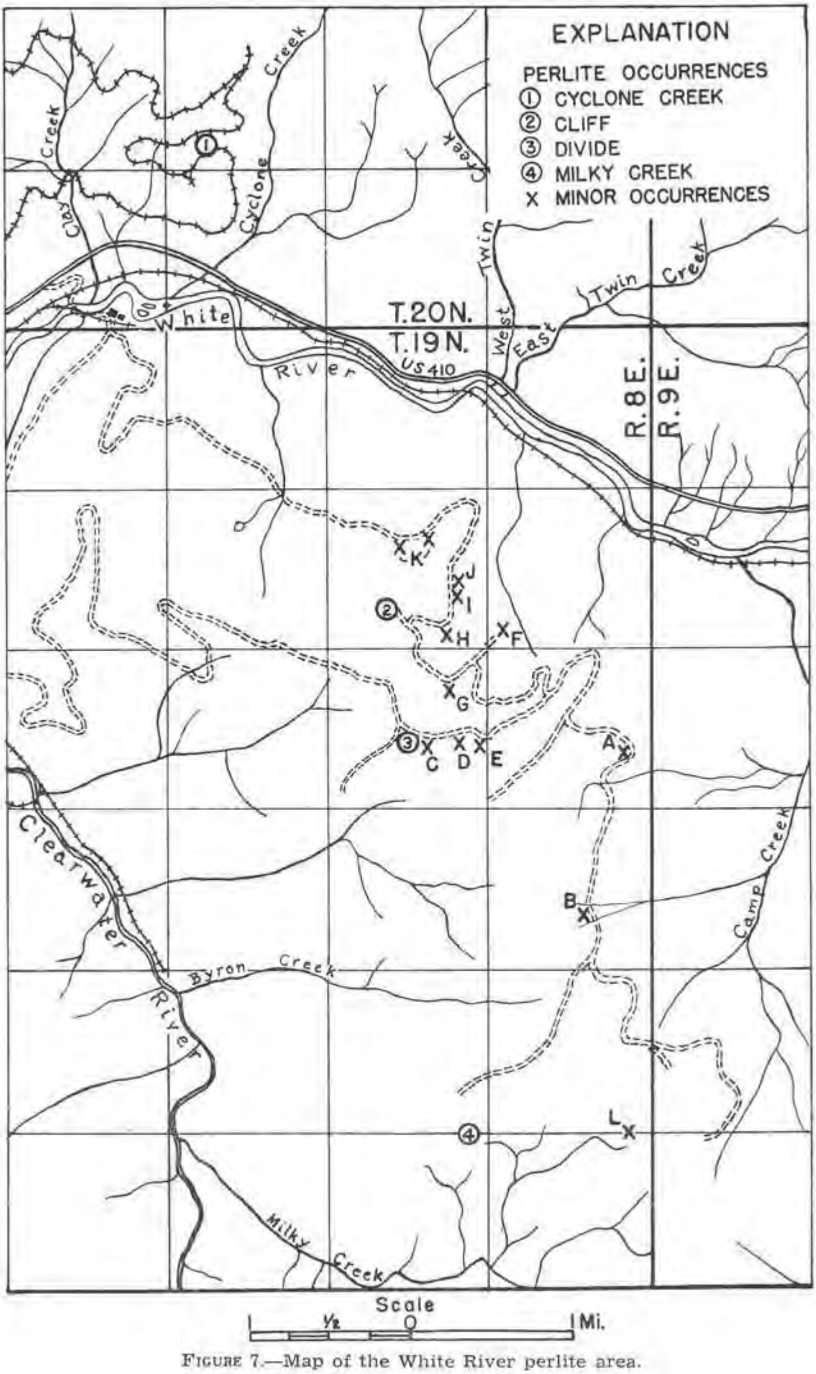

FIGURE 7.—Map of the White River perlite area.

Geology

With the exception of alluvium and glacial gravels in the White River Valley, the only rock exposed in the area is that of the Keechelus andesitic series. The Keechelus rocks cover a large area in the central Cascade Mountains in Washington. They were first mapped and described by Smith and Calkins[1] in the Snoqualmie quadrangle, east of the White River perlite occurrences. The series was mapped to within 10 miles of the perlite area from the north by Fuller.[2] Post-Eocene andesites were mapped by Daniels,[3] along the eastern border of the Pierce County coal fields, west and southwest of the perlite area. About 4 miles to the northwest Evans[4] mapped lava beds which he indicated were Eocene in age, but which Warren[5] in his remapping of part of the same area designated as Keechelus andesitic series rocks. In an earlier report Warren[6] mapped the Keechelus andesitic series in the Mount Aix quadrangle southeast of the perlite area and concluded that it is lower Miocene or older. He suggested the probability of an unconformity within the series, and described the lower part as flow-rocks, intrusive sheets and dikes, agglomerates, and tuffaceous sediments, the flow-rocks ranging from rhyolite to basalt but being predominantly andesite and dacite. He found the lower part to be 2,000 feet or more in thickness, to be universally hydrothermally altered, and to have 30° dips commonly and dips as high as 60° in some places. The upper part of the Keechelus he described as andesite flows, agglomerates, and tuffs, having a maximum thickness of possibly 2,000 feet. Dips in the upper part are nearly as steep as in the lower, but probably all are initial dips and not the result of folding. Alteration in the upper part appears to be due entirely to weathering and is not so pronounced as in the lower part of the Keechelus andesitic series.

Far too little field work was done to make detailed correlations among the volcanic rocks in the White River perlite area and those in the above-mentioned surrounding areas, but it is obvious that they may all be grouped together, at least in a general way. The rocks in the perlite area appear very similar to the lower part

[1] Smith, G. O., and Calkins, F. C., U. S. Geol. Survey Geol. Atlas, Snoqualmie folio (no. 139), 1906.

[2] Fuller, R. E., The geology of the northeastern part of the Cedar Lake quadrangle with special reference to the de-roofed Snoqualmie batholith: Univ. Washington Master's Thesis, 96 pp. 1925.

[3] Daniels, Joseph, The coal fields of Pierce County: Washington Geol. Survey Bull. 10, 1914.

[4] Evans, G. W., The coal fields of King County: Washington Geol. Survey Bull. 3, 1912.

[5] Warren, W. C., Preliminary geologic map and brief description of the coal fields of King County, Washington: U. S. Geol. Survey preliminary report, 1945.

[6] Warren, W. C., Tertiaries of the Washington Cascades: Pan-Am. Geologist, vol. 65, pp. 241-247, 1936.

of the Keechelus andesitic series as described by Warren in the Mount Aix quadrangle. They consist largely of andesitic flow-rocks, but tuffaceous sediments are common. Some of the flow-rocks are rhyolitic, and others are basaltic. A perlitic glassy phase of the volcanic rocks occurs in what appears to be a neck near the center of the NE¼SE¼ sec. 13, (19-8E), and in other places in what appear to be flows or sills overlying tuff and underlying non-glassy flow-rocks. The andesite flows range in color from cream to almost black. They are commonly massive but in some places have columnar structure. Some flows are more resistant to erosion and give rise to prominent cliffs. The tuffs, being softer than the flows, do not crop out prominently, and some of the soft, clayey tuff beds are probably responsible for the many large landslides in the area. Some of the tuff is cream to white colored, moderately hard, and shows no bedding, but the tuff found underlying the perlite bodies is medium-brown colored, very soft and sticky when wet, and is well-bedded, indicating it to be water-laid.

The structure is obscure, but the series is folded. The regional strike is northeast, and dips are generally less than 40° both to the northwest and southeast. Local variations from the regional structure are numerous, and landslides cover a large part of the area, making detailed determinations of structure almost impossible.

Altered rock, ranging from hard chalcedonic quartz to soft clay and including kaolinized and alunitized andesite, is widely distributed in the area. The area in which perlite has been found roughly coincides with that in which alunite occurs, and the origins of the two materials may be closely related. Certainly, the intensive hydrothermal alteration which is related to the alunite deposits also affected the rocks in the vicinity of the perlite bodies; and the association with the perlite of clay and siliceous nodules and geodes makes it appear that solutions of the same origin may have been responsible for the alteration at both the alunite and perlite deposits. However, the clay which is in contact with the perlite bodies, apparently an alteration product of the perlite itself, is bentonitic, which indicates alkaline solutions acting in a reducing environment,[1] whereas the association of alunite and kaolin indicates acid solutions acting in an oxidizing environment.[2] This apparent anomaly may be resolved by comparison with somewhat similar conditions at Magnet Cove, Arkansas, and Yellowstone Park,[3] where evidence indicates that bentonite was formed at lower

[1] Ross, C. S., and Hendricks, S. B., Minerals of the montmorillonite group: U. S. Geol. Survey Prof. Paper 205-B, pp. 68-69, 1945.

[2] Lindgren, Waldmar, Ore deposits of the western states, p. 190, 1933.

[3] Ross, C. S., op. cit., pp. 67-69.

levels in volcanic vents under the influence of alkaline waters which upon rising became increasingly acidic and thereby produced kaolin by alteration of feldspars. The same waters by becoming still more acidic may have deposited alunite.① Thus, in the White River area the perlite bodies appear to mark the sites of volcanic vents and the alunite deposits may well be peripheral to the vents, a relationship which should be kept in mind in prospecting either for perlite or alunite in this area.

Cyclone Creek

Dark-gray to black perlite is exposed in a borrow pit on the "110-line" of the White River Lumber Co. logging railroad, on the south slope of Grass Mountain at an altitude of 2,375 feet. The deposit is a little less than ½ mile west of Cyclone Creek and 1 mile north of White River, in the SE¼SW¼ sec. 27, (20-8E). The perlite is exposed in a face 6 feet high and 12 feet wide in the west end of the borrow pit, on the north side of the railroad grade. At the time the pit was excavated, perlite was reported to cover an area about 30 feet square in the floor of the pit, but the pit floor is now covered by mud and water, so cannot be seen. The pit face and other surface exposures and float indicate the perlite body to have a width of 20 feet and length of at least 75 feet. The uppermost exposure is 15 feet higher than the pit floor. Banding in the perlite (probably flow structure) trends N. 25° W. and dips 65° SW., which is approximately parallel to the long dimension of the deposit. Soil cover varies from a few inches to perhaps 3 feet thick.

Andesite is in contact with both sides of the perlite body, and soft, clayey light-colored tuff is exposed in railroad cuts within 300 feet of the deposit to both the east and the west, but exposures are too poor for structures to be determined with any assurance of accuracy.

The unweathered perlite is black, has rough granular texture, and shows flow-structure banding. A few scattered white feldspar crystals are visible. On exposed surfaces weathering has advanced to a depth of 2 or 3 inches, changing the color to light gray. In thin section the rock is seen to be 10 percent phenocrysts of plagioclase (andesine, An_{32}) and a few grains of hypersthene in a groundmass of colorless glass which has very well developed perlitic cracks. Small elongated areas parallel to the flow banding show devitrification of the glass, and microspherulites are fairly abundant. The unaltered glass has numerous black trichites (thin filaments and hair-like crystallites) in bent, irregular shapes and radiating groups.

① Lindgren, Waldmar, op. cit., p. 190.

Results of laboratory tests made on three samples of Cyclone Creek perlite are shown in the table on pages 26 and 27. The sample "Cyclone Creek (1)" represents the 20-foot width of the perlite body near the middle of the deposit. The sample "Cyclone Creek (2)" is a cut from the larger sample which was tested in the commercial perlite expansion furnace, and which was taken to represent the 12-foot face of perlite in the borrow pit. A separate sample "Cyclone Creek (3)" was taken as a duplicate from the same place.

A chemical analysis of this perlite made for the owner by a private laboratory is shown in the table below.

Analyses of White River perlite

Deposit	Ig. loss	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
Cyclone Creek	2.86	81.34	2.29	10.05	1.48	tr.
Divide	6.36	68.06	2.79	11.69	1.95	0.83
Milky Creek	6.30	72.74	2.39	11.75	1.53	tr.
Sec. 11, (19-8E)	6.52	68.82	2.87	12.31	2.10	0.86

In order to test the expansion qualities of the Cyclone Creek perlite on a pilot-plant scale, a representative sample was taken across the 20-foot width of the deposit, in the face of the pit. After crushing, screening to pass 10 mesh screen, and drying, the sample weighed 490 pounds and had a volume of 5.8 cubic feet. The sample was run through the perlite expansion furnace described on page 36. The furnace was operated at 1,750° F. (950° C.) for this test, but the results show the Cyclone Creek perlite not to be of commercial quality when treated in this manner. Only 67 percent by weight of the material fed into the furnace was recovered at the sacker end of the plant. The remaining 33 percent was lost by accumulation on the inner surfaces of the equipment and by loss through the exhaust stack. On long continuous runs this loss probably would be smaller; but such a large loss on even a short run indicates that either the raw perlite has poor expansion qualities, or optimum expansion conditions for this particular material were not maintained in the furnace.

Screen analysis of crushed Cyclone Creek perlite

U. S. standard screen mesh	Percent (by weight) retained on screen
10	0.0
30	48.5
80	36.2
100	3.1
pan	12.2
	100.0

Whereas commercial perlite should expand to 6 to 10 times its original volume when heated, the Cyclone Creek perlite expanded to only 3 times its original volume (assuming the material lost during treatment to have had the same expansion ratio as that recovered). The fine portion of the product expanded considerably more than this, however, as indicated by the fact that the fines had a volume of 7 cubic feet and weighed 115 pounds, an average of 15 pounds per cubic foot. The coarse expanded perlite weighed 211 pounds and had a volume of 6 cubic feet, an average of 35 pounds per cubic foot.

Screen analysis of expanded Cyclone Creek perlite

U. S. standard screen mesh	Coarse Percent (by weight) retained on screen	Fine Percent (by weight) retained on screen
14	1.0	0.0
20	13.0	0.4
35	28.1	4.4
45	23.6	7.5
60	20.0	13.5
100	11.2	26.5
150	1.7	16.8
200	0.4	11.0
pan	1.0	19.9
	100.0	100.0

Of the expanded perlite produced, a large part was fines, the fines portion being 54 percent by volume and 35 percent by weight. This high ratio of fines to coarse material probably could have been cut down by varying the furnace conditions and by properly sizing the crushed perlite before it was fed into the furnace. The crushed raw perlite for this test contained 12 percent of minus 100 mesh material, which for lack of facilities was not removed but which should have been removed to permit the furnace to produce best results.

The expanded Cyclone Creek perlite is buff colored, whereas the desirable color is white. The buff color actually is not detrimental, except that the expanded perlite of commerce is white and the public has been educated to demand the white color. The individual expanded perlite grains of the Cyclone Creek deposit are rounded and have good mechanical strength, comparing very favorably with expanded perlite on the market. In the expanded product of this test are many grains which are unexpanded; most of these are dark colored. They largely represent the mineral grains which make up 10 to 15 percent of the raw perlite rock, and the expanded product would be much improved by their prior elimination. Practically all of the unexpanded material is found in the coarse part of the furnace product, a fact which is indicated by the greater bulk specific gravity and darker color of this fraction. The fines are almost white and are relatively free from unexpanded mineral grains.

The pilot plant test indicates the Cyclone Creek perlite to be unsuited to production of commercial expanded perlite under the conditions of the test, but it is reasonable to expect that improvements in treatment technique would result in a salable product. This would involve removing the minus 100 mesh material and all unexpansible mineral grains from the crushed perlite before heat treatment (however, it might prove more practical to remove the unexpanded material after or during furnacing), and it might require somewhat different furnace conditions from those used in this test.

Cliff

South of the White River, perlite occurs in many places in Township 19 North, Range 8 East, but several of these are in landslide blocks. Each perlite body known to be in place and not involved in landslides is at the base of cliff-forming volcanic flows, and the Cliff deposit is one of these. The Cliff perlite body is not exposed, but surface indications are such that its existence can be postulated with considerable assurance.

Rock cliffs 300 to 400 feet high trend diagonally across the SW¼ sec. 11, (19-8E), and below the cliffs is talus which slopes 80 feet downward to a graveled truck-road. Indications of a near-by perlite deposit show along this road, which is maintained on a grade previously occupied by a spur from the "130-E line" of the White River Lumber Co. logging railroad. Numerous quartz-filled nodules and several 18-inch and smaller boulders of greenish-gray perlite are present in some of the road cuts, and perlite float occurs in a cut that is 2,900 feet in altitude, 400 feet east of the center of the SW¼ sec. 11, (19-8E), and 600 feet northwest of the junction of the spur with the "130-E line."

The size of the deposit is entirely unknown, but excavations or shallow drill holes should disclose perlite at no great depth below and to the west of the road. The perlite body from which the float comes is probably at the base of the flow-rocks exposed in the cliffs and probably overlies soft, water-laid tuff—which are the relationships at the Divide deposit three-quarters of a mile to the south. The lava flows in the cliffs above the deposit strike N. 15° E. and dip 15° NW.

The perlite has a conchoidal fracture and a vitreous to resinous luster. It contains about 15 percent feldspar phenocrysts, as much as 3 millimeters in diameter, that are completely altered to clay minerals. Samples tested in the laboratory expanded only slightly when heated.

Divide

Black and dark-green perlite is exposed 300 feet south of the center of sec. 14, (19-8E), in a cut beside the graveled truck-road which follows the grade of the abandoned "210-B line" of the White River Lumber Co. logging railroad. The cut is 500 feet southeast of the junction of "214" with the "210-B line" at an altitude of 3,310 feet and is on the divide between a westward-flowing tributary to Clearwater River and a northward-flowing tributary to White River. Perlite is exposed in the cut through a height of 20 feet and length of 100 feet in an easterly direction. Overlying the perlite is 4 feet of silicified andesite, and, although not exposed here, the underlying material probably is soft, clayey, tuffaceous sediments. The underlying tuff is exposed in a road cut 500 feet east of the deposit. The strike of the andesite ranges from N. 20° E. to N. 35° E., and the dip, from 35° to 65° NW., but part of this variation may be due to surface slump. The deposit is just outside the western edge of a ¾-mile-wide landslide area, but apparently was not itself involved in the landslide.

The perlite body is irregular in shape and is mixed with bentonitic clay, being made up of alternating layers of perlite, clay, and mixed perlite and clay.

Section exposed in cut at Divide deposit

	Inches
Rhyolite, hard, gray	12
Rhyolite, soft, red	36
Clay, cream-colored; contains jasper bands	14
Perlite, black	22
Clay, cream-colored; contains quartz-filled nodules	30
Clay, red; contains red jasper geodes	8
Perlite, black, friable, mixed with clay	60
Clay, cream-colored	1
Clay, red	½
Clay, cream-colored	½
Perlite, dark green, friable, mixed with clay	6
Clay, cream-colored	1
Perlite, black (base concealed)	6+
	197+

Of an exposed section of 197 inches, only a total of 34 inches is solid perlite, and that is distributed among three layers that are separated by clay. The 60-inch layer of friable perlite contains much clay but may grade laterally into solid perlite without clay, in which case the deposit could furnish sufficient tonnage to be of commercial interest. Clay cannot be tolerated in any of the presently used methods of processing perlite, but it might be practical to wash the material to eliminate the clay, and it is conceivable also that sometime in the future a new usable product could be made directly from the clay-perlite mixture. A screen analysis of a sample from the 60-inch friable perlite layer shows 5.7 percent clay (–200 mesh) and 94.3 percent perlite. The clay is present as thin films in the shrinkage cracks between individual "pearls" in the perlite. Apparently it has formed by alteration of the glass, and probably it is bentonitic.

In thin section the perlite is seen to be largely clear glass, showing flow banding and having very well developed perlitic structure. There are a few scattered hypersthene phenocrysts and about 8 percent rounded oligoclase feldspar phenocrysts. The rock which overlies the perlite is a highly silicified porphyritic andesite, containing phenocrysts of plagioclase feldspar (andesine, An_{38}), euhedral pyroxene, and a few flakes of biotite. The groundmass is a solid mat of intergrown secondary quartz grains and scattered minute grains of magnetite.

Results of laboratory tests of perlite from the Divide deposit are shown in the table on pages 26 and 27. A chemical analysis of this perlite is given in the table on page 48.

Milky Creek

Two masses of black perlite barely protrude through a soil-covered steep hillside which rises from the north side of Milky Creek, a tributary to Clearwater River. The exposures are near the head of the creek, in the NE¼NE¼ sec. 35 and the SE¼SE¼ sec. 26, (19-8E) at an altitude of about 4,000 feet. This is about ½ mile southeast of the end of the "K-line" truck-road of the White River Logging Co. and 2½ miles south of the Divide deposit.

Both perlite exposures are about 10 feet square. The upper one is about 200 feet north of the south line of sec. 26, (19-8E) at an altitude of 4,100 feet, and the lower one is about 300 feet south of the section line, at an altitude of 4,050 feet. Perlite float is abundant for several hundred feet southwesterly (diagonally) down the hill from the exposures—apparently much too plentiful to have been derived entirely from the bodies exposed. Trenching probably would disclose perlite in place extending along a line trending N. 10° E. for about 1,000 feet. About 400 feet west of the lower exposure are cliffs of andesite, but no rock is exposed immediately adjacent to the perlite bodies.

The perlite of the Milky Creek deposit is black, has a conchoidal fracture, and a vitreous to resinous luster. It contains about 10 percent feldspar crystals averaging 2 millimeters in length, and locally there is an abundance of spherulites averaging ½ millimeter in diameter. The sperulites make up about 40 percent of a few of the samples examined, which, combined with the 10 percent of feldspar crystals, renders that rock unsuitable for expanded perlite manufacture. However, most of the rock is not spherulitic, though all of it contains feldspar crystals.

Results of laboratory tests on the Milky Creek perlite are shown in the table on pages 26 and 27, and a chemical analysis is reported in the table on page 48.

Minor Occurrences

Twelve minor occurrences of perlite are in the White River area, in secs. 11, 12, 13, 14, and 24, (19-8E). Of these, only one, the (A) occurrence (fig. 7, p. 44), is known to be in place and not moved by landslides. This is at the center of the NE¼SE¼ sec. 13, (19-8E), where two parallel, nearly vertical 5-inch bands of perlite separated by 12 inches of andesite are exposed for a height of 4 feet in a road cut. The bands trend N. 35° W. and dip 80° SW., but flow banding in the near-by andesite is extremely variable in altitude. Scattered throughout the perlite are very abundant spherulites and nodules ranging from microscopic size to 2 inches in diameter. None of the nodules was found to be filled with quartz. In thin section the spherulites are seen to make up 55 percent, and perlitic glass only 40 percent, of the rock. Plagioclase feldspar (andesine, An_{33}) makes up 5 percent of the rock, and a few grains of magnetite and flakes of biotite are present. The andesite bordering the perlite bands is tan to light-purple colored, very vesicular, and has slaggy, ropy surfaces and very well developed flow banding which is irregular but generally vertical. Apparently this is the site of a vent for lava which is part of the Keechelus andesite flows of this area.

At the (B) occurrence on the same road, 1.1 miles south of the (A) occurrence, there are perlite boulders in a borrow pit which extends for 250 feet along the west side of the road between two branches of a small stream. Although no perlite was found in place, there is little question that the boulders came from the bottom of the pit, which is now covered by mud and loose rubble. The perlite is dark-green colored, and contains about 10 percent feldspar phenocrysts. In the face of the pit are purple and greenish andesite flows which strike N. 15° E. and dip 10° NW., but the whole mass may be in a landslide block. The andesite contains nodules ranging from ½ inch to 2 inches in diameter and filled with white and colorless banded chalcedony.

At the (C) occurrence, in a road cut 525 feet east of the Divide deposit, are numerous boulders of perlite as much as 18 inches in diameter, which have slumped from the base of a thin light-colored andesite flow that dips 45° to the north. Underlying the flow is purplish-gray soft bentonitic clay derived by alteration from tuff and retaining the original tuffaceous texture. The perlite here is in the north center of the NW¼SE¼ sec. 14, (19-8E), and is 20 feet higher in elevation than the Divide deposit. This perlite occurrence is within the large landslide area which covers all the NE¼ sec. 14, part of the SE¼ of the same section, and parts of the adjacent secs. 11, 12, and 13.

In the same landslide area, 775 feet east of the (C) occurrence and 20 feet higher in elevation, a road cut exposes a band of black perlite which averages 18 inches thick. In this, the (D) occurrence, the perlite overlies brown tuffaceous clay and underlies andesite. At the west end of the cut the perlite is exposed at road level. In the south face of the cut, it rises toward the east to a height of 12 feet in a distance of 50 feet, then continues level for 280 feet to the eastern end of the cut.

At the (E) occurrence, also within the landslide area, in the center of the NE¼NE¼SE¼ sec. 14, (19-8E), a 1-foot perlite band is exposed 4 feet above road level in a cut 500 feet east of the (D) occurrence. Perlite is exposed for a length of 30 feet, overlain by andesite and underlain by tuffaceous clay.

Just within the eastern edge of the landslide area, at the (F) occurrence, exposed in a road cut are boulders of solid perlite in a 16-inch layer of friable perlite partially altered to clay. Underlying the perlite is 6 inches of white bentonitic clay, under which is 36 inches of hydrothermally altered andesite. Perlite float is scattered for 150 feet westward from the edge of the timber into the logged-off area. The perlite exposure is at the north center of the SW¼-SW¼ sec. 12, (19-8E), at the end of the "130-E line" of the White River Lumber Co. logging railroad.

Two feet of perlite overlying 10 feet of tuffaceous clay is exposed for a length of 50 feet at the (G) occurrence, in a road cut at the center of the NE¼ sec. 14, (19-8E), at an altitude of 3,000 feet. The road follows the grade of the abandoned "130-E line" of the White River Lumber Co. logging railroad. The deposit is within the landslide area.

Down the road 0.8 mile from the (G) occurrence, the perlite of the (H) occurrence is exposed on both the east and west banks of a small stream. This is at an altitude of 2,780 feet, also within the landslide area, in the SW¼SE¼ sec. 11, (19-8E). For 50 feet along the west bank the exposure is 4 feet thick, and for 20 feet along the east bank it is about 3 feet thick. The two exposures are 150 feet apart. A chemical analysis of this rock is shown in the table on page 48.

At the (I) occurrence perlite is exposed in the west center of the NE¼SE¼ sec. 11, (19-8E) at an altitude of 2,700 feet in a road cut in the abandoned "130-C" logging railroad line. This is within the landslide area. The 16-inch layer of friable black perlite, partially altered to clay and similar to that at the Divide deposit, overlies 36 inches of soft yellowish-brown tuffaceous clay which in turn overlies hard green tuff. The exposure extends 50 feet along the road.

Perlite is exposed for 10 feet at the (J) occurrence, in a 100-foot road cut 700 feet north of the (I) occurrence, at the NE. corner of the NW¼SE¼ sec. 11, (19-8E). About 12 inches of dark-green friable perlite, partially altered to clay, overlies soft tuffaceous clay.

Perlite boulders up to 12 inches in diameter occur abundantly in landslide material in road cuts along the abandoned "130-C" line of the logging railroad in the SW¼NE¼ sec. 11, (19-8E) and at the junction with the "130-A" line in the SE¼NW¼ of the same section. This, the (K) occurrence, is near the center of the large landslide area, and all the rocks here are much disturbed and intermixed.

Outcrops of perlite have been reported by R. E. Ljungdahl[1] as extending eastward for about a quarter of a mile from a place near the south line of the SE¼ sec. 25, (19-8E) that is 1 mile east of the Milky Creek deposit. This is at an altitude of about 4,000 feet. The perlite of this (L) occurrence is reported to be similar in appearance to that at the Milky Creek deposit, but outcrops here are said to be larger and more numerous.

Mashel River Occurrence

General Statement

A rock sample submitted for identification to the Division of Geology in 1937 by Mr. J. C. Miller, 8002 South G Street, Tacoma, proved to be black vitrophyre, and other samples of vitrophyre submitted by Mr. Miller in 1948 were found to have a perlitic structure. These samples, from near the Mashel River, were similar in appearance and had expansion qualities similar to the perlite from the near-by White River area. The exposure from which the samples were taken and the surrounding area were examined by the writer in 1948, and perlite was found as float scattered along a hillside for nearly a quarter of a mile south of the outcrop. Trenching across the probable extension of the outcrop should disclose

[1] Ljungdahl, R. E., personal communication, 1948.

more perlite in place. The outcrop is as large as, or larger than, any of those in the White River or Wenatchee areas, and the deposit may be of commercial interest, as it is only ½ mile from a graveled road and 7½ miles by road from a branch line of the Chicago, Milwaukee, St. Paul and Pacific Railroad at Eatonville.

Geography

The Mashel River perlite deposit is in south-central Pierce County, about 12 miles west of Mount Rainier and 25 miles southwest of the southernmost perlite deposit in the White River area. It is at an altitude of about 1,900 feet, on a steep hillside which rises from the west bank of Mashel River, 1 mile upriver from the mouth of Busy Wild Creek, in the NW¼ sec. 30, (16-6E).

This is an area of considerable relief, the peaks in the immediate vicinity averaging about 3,500 feet in altitude, more than 2,500 feet higher than the river level at the deposit. Ridges are sharp, and valleys are steep sided. In this area the Mashel River has a gradient of about 100 feet per mile. The River does not reach far enough eastward to tap the snow fields of Mount Rainier, but rainfall in the area is heavy and most of the gullies, even the very smallest ones, are occupied by streams. A heavy growth of fir covers the hillsides, and underbrush grows thickly along the streams.

Geology

Other than alluvium, the only rocks known in the vicinity of the perlite deposit are those of the Keechelus andesitic series (see pp. 45, 46).

Daniels[1] shows andesite to underlie all the Mashel drainage area except a 5-mile-wide band trending northward across the upper river; here coal-bearing Puget group rocks occur. The coal measures are 2½ miles east of the perlite deposit.

The Keechelus andesitic series as exposed along the banks of the Mashel River west of the perlite deposit are steeply-dipping thick and thin flows of andesite and basalt and abundant interbedded andesitic agglomerate. About a quarter of a mile southwest of the deposit are cliffs of platy andesite, and on the hillside below these cliffs and above the river are small pieces of perlite float. Apparently the float originated below the cliffs, but the hill is covered by soil and talus, so no outcrops were found. The area northeast of the cliffs, where the perlite crops out, is heavily timbered, and soil covers the hill so that the only rock in place is the perlite exposure.

[1] Daniels, Joseph, The coal fields of Pierce County: Washington Geol. Survey Bull. 10, pl. 1, 1914.

Deposit

The perlite shows as a nearly vertical cliff about 15 feet high some 500 feet N. 60° E. from the place where the Busy Wild trail crosses the line between sec. 25, (16-5E) and sec. 30, (16-6E). This trail, old and barely discernible, follows up the west side of Mashel River from the mouth of Busy Wild Creek and at the perlite deposit is about 300 feet west of the river and 100 feet above it. The perlite cliffs begin at trail level, at an altitude of 1,850 feet, and trend about 350 feet N. 40° E. diagonally up the hill to a place about 60 feet higher than the low part of the exposure at the trail. The average width of the outcrop is about 10 feet.

The perlite has an indistinct flow structure, expressed by alignment of feldspar crystals, slight banding of colors in the rock, and irregular platyness. At the southwest end of the outcrop the flow structure strikes N. 25° E. and dips 70° SE. The weathered surfaces of the perlite are medium-gray colored, owing to an extremely thin white coating on the black fresh rock. The white coating outlines each of the individual "pearls" and makes the perlitic structure of the rock much easier to see on the weathered surface than on surfaces of fresh rock. Fresh surfaces show a rough, granular texture and vague flow-banding. White to colorless feldspar crystals averaging 2 millimeters in length make up about 10 percent of the rock. The glass is black, has vitreous to pitchy luster, and breaks with a conchoidal fracture. The rock was not examined in thin section, but it appears megascopically to be very similar in every respect to the perlite in the White River area.

Results of laboratory tests on the Mashel River perlite are shown in the table on pages 26 and 27.

Prosser Occurrence

Mr. A. M. Ritchie[1] in 1948 described an occurrence of black volcanic glass in Benton County near Prosser. This glass has well-defined perlitic structure, yet appears to be of basaltic composition. Perlitic basaltic glass is rare, but it is reported by Harker,[2] who merely mentions that perlitic structure in basaltic glass is less common than in obsidian. The Prosser is in the SW¼NE¼ sec. 20, (8-24E), in the bottom of one of many similar steep-sided gullies on the north slope of the Horse Heaven Hills. The gully is a few hundred feet east of a secondary road which descends from the wheat-ranching country on top of the hills to the Yakima River Valley, joining State Highway 3-A about 3 miles west of Prosser. The perlite is at

[1] Ritchie, A. M., personal communication.
[2] Harker, Alfred, Petrology for students: Cambridge University Press, London, p. 187, 1935.

an altitude of 1,500 feet, and the gully here is about 500 feet east of the road. Water flows in the gully only during rainstorms and from the melting of snow in spring.

The deposit is only 2 miles by road from the main line of the Northern Pacific Railway, but because of the small indicated volume of rock available it is not likely to be commercially valuable. This and probably other similar deposits appear to be the source of the stream-worn "obsidian" pebbles commonly found in the Yakima River gravels in the vicinity of Prosser. Since 1936, seven different people in the lower Yakima Valley have sent in specimens of this material to the Division of Mines and Geology for identification. The descriptions of these specimens indicate they are all black volcanic glass, some have perlitic texture, and several have a pale blue film coating their surfaces—all of which is descriptive of the Prosser perlite also. One of the samples is reported to come from sec. 34, (8-22E), which would be on the steep north slope of the Horse Heaven Hills about 10 miles southwest of the Prosser deposit. Another of the samples is reported to have come from sec. 12, (8-24E), also on the north slope of the Horse Heaven Hills, and 4 miles northeast of the Prosser deposit. Samples submitted in 1948 by Mr. R. C. Matney of Prosser included black perlite and brown and black pitchstone. Results of tests on his perlite sample, "Prosser (2)," are shown in the table on pages 26 and 27, and the same table shows results of tests on somewhat similar material "Prosser (1)," from the Prosser perlite deposit.

The Prosser perlite occurs as a 2- to 10-inch layer exposed for a length of 40 feet. It is the chilled base of a dense lava flow more than 50 feet thick. The flow and perlite strike N. 70° W. and dip 65° SW. The lava appears to be basalt, but the optical properties of its glassy base indicate the glass to be somewhat more acidic than basalt. Underlying the perlite is 8 inches of purple tuffaceous mudstone, 8 inches of medium-gray tuffaceous mudstone, then 50 feet or more of black vesicular basalt. The vesicles in the basalt are as large as 2 inches in diameter and some are filled with olive-green opal.

The perlite is black and opaque. It has the luster of obsidian, but has perlitic texture. When crushed it breaks down readily to coarse granular fragments. An outstanding feature of the rock is the prevalent light-blue film of altered glass which covers all joint surfaces, including the surfaces surrounding the "pearls." The glass contains no spherulites nor phenocrysts.

Gillott Occurrence

A rock sample submitted to the Division in 1941 by Mrs. J. A. Gillott of Woodland was a black perlite having phenocrysts of glassy, colorless feldspar. The writer visited the location but was unable to find the 40-foot prospect adit from which the perlite came. However, perlite float was found in the bed of the small stream near which the adit is reported to be. This location is in north-central Skamania County, in the E½ sec. 19 or W½ sec. 20, (8-7E), on a short westward-flowing tributary to Clear Creek that is 7 miles north of the confluence of Clear Creek and the Lewis River. The deposit probably is at an altitude of between 2,000 and 3,000 feet.

Should the deposit prove to be of commercial size, it would still be of little value at present because of its inaccessibility, as it is 14 miles by trail from the nearest road and 26 miles by road to the Northern Pacific Railway at Yacolt. Truck roads and a railroad are being extended into the area in connection with logging operations, so the deposit may soon be much more accessible than it is now.

The perlite is black and opaque, even on thin edges. Its perlitic structure causes it to break down readily to coarse granular fragments when crushed. In thin section the glass is medium brown and shows perfect perlitic cracks. Under the microscope, it is seen to be about 10 percent phenocrysts of plagioclase feldspar and femic minerals, the latter being very much in the minority.

Results of laboratory tests on the Gillott perlite are shown in the table on pages 26 and 27.

Peterson Occurrence

A sample of perlite was submitted for identification in 1943 by Mr. E. Peterson, of Goldendale. Mr. Peterson is no longer in Washington, but Mr. R. A. Jackson, who was his employer at that time, reports that the perlite probably came from the headwaters of the Klickitat River in western Yakima County, south of Goat Rocks and north of Lakeview Mountain. This would be in Township 11 North, Range 11 or 12 East.

The rock is volcanic breccia, composed of minus ¼-inch angular fragments of flow rocks of various textures and phenocrysts of feldspar and femic minerals, all in a matrix of perlitic glass. The glass comprises only about 50 percent of the rock. Many of the breccia fragments are flattened and oriented in parallel lines, showing a fairly well developed flow structure in the rock. The glass is black, but the breccia fragments are brown and gray, giving a mottled appearance to the rock as a whole.

Results of laboratory tests on the Peterson perlite are shown in the table on pages 26 and 27.

Witikka Occurrence

Mr. P. A. Witikka of Woodland in 1946 submitted to the Division a sample of vitrophyre from near his home. The sample came from a 2-foot-wide "chimney" near the top of a 1,600-foot hill in south-central Cowlitz County. The vitrophyre is black and opaque and breaks with hackly fracture. In thin section the rock has a ground-mass of perlitic brown glass in which are abundant globulites. About 10 percent of the rock is made up of euhedral phenocrysts of plagioclase feldspar (andesine) in crystals as much as 2 millimeters in length, a few smaller grains of augite, and scattered crystals of pyrite. Results of laboratory tests made on the Witikka perlite are given in the table on pages 26 and 27.

Crawford Occurrence

Perlite has been reported to occur in Clark County near Crawford, about 20 miles northeast of Vancouver, but the report is unauthenticated. Battle Ground Lake, at Crawford, occupies a prominent depression about a quarter of a mile wide, which appears to be a small volcanic crater. The presence of a crater would make the occurrence of perlite near by not unlikely.

OTHER VOLCANIC GLASSES

GENERAL DESCRIPTION

Volcanic glasses other than perlite are obsidian, pitchstone, and basaltic glass. Other rocks which contain from little to much glass are vitrophyre, pumice, pumicite, and tuff.

Obsidian.—Obsidian has a bright, glassy luster, and is commonly jet-black but may be red or brown. It is characterized by conchoidal fracture and translucency of thin fragments. It ranges in hardness from 5.5 to 7.0; in specific gravity, from 2.13 to 2.42; and in index of refraction, from 1.48 to 1.51. Combined water is generally less than 1 percent, and silica and other oxides may vary between wide limits. Obsidian is acidic, corresponding in chemical composition to rhyolite, dacite, or andesite.

Pitchstone.—Pitchstone is similar in composition to obsidian except that it contains from 5 to 11 percent combined water. It has a pitchy luster; is black, brown, red, or green; and may have a conchoidal fracture, but generally not so well developed as in obsidian. Thin edges are translucent. Hardness ranges from 5.5 to 7.0; specific gravity, from 2.22 to 2.51; and index of refraction, from 1.492 to 1.506.

Basaltic glass.—Basaltic glass is comparatively rare and occurs generally in thin layers as chilled selvages of basalt flows, dikes, and sills. It is opaque and lustrous, and commonly is black but may be brown or green. George[1] states that the specific gravity of basaltic glass, tachylyte, scoria, and diabase ranges between 2.50 and 2.99; and the index of refraction, between 1.506 and 1.612; but Peacock[2] reports basaltic glasses from Iceland which had indices as high as 1.615. Names which have been applied to basaltic glasses by various writers are sideromelane, tachylyte, and hyalomelane. Peacock and Fuller[3] support the use of the term sideromelane for transparent, pitchy-lustered basaltic glass in which, due to ultra-rapid chilling, the iron oxide has been prevented from precipitating. They restrict the term tachylyte to the opaque, dark-colored basaltic glass which occurs as selvages of dikes and sills where the cooling was slow enough to allow crystallites of magnetite and occasionally other minerals to form. For the purposes of this report the inclusive term basaltic glass will be used.

Vitrophyre.—Vitrophyre may be defined as any porphyritic rock having a glassy groundmass. The glass may have the properties of obsidian, pitchstone, or basaltic glass, and it may or may not have perlitic structure. Most of the perlites of Washington are porphyritic and may be properly classified as vitrophyres.

Pumice.—Pumice is a highly cellular volcanic rock, commonly of rhyolitic composition, which is made up largely of glass; it may contain abundant crystalline material. The glass is so filled with air bubbles that the pore space may be more abundant than the glass. The bubbles are commonly drawn out into long tubes.

Pumicite.—Pumicite, known also as volcanic ash and volcanic dust, is composed of fine angular fragments of glass of sand-size or less which have been ejected from violently erupting volcanoes. The occurrences of both pumice and pumicite in Washington have been described in detail previously.[4]

Tuff.—Tuff is the consolidated equivalent of pumicite and other fine ejecta from explosive volcanic eruptions. Occasionally it is predominantly glass, but generally the originally glassy material of a tuff is so highly altered that it can be recognized only by its texture.

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[1] George, W. O., op. cit., p. 366.

[2] Peacock, M. A., The petrology of Iceland, part 1, The basic tuffs: Trans. Royal Soc. Edinburgh, vol. 55, pp. 51-76, 1926.

[3] Peacock, M. A., and Fuller, R. E., Chlorophaeite, sideromelane, and palagonite from the Columbia River Plateau: Am. Mineralogist, vol. 13, no. 7, pp. 361-369, 1928.

[4] Carithers, Ward, Pumice and pumicite occurrences of Washington: Washington Div. Mines and Geology Rept. Inv. 15, 78 pp., 1946.

ORIGIN

Volcanic glasses are the product of rapid chilling of molten lavas either at the surface or at comparatively shallow depths. The more acid lavas, which upon slow cooling would form rhyolite or andesite, produce obsidian when cooled quickly at atmospheric pressure. Likewise, more basic lava, which upon cooling slowly would produce basalt, when rapidly cooled gives basaltic glass. If the original molten acidic lava is supercharged with dissolved gases and is cooled rapidly with simultaneous release of pressure—conditions which prevail in explosive volcanic eruptions—the resulting glass is pumice or volcanic ash. When similar supercharged molten acidic lavas cool quickly but under pressure—conditions which prevail along the sides of some dikes and sills and in underwater flows when they are emplaced—the resulting glass is pitchstone or perlite. These statements are summarized below in a classification of volcanic glasses based upon conditions obtaining at the time of their solidification.

Classification of volcanic glasses

Molten lava		*Glassy rock equivalent*		
		Cooled slowly	*Cooled quickly*	
			With pressure release	*Under pressure*
Acidic		Rhyolite and andesite	Obsidian	Obsidian
	Supercharged with dissolved gases	Rhyolite and andesite (vesicular)	Pumice and volcanic ash	Pitchstone and perlite
Basic		Basalt	Basaltic glass (sideromelane?)	Basaltic glass (tachylyte?)
	Supercharged with dissolved gases	Basalt (vesicular)	Scoria, bombs, and basaltic tuff	Perlitic basaltic glass

UTILIZATION

Those volcanic glasses which are capable of expansion can be used to make fine-grained lightweight aggregate, which with proper binders can be made into bricks, structural shapes, and acoustic tile. The same material may be used for lightweight concrete aggregate, plaster aggregate, thermal insulation, filtering and porous supports for catalysts or chemicals in the chemical industries, special foundry sand, chicken litter, and as a rooting medium for seeds and cuttings. Unexpanded volcanic glasses may be used to replace feldspars in ceramic bodies and glazes,[1] and may prove to be suitable as raw material for mineral-wool manufacture. Some of the earliest tests on perlite[2] showed it to be adaptable to many uses as electrical insulation material, and some of the other volcanic glasses may be as good as perlite for such uses. Aside from pumice and pumicite, probably the only nonperlitic volcanic glass which has been used commercially is obsidian, which since ancient times has had a limited use for jewelry.

OCCURRENCES

Two nonperlitic volcanic glass occurrences in Chelan County were examined. One of these, the Crum Canyon deposit, appears to be large enough and free enough of phenocrysts eventually to have commercial value; the other, the Old Butte deposit, may be fairly large, but the rock is porphyritic and the ratio of glass to crystalline material is comparatively small. Many other nonperlitic glass occurrences are known in eastern Washington (fig. 2, p. 17). Most of these deposits are small and all are of basaltic glass, which makes them of doubtful value at this time; consequently none of the occurrences were studied in the field and samples from only four of them have been tested in the laboratory. Several of the occurrences have been described previously, and the descriptions of the basaltic glass in the Moses Coulee and Asotin areas are largely abstracted from the earlier reports.

CRUM CANYON AREA

Pitchstone occurs in several places in Crum Canyon, a tributary to Entiat River, in east-central Chelan County. The glass was found abundantly as float along a zone 100 feet long, and in four outcrops in road cuts, all near the south quarter corner of sec. 24, (26-20E), at altitudes ranging from approximately 2,500 to 2,650 feet. An occurrence of dark-brown pitchstone vitrophyre has been reported[3] in Crum Canyon about 1 mile south of the above location, in an outcrop under a power line, about 800 feet southwest of the stamp mill of the Rex (Rogers) gold mine. The deposits in Crum Canyon are accessible by road from Entiat, a town on a branch line of the Great Northern Railway and on the paved highway U. S. 97, about 20

[1] Plummer, Norman, Ceramic uses of volcanic ash: Am. Ceramic Soc. Bull., vol. 18, pp. 8-11, 1939.

[2] Hastings, E. F., Perlite: Arizona Dept. Min. Resources, pp. 9-10, 1947.

[3] Personal communication from G. F. Fales, Cashmere, Wash., 1948.

miles north of Wenatchee. A paved highway leads up the Entiat River, and at a point 7½ miles from Entiat a graveled road branches to the north up Crum Canyon; the deposit is reached by this road 3½ miles from the intersection.

The area surrounding the deposits is sparsely timbered with pine, and there is little underbrush. The climate is rather arid, and no surface water is available for mining purposes.

The geology of the area has been described in two articles by Waters,[1] in which he mapped and described Chelan granodiorite in a region north of Entiat River which includes all the Crum Canyon area. The southwest end of a group of large andesite and rhyolite dikes is mapped less than a mile north of the Crum Canyon pitchstone exposures. Waters assigned the Chelan granodiorite to a Jurassic (?) age and the andesite and rhyolite dikes to an Eocene age. In Crum Canyon the granodiorite is coarse grained and slightly gneissic. The dikes in which the pitchstone occurs appear similar to, and may be considered a part of, the group to the north mapped by Waters.

In Crum Canyon at least three separate dikes are exposed; these vary between N. 40° E. and N. 75° E. in strike and between 60° and 70° SE. in dip. The dike rock has a granular texture and is nearly white, but it is moderately stained by brown iron oxides, giving the rock a mottled and streaked brown and white appearance. Microscopic examination of a thin section shows the rock to be made up of an intergrowth of secondary quartz, altered feldspars, limonite, and a few small flakes of biotite. Little remains to indicate the original texture or mineral composition of the rock, but it appears to be an aplite. A thin section of the pitchstone phase of the dikes shows colorless glass and an abundance of secondary quartz in irregular patches and streaks. Needle-like and hexagonal pale-green microlites are uniformly distributed through the glass and comprise about 25 percent of the volume of the rock. Phenocrysts of andesine feldspar, quartz, and biotite, in descending order of abundance, together make up about 10 percent of the rock.

The four pitchstone exposures (fig. 8, p. 65) near the south quarter corner of sec. 24, (26-20E) show in road cuts where the road crosses a small tributary valley on its route to the top of the ridge dividing the Entiat and Columbia Valleys. Exposure no. 1 is approximately 2,500 feet in altitude and is 3.5 miles by road from the Entiat River road. Thoroughly fractured pitchstone shows for a dis-

[1] Waters, A. C., A petrographic and structural study of the Swakane gneiss, Entiat Mountains, Washington: Jour. Geology, vol. 40, p. 606, 1932. ——————, Geology of the southern half of the Chelan quadrangle, Wash.: Yale Univ. Doctor's Thesis (unpublished).

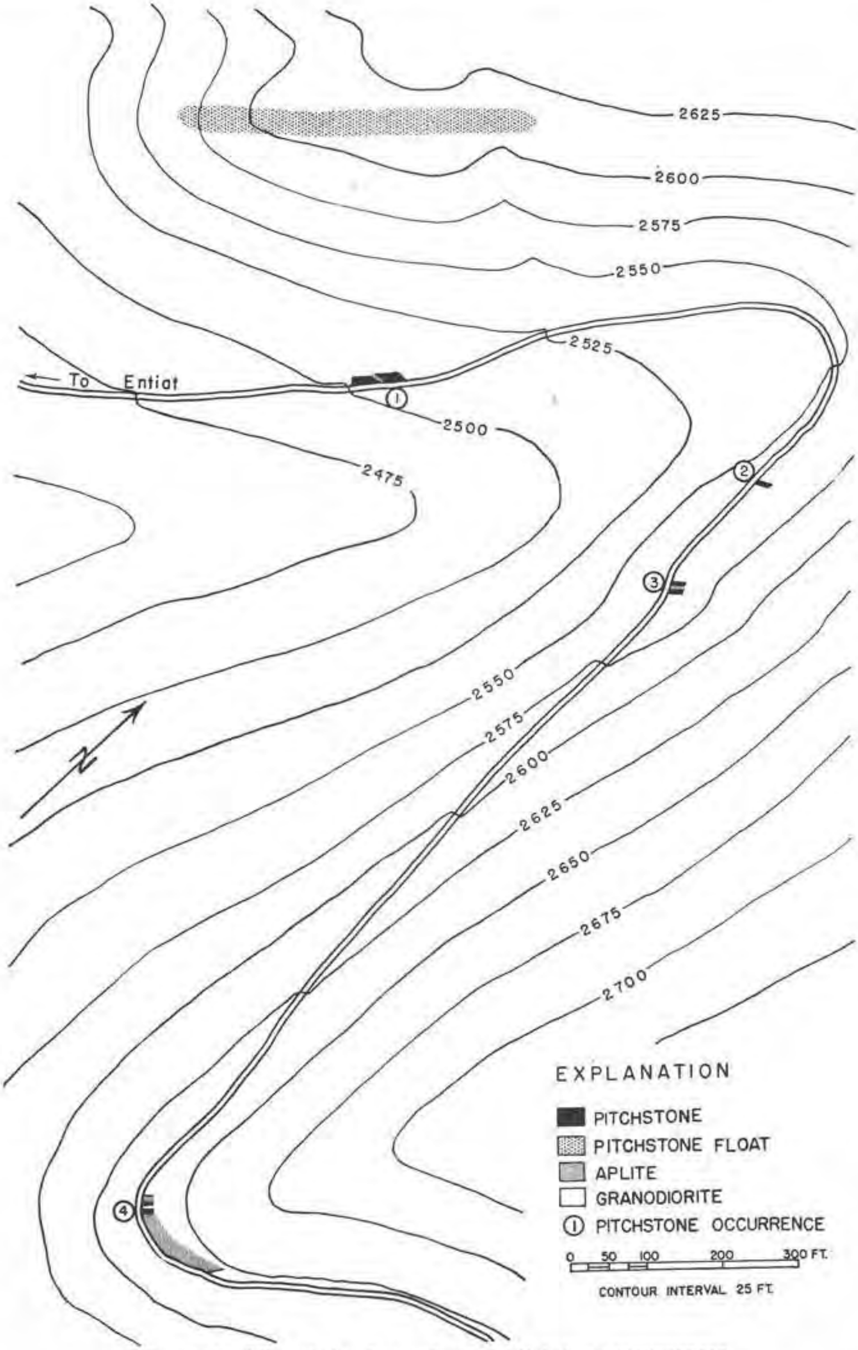

FIGURE 8.—Map of the Crum Canyon pitchstone occurrences.

tance of 70 feet to a maximum height of 5 feet in the cut along the northwest side of the road. The glass makes up a dike cutting the surrounding gneissic biotite-hornblende granodiorite. Near the center of the exposure, bordered on both sides by glass, is a 2-foot-wide band of aplite striking N. 70° E. and dipping 80° SE. The glass is dark green and translucent, and scattered through it are a few phenocrysts of megascopically recognizable feldspar and biotite. The rock is brittle and thoroughly fractured, so that it is only rarely that hand-size solid pieces are found. The slightest shock reduces the glass to a mass of minus-one-half-inch sharp, angular fragments. The glass apparently is the chilled equivalent of the rock in the central aplite band.

Pitchstone shows again at exposure no. 2 in a cut along the east side of the road 800 feet beyond the first exposure and 60 feet higher in altitude. Here, dark-green splintery glass shows to a height of 3 feet in an 18-inch dike which strikes into the hill N. 75° E. and dips 70° SE.

At exposure no. 3, up the road and south 180 feet from exposure no. 2 and 5 feet higher in altitude, is a 12-foot aplite dike which is bordered on each side by 6 inches of devitrified glass and 26 inches of dark-green fresh pitchstone. The fresh pitchstone is brittle and thoroughly fractured and appears to be very similar to that at exposure no. 1. The strike of the dike is N. 40° E. and the dip is 75° SE. Here, as at the other exposures, the dike cuts granodiorite and the pitchstone appears to be a chilled border phase of the dike.

Exposure no. 4 is 0.2 mile to the south and up the road from no. 3. Here, at the nose of a ridge and at an altitude of approximately 2,640 feet, a 70-foot aplite dike striking N. 40° E. and dipping 60° SE. has two bands of pitchstone adjacent to the borders of an included mass of wall rock near the footwall of the dike.

Section from footwall to hanging wall at exposure no. 4

	Ft.	*in.*
Granodiorite		
Aplite	15	0
Devitrified glass		4
Green pitchstone		4
Decomposed granodiorite	2	6
Devitrified glass		6
Green pitchstone	2	6
Devitrified glass		4
Aplite	60	
Granodiorite (base)		

The pitchstone is dark green, brittle, and greatly fractured. A few scattered crystals of feldspar are visible. The glass is exposed to a height of 7 feet in the road cut but does not crop out on the ridge elsewhere. The dike forms a topographic ridge which trends up the hill N. 35° E. A mining claim notice on a stake just above the road indicates that the deposit was staked and recorded in 1934 as the Golden Rode (sic) claim.

Up the hill 350 feet to the northwest of exposure no. 1, pitchstone and aplite float are very abundant for a distance of about 500 feet along a line which trends diagonally up the hill from an altitude of 2,565 feet to 2,620 feet. Although the dike does not crop out, the abundance of float indicates the rock to be near by, and as the soil overburden is not deep the hillside could be easily prospected by shallow trenches.

The results of laboratory tests made on Crum Canyon pitchstone are shown in the table on pages 26 and 27. The samples tested showed only small expansion, but a noteworthy feature disclosed by the tests is the nearly colorless glass produced when the pitchstone is fused. In the table two samples of glass from exposure no. 1, from the hanging wall and footwall sides of the aplite dike, are designated "Crum Canyon (1,a)" and "Crum Canyon (1,b)" respectively; the samples of pitchstone from exposure no. 3, from the hanging wall and footwall sides of the aplite dike, are designated "Crum Canyon (3,a)" and "Crum Canyon (3,b)"; and a sample representing the pitchstone at exposure no. 4 is designated "Crum Canyon (4)."

Old Butte

Northwest of the perlite deposits in the Wenatchee area (see fig. 5, p. 31) are three plug-like masses of volcanic rock which have been reported[1][2] to be glassy in part. These make up the craggy prominences known as Squaw Saddle, Old Butte, and Castle Peak, which lie in a N. 40° W.-trending line in secs. 8 and 16, (22-20E), about 1 mile southwest of Wenatchee. The highest parts of each of these crags are near 2,000 feet in altitude, about 1,000 feet above the valley floor at their bases. Their central parts are intrusive andesite, roughly circular or oval in outline, and have a total area of less than 80 acres. A description of the general geology of the area is given on pages 30-32. The Squaw Saddle andesite is described in detail by Smith and Calkins;[3] its glassy border phase

[1] Chappell, W. M., Geology of the Wenatchee quadrangle, Washington: Univ. Washington Doctor's Thesis (unpublished), pp. 123-129, 1936.
[2] Smith, G. O., and Calkins, F. C., A geological reconnaissance across the Cascade Range near the forty-ninth parallel: U. S. Geol. Survey Bull. 235, pp. 31, 57, 1904.
[3] Smith, G. O., and Calkins, F. C., idem, p. 57.

is stated to be composed of a light olive-green glassy groundmass of resinous luster, in which are abundant phenocrysts of plagioclase, hornblende, augite, and magnetite. The groundmass consists of microlites of plagioclase and hypersthene and grains of magnetite in a clear glassy base.

Half a mile northwest of the peak of Squaw Saddle is the crag known as Old Butte. Part of its central andesite mass is glassy—similar to that at Squaw Saddle. A cliff near the northwest end of the body shows olive-green dull- to resinous-lustered glassy andesite for a horizontal distance of 70 feet and to a height undetermined but in excess of 15 feet. The rock is porphyritic, the phenocrysts being feldspar and dark ferromagnesian minerals. Although the phenocrysts are fairly abundant, the percentage of glass appears to be greater than in the similar rock at Squaw Saddle. The glassy phase of the Old Butte rock was tested in the laboratory and results are given in the table on pages 26 and 27 under the heading, "Old Butte (1)." Results of tests on the adjacent nonglassy andesite are given for comparative purposes in the same table under the heading, "Old Butte (2)."

Moses Coulee Area

Basaltic glass occurs commonly as thin selvages on the pillow lavas which are widely distributed throughout central and southeastern Washington. The glass and associated palagonite were produced through the drastic chilling of molten basaltic lava in bodies of water. Although such occurrences are common, few of them contain large enough amounts of glass, free of foreign material, to make them of commercial interest even if there were a demand for basaltic glass. However, if a demand should develop, one of the best areas to prospect would be in the vicinity of Moses Coulee. There large masses of palagonite-breccia containing basaltic glass are so conspicuous in the cliffs as to be readily seen by the casual traveler along highway U. S. 10 immediately south of Moses Coulee. This occurrence of palagonite and associated glass, and others in the Moses Coulee area, are described by Fuller[1] and Peacock[2] whose accounts are the source of most of the following information concerning the basaltic glass of that area.

Moses Coulee is in central Washington near the western edge of the Columbia River lava plateau. It trends northeastward through south-central Douglas County for a distance of about 40 miles from

[1] Fuller, R. E., The aqueous chilling of basaltic lava on the Columbia River plateau: Am. Jour. Science, vol. 21, 5th series, pp. 281-300, 1931.
[2] Peacock, M. A., and Fuller, R. E., Chlorophaeite, sideromelane and palagonite from the Columbia River Plateau: Am. Mineralogist, vol. 13, no. 7, pp. 369-371, 1928.

its junction with the valley of the Columbia River 3 miles below Rock Island dam. Conspicuous, fore-set beds of palagonitic and glassy basalt, visible from highway U. S. 10, extend for about 1 mile in the steep cliffs above the highway along the east wall of the Columbia Valley 3 miles south of the mouth of Moses Coulee. The cliffs rise about 500 feet above the road. Their lower parts are masked by talus, but the upper cliffs contain a persistent horizon of breccia about 75 feet thick. The breccia represents the basal phase of a very fluid basaltic lava flow which advanced from the south into a shallow body of water, building north-dipping fore-set beds of ellipsoidal lava enclosed in a breccia of granulated glass and palagonite. Locally, the breccia is made up of granular fragments of vesicular and ropy basaltic glass, but in most places the glass has been almost completely altered to palagonite. Near the north end of the palagonitic flow the breccia is unaltered and is a porous mass of finely to coarsely vesicular fragments of black vitreous glass. A specimen of this rock is described by Peacock and Fuller[1] as consisting of irregularly shaped fragments of black basaltic glass as much as 4 centimeters long. The fresh glass has a hackly-conchoidal fracture, a vitreous luster, large distorted steam cavities up to 2 centimeters long, and numerous much smaller vesicles. There is a slight development of white and rusty alteration products along incipient cracks and inside some of the steam cavities, but the glass is otherwise unaltered. It is translucent on thin edges, and the powdered material has a faint green color. The glass has a hardness of 5½ and a specific gravity of 2.74. The microscope shows a few tabular microlites of sodic labradorite and faintly colored rhombic and monoclinic pyroxene. The glass is homogeneous, isotropic, perfectly clear and fresh, and has a refractive index of 1.583. The chemical analysis given by Peacock and Fuller[2] (see page 70) shows an unusually high ratio of FeO to Fe_2O_3.

Glassy margins on masses of basalt are reported by Fuller[3] at the base of a mass of ellipsoidal lava exposed in the north wall of Moses Coulee about 7 miles from its mouth, and palagonite and basaltic glass occur in the valley of Douglas Creek, a tributary which enters Moses Coulee about 16 miles northeast of the Columbia River. The glass occurs in the Douglas Creek Canyon at the lower of two falls, in the NW¼ SW¼ sec. 30, (23-24E), about ½ mile from the canyon mouth. The oldest rocks exposed in the Moses Coulee area are in a 35-foot section of well-stratified, interbedded light-gray to

① Peacock, M. A., and Fuller, R. E., op. cit., p. 370.
② Peacock, M. A., and Fuller, R. E., op. cit., p. 371.
③ Fuller, R. E., op. cit., pp. 291, 295-297.

Analysis of Moses Coulee basaltic glass
by W. H. and F. Herdsman

SiO_2	51.30
Al_2O_3	18.54
Fe_2O_3	0.26
FeO	11.21
MgO	4.03
CaO	8.55
Na_2O	2.83
K_2O	1.05
H_2O+	0.30
H_2O-	tr.
TiO_2	1.40
MnO	0.35
P_2O_5	0.05
CO_2	nil
S	nil
	99.87

buff arkosic sands and light to very dark colored shales, which underlies the basalt at the upper falls of Douglas Creek. This is the type locality for the Douglas Canyon formation of Hoffman,[1] which was considered by him to be late Miocene in age and correlative with the Latah and Ellensburg formations. The Columbia River basalt conformably overlies the sedimentary series, and the contact can be traced for several hundred yards in the canyon wall. At the lower falls the material underlying the basalt is well exposed, but there it is yellow massive palagonite breccia, a thin upper zone of which is slightly stratified and contains fragments of basaltic glass. Below the upper zone is a mass of palagonite breccia and included irregular blocks and streaks of micaceous sediments; basaltic glass is enclosed by, and associated with, the sediments. Below the lower falls, massive basalt is exposed at the base of the granular palagonite and sediments, and small apophyses from the basalt are selvaged by basaltic glass, which locally has structure which approaches perlitic.

Asotin Area

Basaltic glass, associated with palagonite, occurs in several places along the west bank of the Snake River in southeastern Washington near the towns of Asotin and Clarkston in Asotin County and along the opposite side of the river in Idaho. Farther south in Asotin County, basaltic glass has been reported[2] in the canyon of the

① Hoffman, A. D., The Douglas Canyon flora of east central Washington: Jour. Geology, vol. 40, pp. 733-738, 1932.

② Peacock, M. A., and Fuller, R. E., Chlorophaeite, sideromelane and palagonite from the Columbia River Plateau: Am. Mineralogist, vol. 13, no. 7, pp. 361-369, 1928.

Grande Ronde River, south of Anatone. The occurrences near Asotin and Clarkston are in a zone about 11 miles long and 1 mile wide, trending N. 35° W., roughly parallel to the 1,100-foot-deep Snake River Canyon, from sec. 1, (9-46E) to sec. 23, (11-45E). The occurrence in the Grande Ronde Canyon is 20 miles south of Asotin, where the river is incised 2,800 feet into the north-sloping basalt plateau. This area is 35 miles by road from Lewiston, Idaho, the closest point on the Camas Prairie Railroad. Asotin is 8 miles by road from Lewiston.

The general geology of the Asotin region is described by Russell,[1] who also briefly mentions glassy tuff at Swallow Rock, 2½ miles north of Asotin. This occurrence and others in the area are described in more detail by Peacock,[2] Fuller[3] and Lupher and Warren,[4] in reports which are the bases for the following descriptions.

Practically the whole of Asotin County is underlain by basaltic flows of the widespread Tertiary Columbia River lava of Russell. Rocks older than the lavas are not exposed in the immediate vicinity of the basaltic glass outcrops, but there are small exposures along the Snake River near the mouth of the Grande Ronde. An arkosic sandstone unit about 250 feet thick is interbedded with the upper part of the Columbia River lava, about 200 feet from the top of the section. The Columbia River lava flows are remarkably uniform and continuous, individual flows being traceable for thousands of yards along the canyon walls; but interrupting the gently dipping flows in the Asotin area are masses of columnar, hackly, and massive basalt having V- or U-shaped cross sections and elongated, generally oval, plan views. These are the Asotin craters of Fuller,[5] which were determined by Lupher and Warren[6] to be remnants of a former Snake River Canyon lava fill, composed of two thick basalt flows that have a maximum observed thickness of 850 feet. Patches of intracanyon lavas show along both sides of the Snake River for a distance of 7 miles above Asotin and 12 miles below, and basaltic glass may be found in any of the remnants. Fuller specifically describes three occurrences of glass on the Washington side of the river. In addition, both he and Lupher describe several occurrences of palagonite, and as palagonite results from the alteration of ba-

[1] Russell, I. C., Geology and water resources of Nez Perce County, Idaho: U. S. Geol. Survey Water-Supply Paper 53, pt. 1, 85 pp., 1901.

[2] Peacock, M. A., and Fuller, R. E., op. cit., pp. 361-369.

[3] Fuller, R. E., The Asotin crater of the Columbia River basalt: Jour. Geology, vol. 36, pp. 56-74, 1928.

[4] Lupher, R. L., and Warren, W. C., The Asotin stage of the Snake River Canyon near Lewiston, Idaho: Jour. Geology, vol. 50, no. 7, pp. 875-876, 1942.

[5] Fuller, R. E., op. cit.

[6] Lupher, R. L., and Warren W. C., op. cit.

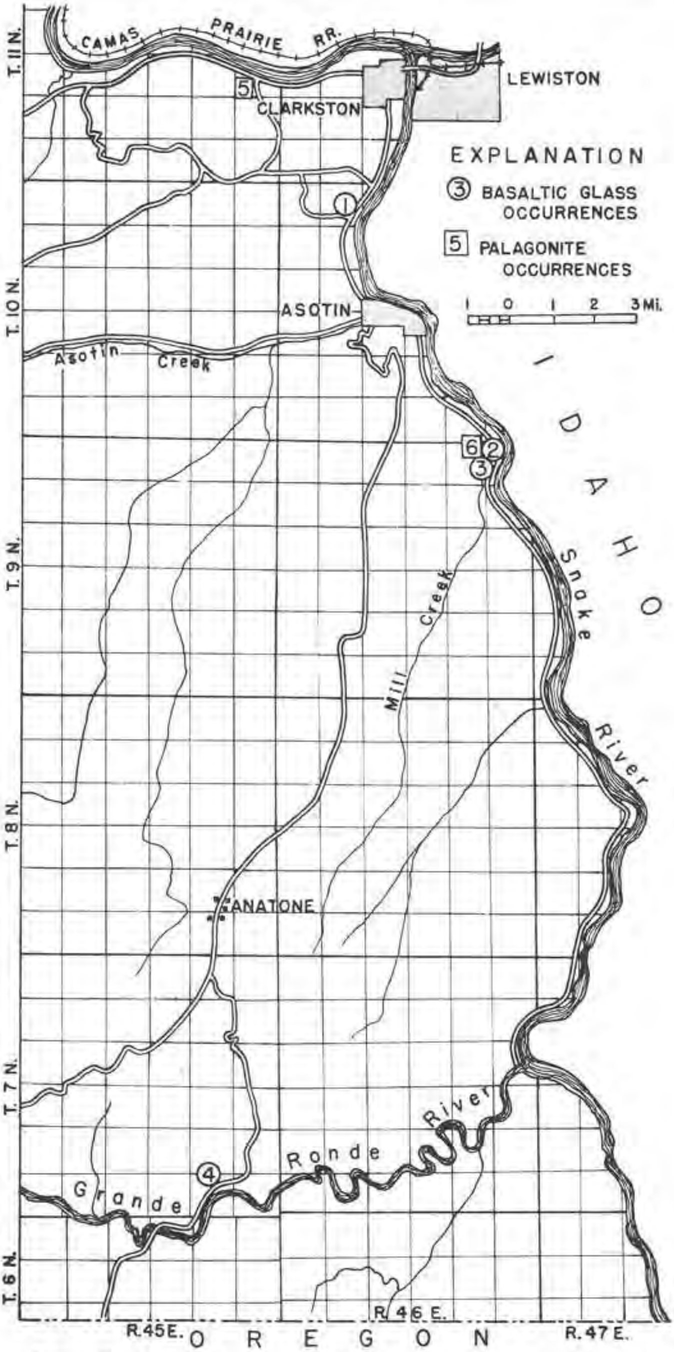

FIGURE 9.—Map of the Asotin area volcanic glass occurrences.

saltic glass, the unaltered glass might be found at any of these palagonite occurrences.

Figure 9 (p. 72) shows the locations where basaltic glass and palagonite have been reported, and the map of Lupher and Warren[1] shows the outline of the intracanyon lava masses, which may be used to delimit areas favorable for the occurrence of glass. It is reported that a layer of palagonite, generally less than 6 feet thick, is present in most places at the base of the lower flow, and the same material also occurs as irregular and lenticular masses ranging from a few feet to more than 200 feet in thickness at and near the base of the upper flow.

At location no. 1 (fig. 9, p. 72) a tuff composed of a mixture of basaltic glass and palagonite is exposed in a gully in the SE¼ sec. 5, (35-46E), on the south side of Swallow Rock, a rock promontory on the west bank of the Snake River, 2 miles north of Asotin. This tuff, known locally as Asotin sandstone, has been used to a small extent as building stone. The tuff beds intertongue with minor sheets of lava which grade into the lower part of the upper intracanyon flow. Tuff is exposed over an area of several acres and to a depth of more than 15 feet. The rock is medium-grained, friable, and porous. It is composed of yellow-brown earthy palagonite grains scattered through somewhat more abundant similar-size grains of black glass. The color of the glass is partially hidden by thin coatings of the brown palagonite. Peacock and Fuller[2] describe a thin section of the rock as being made up of olive-buff fragments of basaltic glass averaging 0.5 millimeter in diameter and containing a small amount of pyroxene and plagioclase microlites. Internally, the glass fragments are perfectly fresh and have a refractive index of 1.592. Marginally, each grain is altered to yellow palagonite showing a low and variable refractive index of 1.47 ± 0.01.

The results of laboratory tests made on the basaltic glass tuff from Swallow Rock are given under the heading, "Asotin," in the table on pages 26 and 27.

At location no. 2 (fig. 9, p. 72), in the NW¼ sec. 1, (9-46E), 3½ miles southeast of Asotin, is a mass of intracanyon lava about 600 feet deep, 300 feet wide, and 1,500 feet long in a N. 45° W. direction. The base of the body is 400 feet above river level. Pyroclastics near its margins contain local masses of unaltered granular basaltic glass. Peacock and Fuller[3] state that a tuff at the top of the lava body

[1] Lupher, R. L., and Warren, W. C., op. cit., p. 867.
[2] Peacock, M. A., and Fuller, R. E., op. cit., p. 375.
[3] Peacock, M. A., and Fuller, R. E., op. cit., p. 374.

consists wholly of lightly cohering fragments of basaltic glass about 2 millimeters in diameter. In thin section the glass is perfectly fresh and carries a small amount of olivine and calcic plagioclase phenocrysts. The refractive index of the glass is 1.597.

About 500 feet from the southwestern border of the intracanyon lava body of location no. 2 is a similar but slightly smaller body at location no. 3. Here Fuller ① reports basaltic glass as a border phase of the younger lava at its contact with the Columbia River lavas.

Large masses of palagonite at locations no. 5 and 6 further extend the area in which basaltic glass may be found. Location no. 5 is 3 miles west of Clarkston, on the south side of the Snake River at the mouth of an intermittent stream, near the east quarter corner of sec. 23, (11-45E). The base of the lower intracanyon flow is exposed beside the highway only about 30 feet above river level. Palagonite at the base of the flow overlies 20 feet of sediments that are largely sandstone. Fuller② reports analyses showing the basaltic glass at this location to contain 49.63 percent SiO_2 and 10.17 percent Fe_2O_3, and its crystalline equivalent to be very similar in composition, having 48.86 percent SiO_2 and 11.65 percent Fe_2O_3, calculated on an anhydrous basis.

The basaltic glass reported by Peacock and Fuller③ as occurring in the Grande Ronde Valley south of Anatone (location no. 4) is a border phase of a 55-foot trachydolerite dike which cuts Columbia River lavas. The dike is at the bottom of Shumaker Canyon in the NE¼ sec. 35, (7-45E) and is tunneled for the road which leads southward from Anatone to Paradise, Oregon. The glass occurs as 1- to 2-inch selvages on both margins of the dike.④ The following analysis of the Grande Ronde basaltic glass is reported by Peacock and Fuller.⑤

Analysis of Grande Ronde basaltic glass
by Ledoux & Co.

SiO_2	48.90
Al_2O_3	12.70
Fe_2O_3	2.82
FeO	12.93
MgO	2.65
CaO	9.30
Na_2O	1.97
K_2O	2.83
TiO_2	1.86
MnO	.73
ignition	3.11
	[99.80]

① Fuller, R. E., op. cit., p. 65.
② Fuller, R. E., op. cit., p. 62.
③ Peacock, M. A., and Fuller, R. E., op. cit., pp. 361-364.
④ Fuller, R. E., personal communication, 1949.
⑤ Peacock, M. A., and Fuller, R. E., op. cit., p. 363.

Blyn

Basaltic glass is reported[1] in eastern Clallam County, along Jimmycomelately Creek, at the south center of sec. 13, (29-3W). The glass is exposed in cuts along a graveled county road 2 miles south of Blyn, a station on the Chicago, Milwaukee, St. Paul & Pacific Railroad. A road cut 40 feet high and about 150 feet long exposes basaltic breccia and glass-bordered fragments of basalt as much as 1 foot in diameter but averaging less than 4 inches, in a shattered glass matrix. Similar rocks are exposed in smaller outcrops for 0.35 mile south to the northern boundary of the Olympic National Forest. The areas between the road cuts are covered by drift. The glass is intimately associated with nonglassy basalt, and the individual glass masses are small, but possibly larger masses may be found if the incentive for further search is furnished by future discovery of commercial uses for basaltic glass. The results of laboratory tests on the Blyn basaltic glass are given in the table on pages 26 and 27.

Other Reported Occurrences

A sample submitted in 1943 to the Division of Mines and Geology by Mr. Byron Hanmer of Liberty was identified as basaltic glass. Nothing is known of the size of the deposit from which the sample came, and its location is known only approximately as being on the headwaters of Boulder Creek. This is a tributary to Williams Creek, which flows into Swauk Creek at Liberty, in north central Kittitas County. The probable location is in sec. 7 or sec. 8, (20-18E). The rock is shining black and breaks with hackly fracture. In thin section it is shown to be composed of light-brown clear glass, through which are scattered abundant laths of plagioclase up to 1 millimeter in length and somewhat less abundant augite grains of about the same size. The phenocrysts make up approximately 20 percent of the rock. Results of laboratory tests on the rock are recorded in the table on pages 26 and 27.

A sample of basaltic glass was submitted for identification in 1947 by Mr. John W. Marshall of Spokane. Nothing is known of the size or location of the deposit from which the sample came, but laboratory tests indicate the glass to have some peculiar properties, and it is for that reason that the results of the tests are included in the table on pages 26 and 27. The Marshall glass was found to have only a very small amount of uncombined water, and it was the only sample to contain no combined water, although the Hanmer basaltic glass

[1] Glover, Sheldon L., field notes.

had less than 0.5 percent. Strangely enough, the Marshall glass was found to gain, rather than lose, weight when it was heated to 850° C. for 3 hours, so the combined water content was recorded as a minus figure. No acceptable explanation for this anomaly has yet been offered.

OTHER VOLCANIC ROCKS TESTED

A large portion of the State of Washington is covered by volcanic rocks, as can be readily seen on the state geologic map① but only the rhyolites and andesite lavas are likely to produce perlite, the volcanic glass currently in demand, and the areas covered by these rocks are not especially large. Such areas are outlined on the map (fig. 2) on page 17. Thorough prospecting in these areas probably will disclose occurrences of volcanic glass not now known. The prospector should use care in his identification of the glassy volcanic rocks. Many that appear superficially to be vitrophyres having glassy groundmasses actually have aphanitic groundmasses, the texture being so fine that individual crystals cannot be distinguished by the naked eye. The crystalline nature of some aphanitic rocks can be determined only by microscopic examination of thin sections or crushed fragments.

Samples of volcanic rocks from four localities, designated "Old Butte (2)," "Hyak," "Randle," and "Ruth Creek," were tested and found to contain little or no glass, in spite of their glassy appearance to the naked eye. The results of the tests are shown in the table on pages 26 and 27. All four of these rocks have feldspar crystals up to 4 millimeters in length, and all but the Hyak rock have grains of femic minerals set in an aphanitic groundmass. The groundmasses in two of the rocks, the Randle and Ruth Creek samples, are black, making the rocks look somewhat like porphyritic obsidian. The other two rocks, represented by the Hyak and Old Butte (2) samples, are light-gray colored. The Hyak rock contains small phenocrysts of quartz.

The Old Butte (2) sample represents the aphanitic phase of the Old Butte andesite in the Wenatchee area, Chelan County, described on pages 67 and 68.

The Hyak sample was collected from a rhyolite exposure in a road cut along highway U. S. 10, near Hyak, about 2 miles west of Lake Keechelus, in western Kittitas County. This rhyolite is a part

① Culver, H. E., The geology of Washington, pt. 1, General features of Washington geology—with accompanying preliminary geologic map of the state: Washington Div. Geology Bull. 32, 1936.

of that mapped by Smith and Calkins[1] as a belt less than ½ mile wide and 6 miles long. It is reported by them to be part of the Guye formation of Miocene age.

The Randle sample is from sec. 15, (11-7E), in eastern Lewis County. It is reported to come from a large dike-like body which extends 3 miles southwestward from the mouth of Greenhorn Creek at the Cispus River to near the top of Iron Creek Butte.

The Ruth Creek sample was collected by Mr. John Pierce of Bellingham, who reports[2] that a large amount of similar black porphyry occurs as float northeast of Mount Shuksan along the ridge between Ruth Creek and Copper Creek. This is in Central Whatcom County, probably in sec. 8, (39-10E). Thirteen miles west, similar rock occurs abundantly as float along the Nooksack River near the Excelsior power plant.

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[1] Smith, G. O., and Calkins, F. C., U. S. Geol. Survey Geol. Atlas, Snoqualmie folio (no. 139), p. 16, 1906.

[2] Pierce, John, oral communication, 1947