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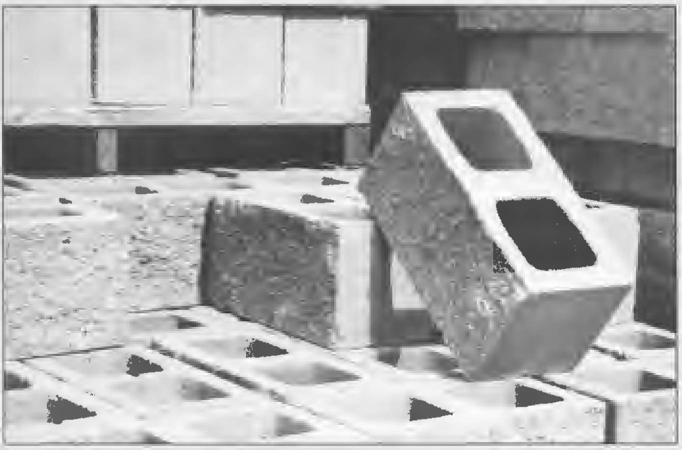

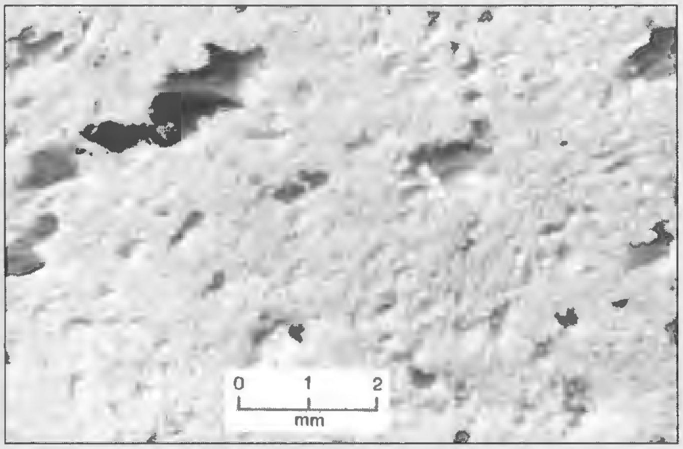

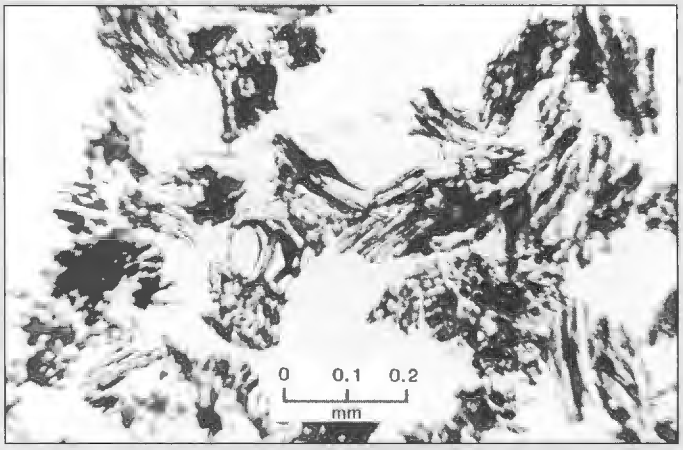

PUMICE

IN OREGON

1992

1859

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

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SPECIAL PAPER 25

PUMICE IN OREGON

By Ronald P. Geitgey
Oregon Department of Geology and Mineral Industries

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COVER PHOTOGRAPHS (top to bottom)

1. One of several mining pits of Central Oregon Pumice Company in Bend, Deschutes County.
2. Lightweight concrete block made with pumice aggregate.
3. Section in finely vesicular pumice, transverse to the direction of vesicle elongation.
4. Example showing the cellular characteristics of pumice retained even in small fragments.

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PUMICE IN OREGON

SUMMARY

Pumice is produced by two companies in Oregon, primarily for lightweight concrete aggregate and horticultural uses. Lesser amounts are sold for absorbents, landscaping, and stonewashing garments. This report reviews these operations and surveys other pumice occurrences to identify possible additional sources of pumice for various markets. Chemical analyses, screen size analyses, and physical data including color, hardness, density, and water absorption are presented for 25 samples from nine eruptive centers. The Bend pumice is the primary source of current production, but producers must operate in an increasingly urbanized environment. Pumice deposits from both Mount Mazama (Crater Lake) and Newberry volcano eruptions have economic potential, but both require additional exploration and testing.

ACKNOWLEDGMENTS

I wish to thank the following reviewers for their respective criticisms and perspectives: Dick Berg, Montana Bureau of Mines and Geology; Mark Ferns, Oregon Department of Geology and Mineral Industries; Jim Gauthier-Warinner, USDA Forest Service, Placerville, California; and Jerry Hoffer, University of Texas at El Paso. Numerous conversations with Jerry Hoffer also helped clarify the still evolving technology, requirements, and testing of the stonewashing industry. I am particularly appreciative of discussions with Bill Miller, Central Oregon Pumice Company; Chuck Clark, Cascade Pumice Company; Griff Griffin, United States Pumice Company; and Marvin Hess, Hess Pumice Products. Laboratory analyses were performed by Chuck Radasch; the plates were prepared by Mark Neuhaus, and the report was prepared for publication by Beverly Vogt, Klaus Neuendorf, and Rhonda Marks, all of the Oregon Department of Geology and Mineral Industries.

INTRODUCTION

Pumice is a volcanic rock composed of bubbles or vesicles in glass matrix formed by the effervescence of gases and rapid cooling of molten material during an eruption. Pumice is characteristically frothy and lightweight, often with density low enough to permit it to float on water. The vesicle walls form thin sharp cutting edges when broken, making pumice an effective abrasive in both lump and powder forms. These characteristics are responsible for the commercial value of pumice as absorbents, insulators, abrasives, and lightweight aggregates and fillers.

PURPOSE AND SCOPE OF STUDY

The purpose of this study is to describe occurrences of pumice in Oregon, to provide basic test data for preliminary evaluation of their commercial potential, to identify areas that would benefit from more detailed work, and to provide a basis for land use planning decisions in areas of conflicting interests.

This study is by no means exhaustive. Exposures were sampled, and areal and stratigraphic data were taken from existing geologic maps. No new field mapping was undertaken and, with the exception of the unique Rock Mesa occurrence, no pumice deposits were investigated within national park or wilderness area boundaries, since such deposits could not now be developed commercially. Laboratory testing was limited by available funds and facilities and by the absence of published test procedures for many end uses.

UNITS USED IN STUDY

Throughout this paper, an unavoidable mixture of units occurs—English, metric, and screen sizes. Volcanologists almost universally use the metric system for measurements, including particle sizes, deposit dimensions, distances, volumes, and ejection velocities. Pumice producers and consumers in the United States use inches and fractions to describe particles of about ⅛ in. or more and screen mesh sizes to describe smaller particles, as well as specialized terminology not included here. This multiplicity of approaches is not surprising, considering that pumice can be regarded as both an igneous rock and a sedimentary deposit offering insights into volcanic processes and that pumice is also a commercial commodity serving a very wide variety of markets. I have attempted to use units in a manner consistent with the source of the information and appropriate to the subject being discussed.

GEOLOGY AND CHARACTERISTICS OF PUMICE

The terminology and classification schemes applied to pumice and associated deposits are confusing, reflecting in part various approaches taken to describe their origins and characteristics, commercial usage in the market place, and legal definitions. "Pyroclastic" is a term referring to fragmental products of volcanic eruptions. It has been variously applied to particles, unconsolidated deposits, and consolidated deposits. "Tephra" is a general term used for unconsolidated pyroclastic fragments and deposits. Both may include pumice, nonvesicular lava, fragmented country rock, and crystals.

CLASSIFICATION BY SIZE

Several classification systems have been devised based on particle size (Fisher, 1961; Schmid, 1981). Finer sizes with an upper limit of 2 mm or 4 mm, depending on the classification system used, are generally called "ash." Pumice below this size may still be finely vesicular or consist of just fragments of vesicle walls, and it is often termed "pumicite" or "volcanic ash" for commercial purposes. Fragments between 2 or 4 mm and about 64 mm in size, again depending on the classification system employed, are called "lapilli." Particles coarser than 64 mm are called "blocks" or "bombs."

BLOCK PUMICE

Pumice particle size is of legal importance in the United States. The Surface Resources Act of 1955 (U.S. Code, Title 30, Section 611) names sand, stone, gravel, pumice, pumicite, and cinders as "common variety" materials. As such, they cannot be acquired on federal land by staking a mining claim but rather must be purchased from the government. The Act defines "block pumice" as pumice that "occurs in nature in pieces having one dimension of two inches or more" and expressly excludes block pumice from the common variety materials. Also excluded are "deposits of such materials which are valuable because the deposit has some property giving it distinct and special value." Conditions under which pumice on federal land can be acquired by locating mining claims or by purchase have been variously interpreted by the courts and by the Interior Board of Land Appeals and remain a source of litigation.

FORMATION OF PUMICE

The formation and preservation of pumice require a balance between the internal gas pressure, viscosity, and temperature of an erupting magma. Dissolved gases, primarily water, may quickly escape from a low-viscosity magma without forming a rigid foam. If higher viscosity, impermeable country rocks, or a blocked vent prevent rapid escape of gases from magma as it nears the surface, an explosive eruption may occur, shattering the bubble walls and generating a volcanic ash of fine glass shards rather than a vesicular pumice. If pumice is reheated, by being entrained in an ash flow for example, it may soften and collapse into nonvesicular glass.

Pumice deposits are readily susceptible to erosion and weathering, especially in humid climates. Low particle density and relatively low strength permit rapid mechanical weathering, and the glassy structure and extremely large surface areas caused by vesicularity promote rapid chemical weathering. As a result, most pumice deposits are quite young geologically, often no more than a few hundred or a few thousand years old.

Pumices are typically formed by eruptions of rhyolitic or dacitic magmas, with silica contents of approximately 65 to 75 percent and with high viscosities and explosive eruptive styles characteristic of that composition range. Basaltic magmas, which have lower silica contents and are more fluid, can generate pumice deposits, but basaltic pumices are less common.

TYPES OF DEPOSITS

The type of pumice produced by an eruption is affected by many factors including magma composition, gas content, style of eruption, and whether the eruption is subaerial or subaqueous. After eruption, deposits can be modified by welding, weathering, erosion, transport, and redeposition. The major types of pumice deposits are summarized below, but the subtleties and complexities of characterizing these eruptions and their products are far beyond the scope of this study. The reader is referred to Cas and Wright (1988) and their extensive list of references. Characterization is complicated by the relative rarity in historic times of large-scale pumice-producing eruptions and by the inherent difficulties in directly observing explosive eruptive processes.

Pumice deposits can be broadly classified into four major types: flows and domes, air-fall deposits, pyroclastic flows, and epiclastic, or reworked, deposits. All may be formed even in the same eruption. There are gradations between types, and deposits may be a mixture of types reflecting variations in eruption conditions. Changes in wind direction, blocking and clearing of the vent, increase in vent diameter, influx of water in the magma chamber, influx of a different magma, and rapid gas exsolution by unloading and depressurization may contribute to the character of the resulting ash and pumice deposits.

Flows and domes

Viscous magmas may be extruded with little explosive activity, forming lava flows and domal mounds. A vesicular rind, or carapace, can develop on their rapidly cooling outer surfaces, often forming a surface of blocky pumice rubble underlain by obsidian or by nonvesicular lava (Figure 1). Continued cooling and crystallization of the flow increase the volatile content of the remaining liquid, which can then cause more vesiculation within the flow, often in interlayers with nonvesicular rock. Buoyant masses of this pumice can forcibly pierce the overlying flow to reach the surface as pumice diapirs. Increased volatile content and resultant increased internal gas pressure can also form explosive craters on the surface of the flow and generate pyroclastic flows long after the eruption has ceased. Typically, pumice flows and domes are only a few square miles in areal extent. Rock Mesa, a pumice flow in the central Cascade Range of Oregon, is about 2½ mi^2 (Fink and Manley, 1987); and Mono Craters, a multiple dome and flow complex in east-central California, covers about 12 mi^2 (Chesterman, 1956, p. 15). Pumices associated with domes and lava flows often have larger vesicles than other pumice types and may form blocks of several feet in dimension. However, the erratic nature of the vesiculation can make exploration and development difficult.

Air-fall deposits

Explosive eruptions eject fragments of dense magma, vesiculated magma (pumice), and country rock in various proportions and with various velocities and degrees of fragmentation. These fragments, and in many cases the deposits formed by them, are broadly referred to as "pyroclastic."

In a Plinian eruption, named after Pliny the Younger's description of the Mount Vesuvius eruption in A.D. 79, pyroclastic material is explosively ejected upward from the volcanic vent. The pyroclastics are boosted into the atmosphere by the explosion and maintained in suspension by convection, giving the appearance of a vertical column that flattens and spreads out at its top. Pliny the Younger compared its shape to that of a pine tree with a tall trunk (Bullard, 1976, p. 193). Judging on the basis of grain size and dispersal characteristics, Walker (1980, p. 77) concluded that some Plinian, or eruptive, columns may exceed 30 mi in height.

Figure 1. Block pumice surface of Rock Mesa, a pumice flow in Lane and Deschutes Counties. The pumice blocks range up to several feet in dimension.

Figure 2. Pumice from the Mazama (Crater Lake) climactic eruption that blanketed preexisting topography developed on basalt flows near Chemult, Klamath County.

Large or dense fragments leave the vent ballistically and fall at distances dependent on muzzle velocity. Smaller or less dense particles such as pumice and ash may be removed from the Plinian column by winds and cooled and deposited over wide areas, depending on column height, wind velocity and direction, and particle size and density.

These air-fall deposits vary in particle size with distance from the vent and commonly contain pumice particles ranging from a few inches downward. Air-fall deposits typically blanket the preexisting topography over large areas (Figure 2) and, unless later modified by erosion and deposition, may have thicknesses of several tens of feet. Most commercial pumice operations utilize air-fall deposits.

Pyroclastic flows

Decreases in eruption activity or overloading by continued eruption can cause the eruptive column to collapse sporadically or continuously. The hot pyroclastic material falls back and flows outward from the vent, following topography, possibly over areas of tens or hundreds of square miles. Such pyroclastic flows can retain enough heat to fuse or weld the particles together after movement stops. The names applied to these rocks have historically been rather imprecise, including "tuffs," "welded tuffs," "ash flows," and "ignimbrites." Pumice fragments may survive intact on upper and lower surfaces that cool before welding occurs, but pumice fragments in the flow interior soften and collapse. Pumice deposits associated with pyroclastic flows tend to be thinner than air-fall deposits, and since unwelded portions are either easily eroded flow tops or are overlain by welded portions, pyroclastic-flow pumices are less frequently exploited commercially than air-fall pumice deposits.

Epiclastic deposits

Epiclastic processes include erosion, transportation, and redeposition by such mechanisms as water, wind, and mass movement. From a commercial standpoint, these processes can either degrade or enhance a pumice deposit. All could reduce pumice particle size and possibly intermix nonpumice material, but wind and water can also sort by size and density and beneficiate the deposit by separating pumice from crystals and rock fragments. Mineable thicknesses of pumicite were produced in the Great Plains when surface drainage washed thin blankets of airborne ash into lake basins.

CHARACTERISTICS OF PUMICE

Vesicle size in various pumices ranges from less than 0.01 mm up to several centimeters, although upper limits of about 1 mm are more common. Shapes include vesicles that are irregular, spherical, elliptical, and elongate to the point of being tubular with a fibrous, silky appearance. In general, smaller vesicles also have thinner vesicle walls and break into finer fragments. Some pumices are cellular with little interconnection between the vesicles and with resultant low permeability. Others have a high degree of interconnection, relatively higher permeability, and absorbent characteristics. Examples of vesicle size and morphology are illustrated in Figures 3 through 8.

Pumice deposits and individual pumice particles may contain crystals that were present in the erupting magma; obsidian clots and layers representing unvesiculated magma; and rock or lithic fragments from the country rock through which the magma was erupted, including products of previous eruptions. In small amounts and for many end uses this foreign material is not detrimental, but for some specialized products, such as abrasives for optical polishing, only clean pumice deposits are suitable.

Density and hardness are two important properties of pumice, but in using them as terms one should apply them precisely to avoid confusion.

"Density" may refer to the glass itself, the apparent density of a pumice particle, or the bulk density of pumice in a deposit or product. Pumice glass may have a specific gravity of 2.5 or more, depending on its chemical composition. Pumice fragments typically have specific gravities less than 1.0 or, in terms of "density," less than 1 g/c^3 or 62.4 lb/ft^3. That is to say they are lighter than water and will float, at least until the vesicles are filled, and the fragment becomes saturated. Bulk density is a function of both particle density and particle size distribution. A given volume of only large fragments weighs less than the same volume containing a mixture of large and small fragments. The typical density range for pit-run material is 1,000 to 1,200 lb/yd^3.

"Hardness" may refer to the glass matrix (possibly including crystals or lithic fragments) or the pumice particle as a whole (more accurately a measure of friability or breakability). Pumice glass typically has a Mohs hardness of 5 to 5½, while a pumice particle may have much lower apparent hardness and be easily cut with a knife or steel saw because the vesicle walls break readily.

Figure 3. Example of large vesicles in a pumice block from the Mazama (Crater Lake) climactic pumice flow, sample location 14 near Beaver Marsh in Klamath County. Knife is approximately 5 cm long.

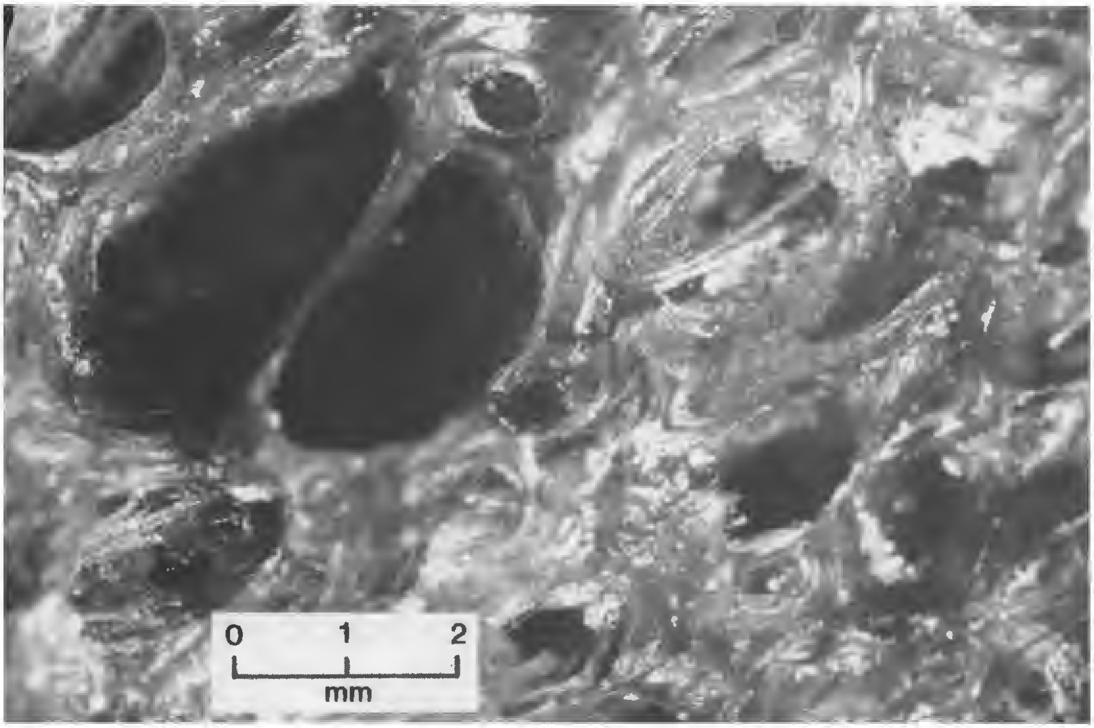

Figure 4. Coarsely vesicular pumice with thick walls from the Rock Mesa block pumice flow, Lane and Deschutes Counties (sample 3).

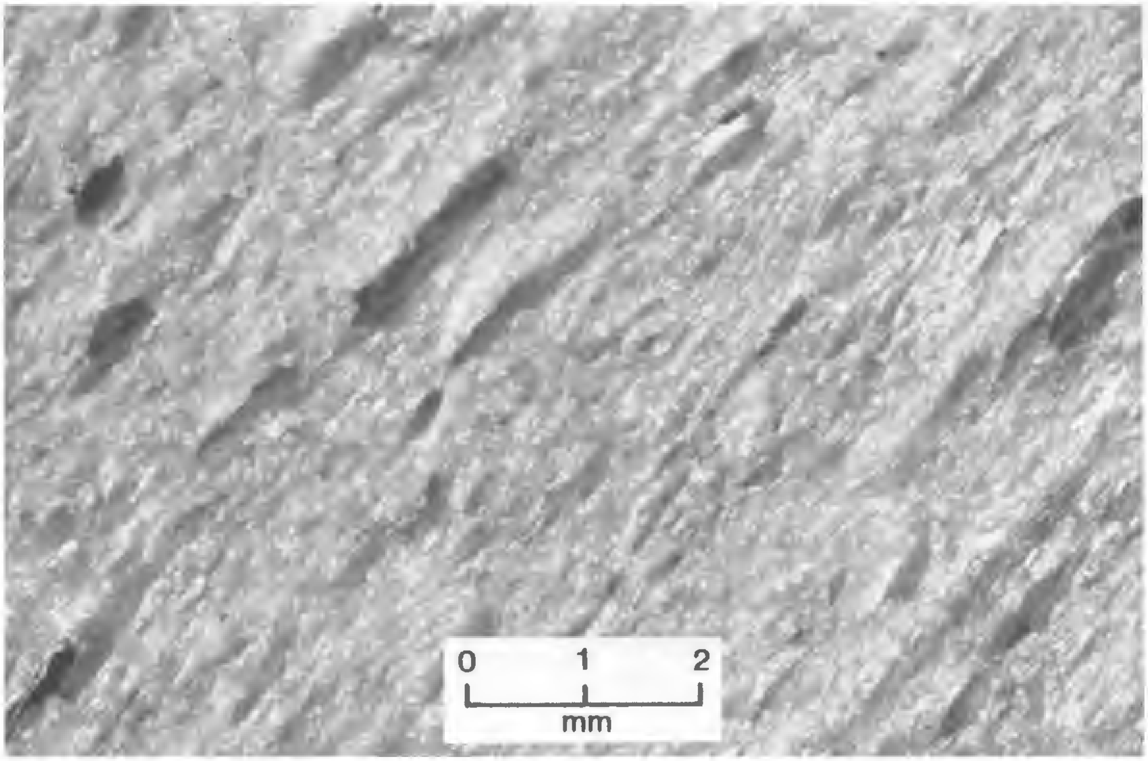

Figure 5A. Section of pumice fragment from Central Pumice Cone, Newberry volcano, Deschutes County (sample 6), parallel to the direction of vesicle elongation.

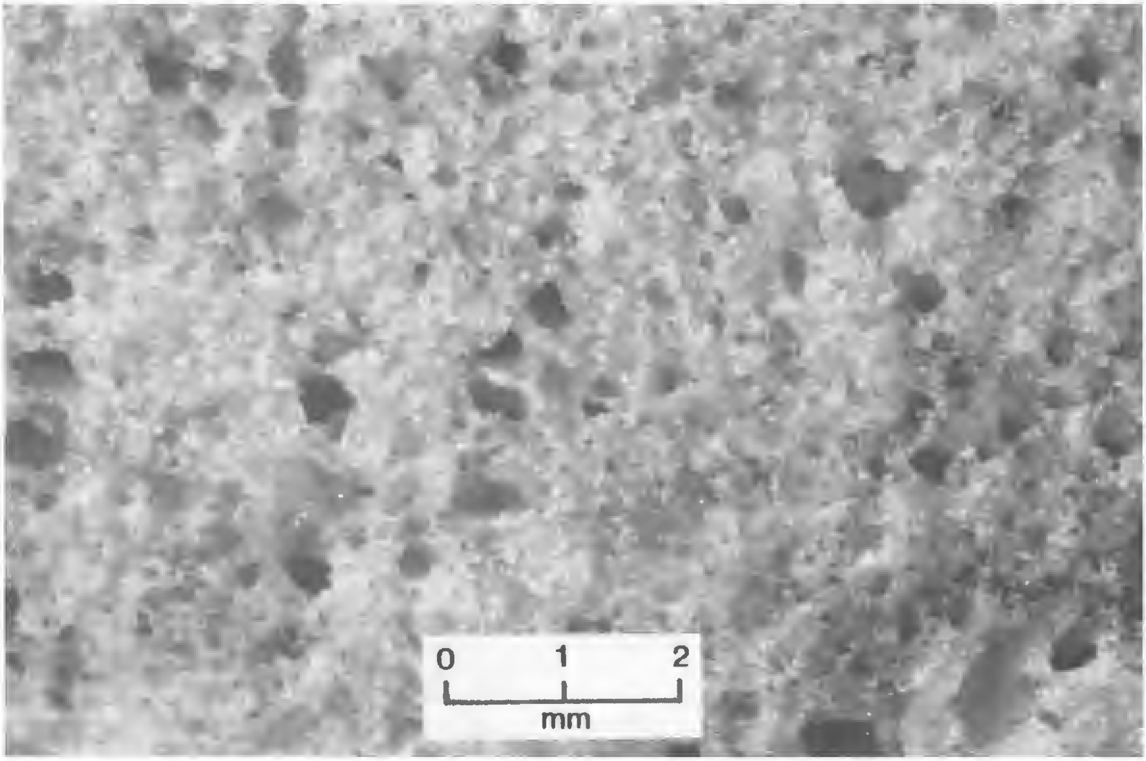

Figure 5B. Section of pumice fragment from Central Pumice Cone, Newberry volcano, Deschutes County (sample 6), transverse to the direction of vesicle elongation.

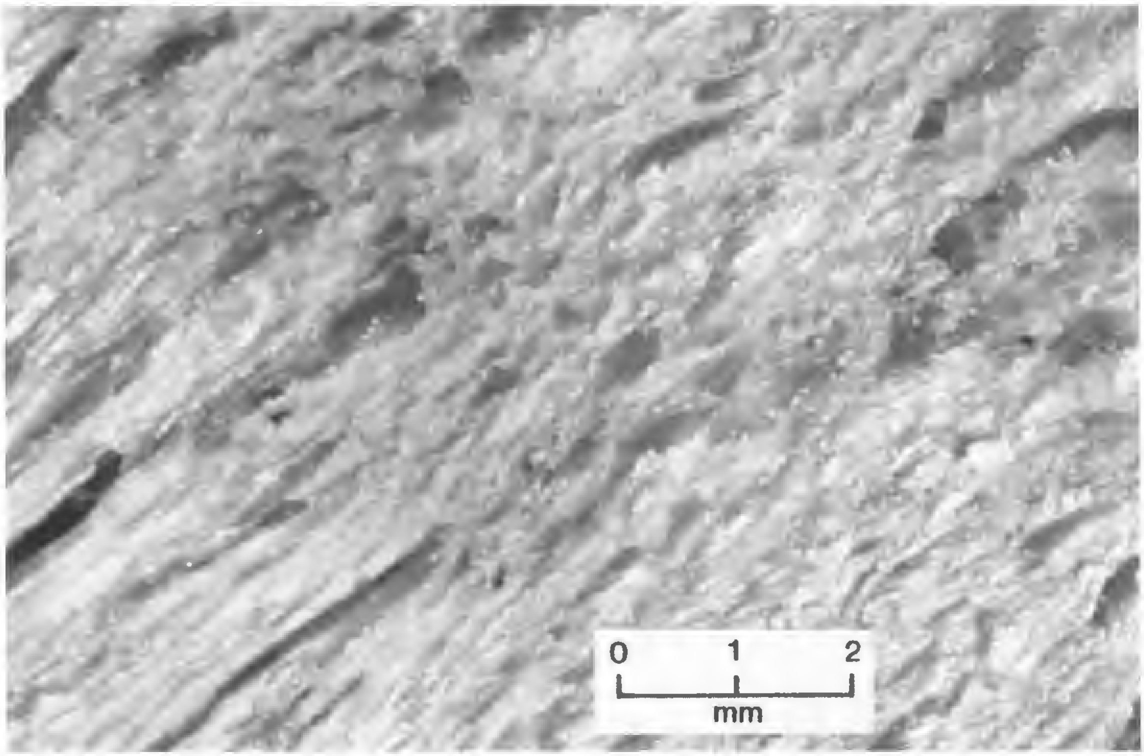

Figure 6A. Section in finely vesicular pumice from the Bend pumice, Deschutes County (sample 2), parallel to direction of vesicle elongation.

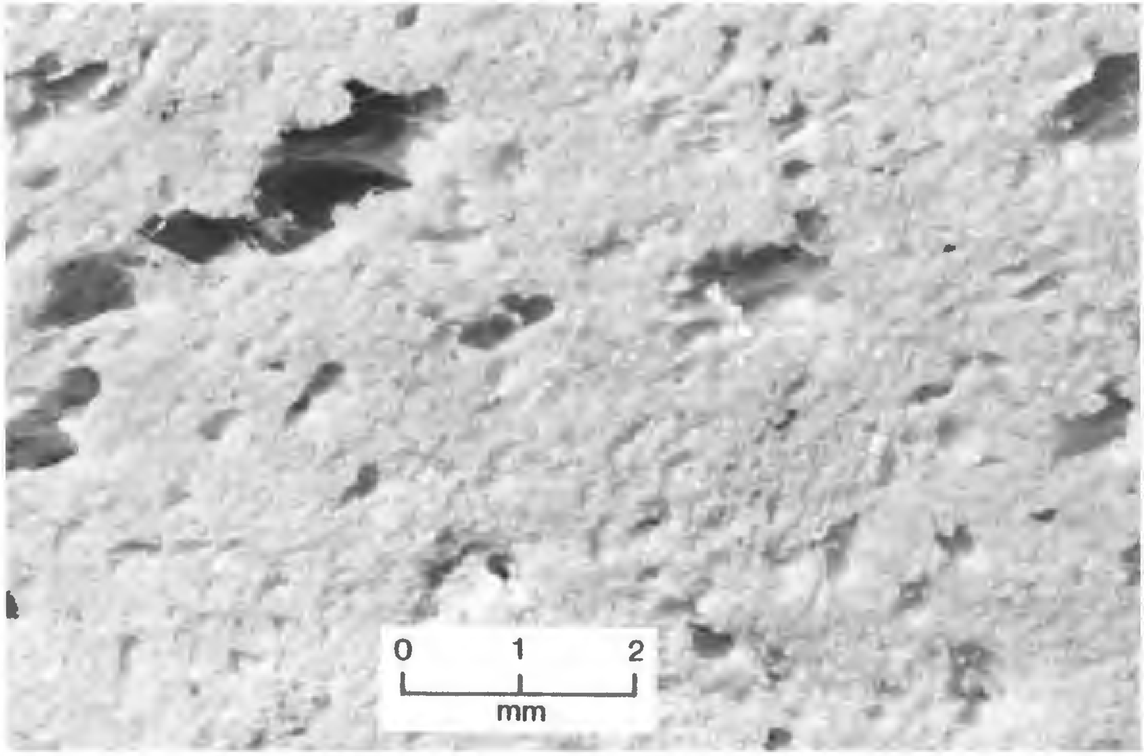

Figure 6B. Section in finely vesicular pumice from the Bend pumice, Deschutes County (sample 2), transverse to direction of vesicle elongation.

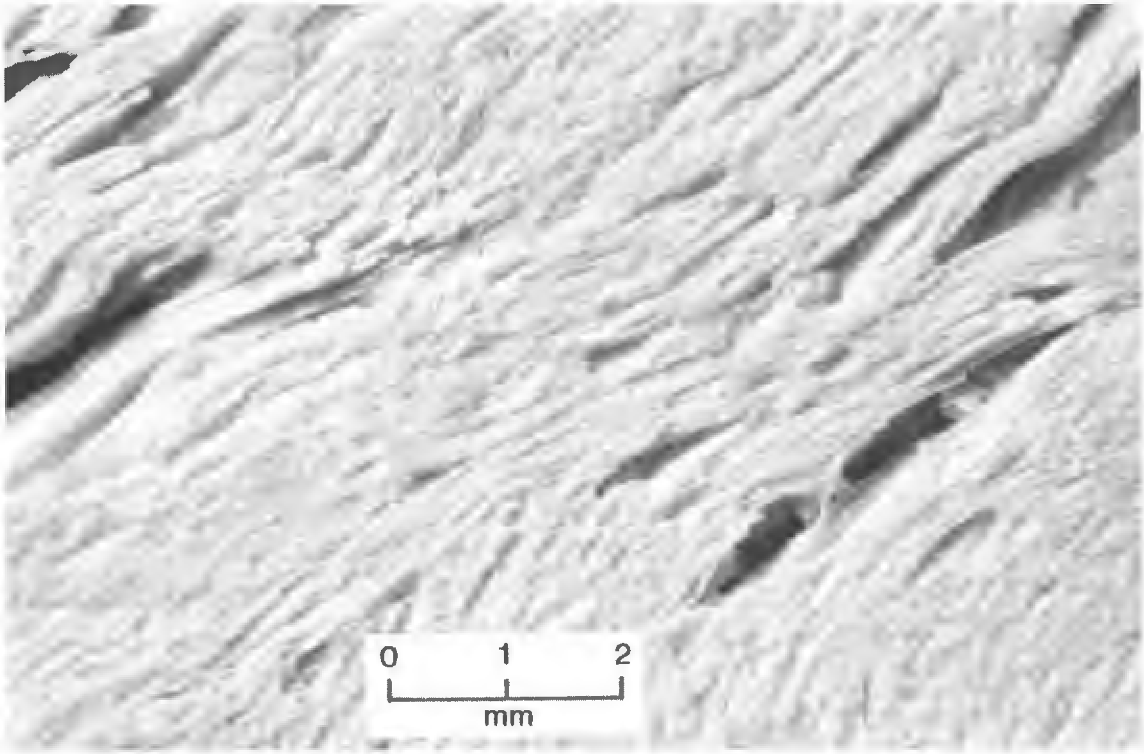

Figure 7. Highly fibrous pumice from Burns Butte, Harney County (sample 22).

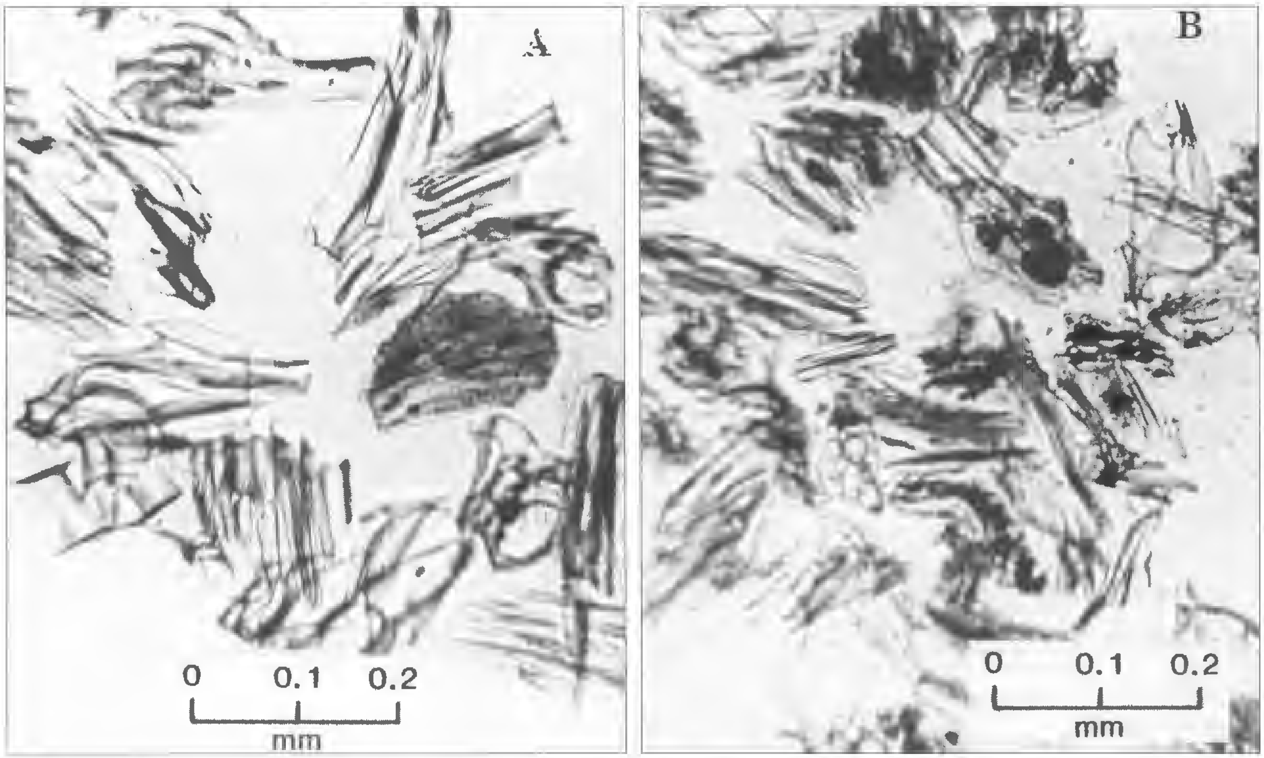

Figure 8. Fine vesicularity in minus 100 plus 200 mesh fragments from (A) Central Pumice Cone, Newberry volcano, and (B) Bend pumice, Deschutes County (samples 6 and 2 respectively). Most of the vesicles have been filled with mounting medium under vacuum. Only a few remain unfilled and appear as black spots in (B).

Table 1. *Uses of pumice*

Use	Product form	Processing	Essential properties
Lightweight aggregate *Decorative and structural* concrete blocks; cast concrete; lightweight structural members, wall panels, floor decking; stucco and plaster mixes; pozzolan in cement; civil engineering, lightweight fill	Granular	Crushing, screening, *blending*	Low density, good crushing *strength, thermal insulation,* acoustical insulation, fire resistance, moisture resistance.
Abrasives			
Grill cleaners; scouring sticks for porcelain, tile, swimming pools; buffing wheel cleaners; cosmetic skin removal	Blocks Irregular lumps	Sawing As mined	Broken vesicle (bubble) walls form sharp-edged particles; wear continues to generate fresh cutting edges.
Stonewashing (water, pumice, and garments tumbled together in laundry machine; pumice must float, abrades and softens textile fibers)	Coarse granular, plus ¼ in.	Crushing, screening	Ditto.
Hand soaps; scouring compounds; rubber erasers; polishing compounds for glass, metal, plastics; dental cleaners; wood finishing; nonskid paints; cleaning printed circuit boards; tumble polishing; leather finishing; matches and striking surfaces	Granular	Drying, milling, screening, air flotation, blending	Ditto.
Absorbents			
Potting soils, hydroponic media, pet litter, floor sweep, turf aeration	Granular	Crushing, screening	High porosity, large surface area, low chemical reactivity.
Acid washing (impregnated with bleaching agents, tumbled dry with garments, requires high absorption rate); gas "charcoal" grills (absorbs fat and grease drippings)	Coarse granular, plus ¼ in.	Crushing, screening	Ditto.
Catalyst carriers; carriers for pesticide, herbicides, fungicides	Granular	Drying, crushing, milling, screening, blending	Ditto.
Architectural			
Loose fill insulation; roofing granules; textured coatings; ground cover	Granular	Crushing, screening	Low density, thermal insulator, acoustical insulator, fire resistance, moisture resistance.
Landscaping; decorative interior and exterior veneer	Boulders Slabs	As mined Sawing	Low density, easily shaped, low maintenance.
Fillers			
In rubber, paints and plastics; mold release compounds; hot asphalt mixes; brake linings	Granular	Crushing, drying, milling, screening, blending	Particle shape, low cost.
Filter media			
Both expanded and unexpanded forms used to filter animal, vegetable, and mineral oils	Granular	Crushing, drying, milling, screening, firing, air flotation	Particle shape, expandability.

USES OF PUMICE

LIGHTWEIGHT AGGREGATE

The valuable qualities, processing techniques, and uses of pumice are summarized in Table 1. The largest volume market for pumice is lightweight aggregate in both cast concrete and concrete blocks. Use of lightweight concrete reduces the total weight of the structure and reduces the bearing-strength requirements of the supporting members while increasing fire resistance and providing thermal and acoustical insulating qualities. Decorative and structural concrete blocks with pumice aggregate are more easily handled, thus reducing construction time and worker fatigue. A typical 8- by 8- by 16-in. structural block with sand and gravel aggregate weighs 38 lb, while the same size made with pumice weighs 23 lb. The most common block of this size made by Oregon producers is a 28-lb block with a 50/50 mixture of pumice aggregate and sand and gravel aggregate, producing a higher strength block while sacrificing some weight advantage (Figures 9 and 10). Blocks have also been manufactured with volcanic cinders or with scoria as lightweight aggregate. Resulting blocks are red or dark gray and have higher weights and greater strengths than pumice blocks. Few are currently produced in Oregon. Most of the available colored blocks are manufactured instead with pumice and pigments.

Pumice for lightweight aggregate is typically sold in sizes ranging downward from 5/16 in. Particle size distribution is controlled by crushing and dry screening. A limited amount of lithic fragments can be tolerated, since their principal effect is merely to increase weight. Obsidian fragments are deleterious, since they may hydrate, expand, and weaken the concrete. Clay and iron oxide coatings and organic debris are also detrimental.

POZZOLAN

Finely ground pumice is added to concrete mixes as pozzolan material. Pozzolan material, which may be opaline shale, diatomite, or fly ash, as well as pumice, reacts with calcium hydroxide that is produced as cement sets. Without pozzolan the calcium hydroxide may readily leach out, weakening the concrete, but with pozzolan it forms compounds that add strength. In the Pacific Northwest, pumice and other natural pozzolans have been displaced by fly ash, a waste product from coal-burning electric plants.

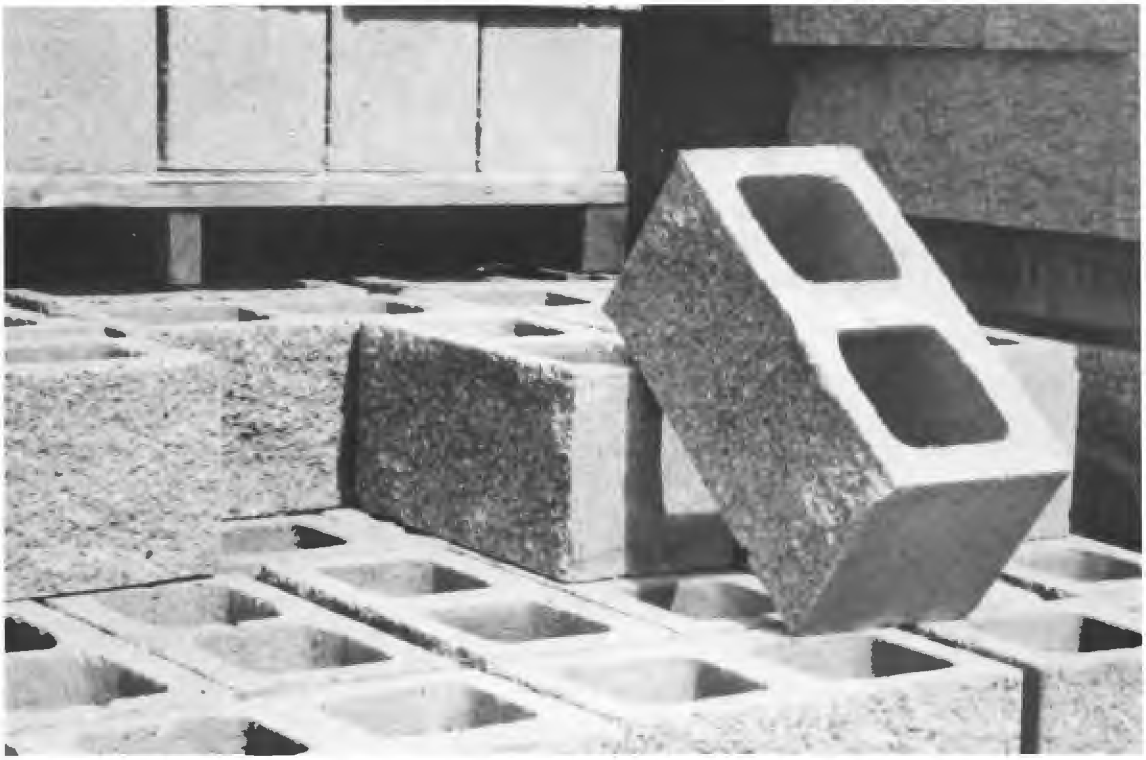

Figure 9. Concrete block made from sand and gravel aggregate and lightweight pumice aggregate. The rough decorative surface, called a split face, is produced by breaking apart a double block unit before it is fully cured.

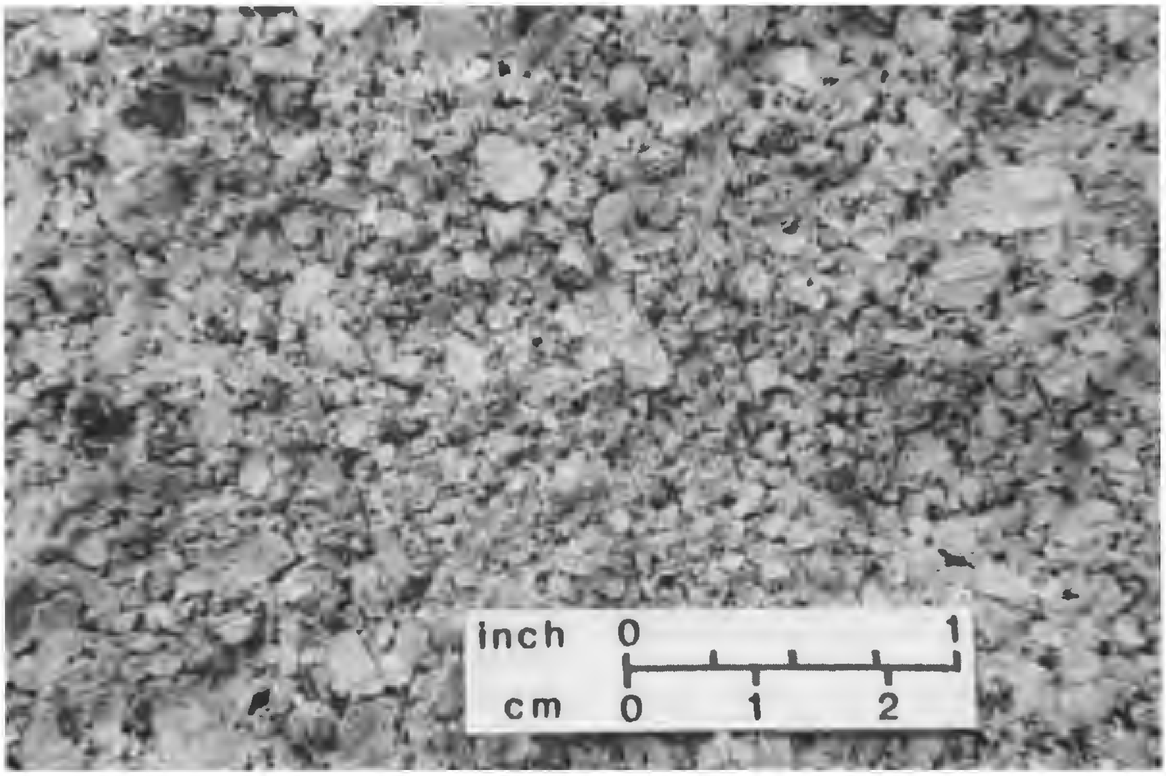

Figure 10A. Split face concrete block with a 50/50 mix of pumice aggregate and sand and gravel aggregate. The pumice appears more prominent because splitting fractures the pumice fragments, exposing their fresh interior, whereas it goes around the sand and gravel particles and leaves them with a thin coating of cement.

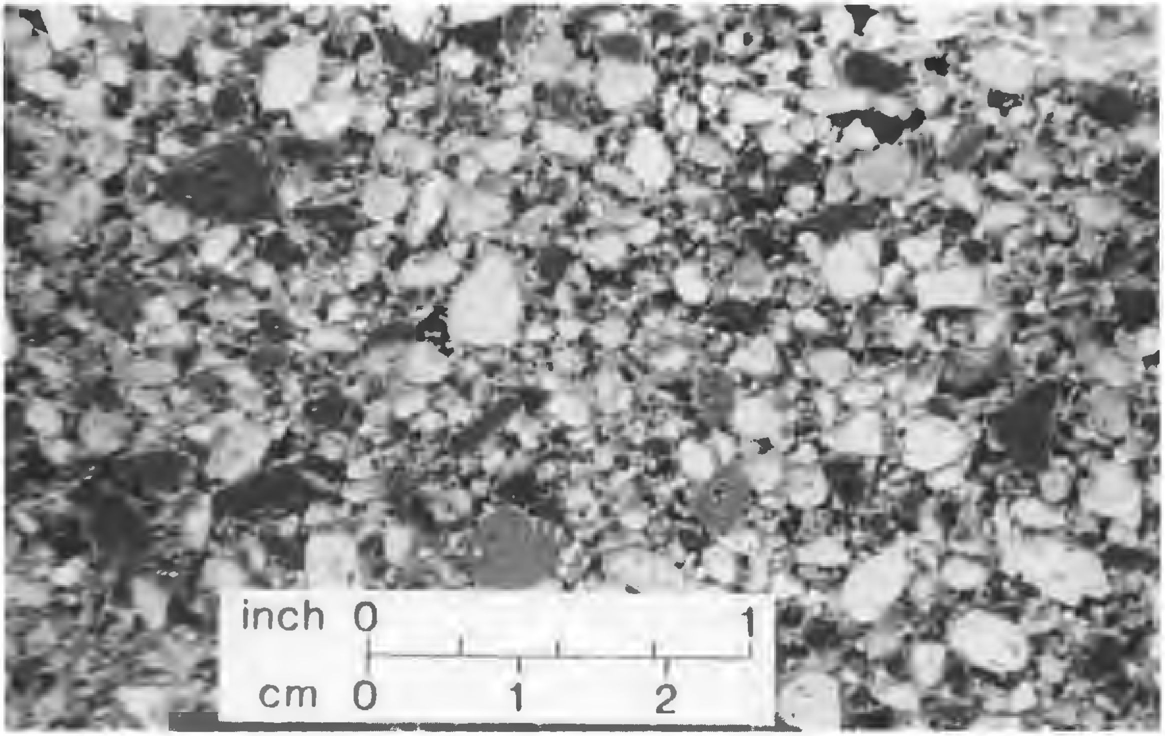

Figure 10B. Sawn face of the same block as in Figure 10A, better illustrating the ratio of lighter colored pumice to darker colored gravel aggregate.

DECORATIVE STONE AND LANDSCAPING

Large blocks of pumice up to several feet in diameter are used as mined for landscaping and sawed in thin slabs for decorative veneer on both exterior and interior walls. They are easily shaped with ordinary tools and offer light weight and moisture and fire resistance. Large block size, low density, uniform vesiculation, and consistent color are required. Obsidian bands may be acceptable in landscaping boulders but are detrimental to slab sawing. Granular pumice is used in other architectural applications such as ground cover, loose-fill insulation, and textured plasters.

ABRASIVES

Pumice in sawn blocks, large lumps, and granular forms is used in a wide variety of abrasive products. The performance of pumice as an abrasive is based on its glass hardness, particle friability, and the shape of its broken fragments. Broken vesicle walls form sharp, knifelike edges that are constantly renewed as the friable surface is abraded. Sawn blocks about 3 by 3 by 6 in. are used to clean restaurant grills, and smaller sizes are sold for cleaning porcelain and ceramic tiles and for removing skin and calluses. Aphyric pumices, i.e., those composed of only glass with no crystals or lithic fragments, are preferred, but those containing crystals similar to the glass in hardness and friability may be serviceable.

Lumps and large granules (>¼ in.) are used to stonewash garments by tumbling pumice, finished garments, and water in a large laundry machine. Pumice abrades the garment surface, softening the fabric and removing the dye. Different effects, or "looks," may be obtained with different pumices and different particle sizes and with variations in the amount of pumice and length of washing time. Stonewashing pumice must float; therefore it must have a specific gravity of less than 1.0 and a low permeability and be hard enough to withstand one or more washing cycles.

Pumice is also used to "acid wash" garments. The term "acid washing" is in common usage but is a misnomer, since bleach and potassium permanganate rather than acids are used and the garments and pumice are tumbled without water. Although abrasion plays a part in acid washing, the principal function of pumice is to serve as an absorbent chemical carrier: Pumice is impregnated with bleaching chemicals by immersion or by spraying in a vacuum chamber and then tumbled dry or damp with the garments. Attrition of the pumice particles continually releases more bleaching chemicals. For acid washing, the pumice need not have a specific gravity of less than 1.0, but it must be porous and permeable enough to readily take up and release the chemicals. Neither clay nor iron oxide coatings are tolerated, since both can be smeared onto the fabric and cause streaks and splotches.

Finer granules in various sizes and size distributions from minus 4 mesh to minus 325 mesh (about minus 5 mm to minus 0.05 mm) are used in numerous abrasive applications including hand soap; non-skid paints; and metal, glass, and plastic polishes. Clean, aphyric pumice is preferred for many abrasives and is essential for such uses as optical-glass polishing. Television tube manufacturers require pumice that has less than 1 percent crystals or lithic fragments (Marvin Hess, personal communication, 1991) and prefer less than ½ percent. Processing of the pumice may include drying, crushing, grinding, milling, screening, air separation, and blending to achieve the necessary size distribution for specific products.

ABSORBENTS

Large surface area and low chemcial reactivity are important attributes of pumice in absorbent applications. In addition to garment bleaching described above, pumice is used in pet-litter products, potting-soil mixes, and hydroponic growth media and as a carrier for catalysts, pesticides, fungicides, and herbicides. Its fire resistance is an added benefit when it is used in gas grills to absorb grease drippings.

FILTER MEDIA

Ground pumice and pumicite are used as filter media to clarify animal, vegetable, and mineral oils. Vesicle wall fragments form minute plates that overlap on the filter support, building an effective sieve for removing fine particulates.

FILLERS

Finely vesicular pumice retains its absorbent and lightweight characteristics even when ground to small particle sizes (Figure 11). It is used as a functional filler in rubber, paints, and plastic products to reduce the amount of more expensive chemicals required, to lower the product's density, to increase tensile strength, and to provide resistance to abrasion. The presence of very fine bubbles also can make pumice an effective opacifying agent in paints, increasing the paint's hiding power.

Specifications for many of the applications described above are neither standardized nor readily available. The end user may request specific size characteristics from the producer or simply purchase what is available either from the producer or from a distributor.

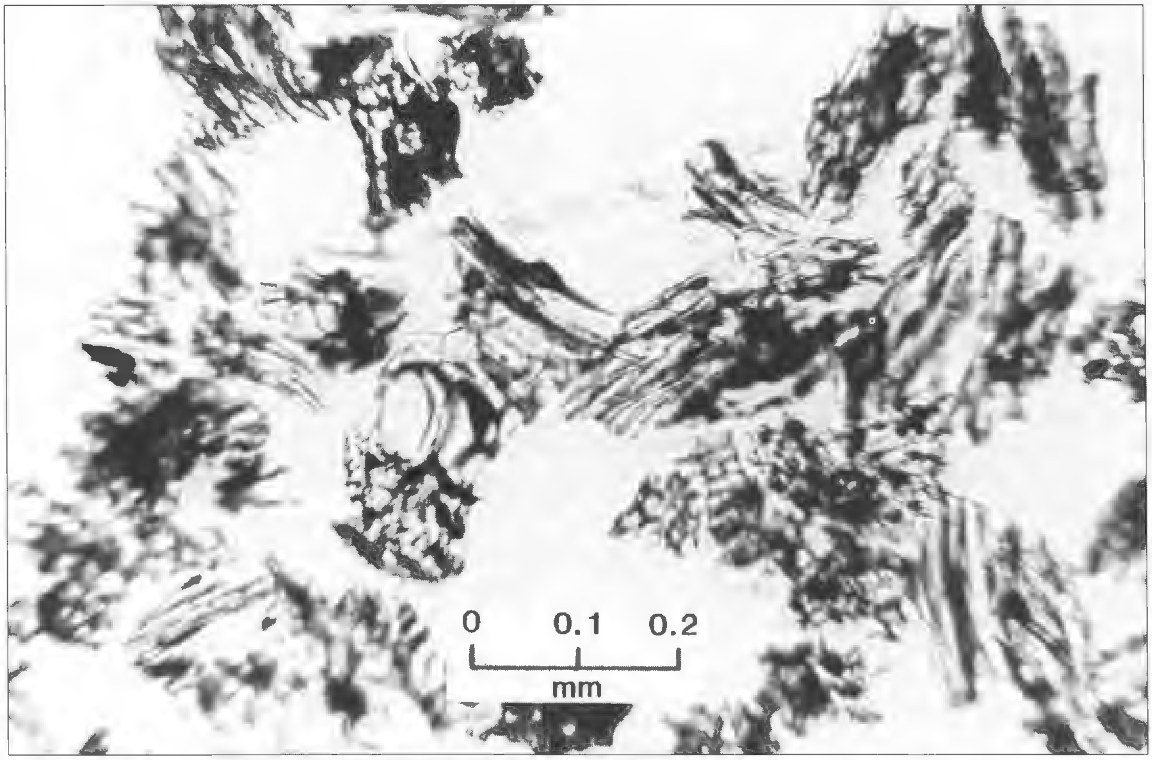

Figure 11. Finely vesicular pumice retains its cellular characteristics even in minus 100 plus 200 mesh fragments. Example from east flank of Newberry volcano, Deschutes County (sample 7).

Figure 12. Cascade Pumice Company pit near Tumalo, Deschutes County. Pumice is mined by front-end loader and transported to portable primary crusher and screening plant.

OREGON PUMICE PRODUCERS

EARLY PRODUCTION

Three pumice operations were described by Moore (1937, p. 174-175). Fine-grained pumice was being produced for pozzolan from a pit close to the Rogue River near McLeod in Jackson County. Large lumps found on the surface in Klamath County had been shipped to Chicago for several years. Demand for only large lumps suggests that the end use was abrasive blocks. A small amount of granular pumice was mined near Chemult in northern Klamath County for use in stucco. All three operations mined what is now recognized as pumice from the climactic eruption of Mount Mazama (Crater Lake); none of them is now active.

Large-scale production of pumice for lightweight aggregate began with the rapid growth in construction following World War II. Production and producers were described in contemporary reports by Wagner (1947, 1949, 1950) and Mason (1951, 1956). As many as seven companies were in operation at one time, mining pumice from deposits near Chemult, Bend, and Burns.

CURRENT PRODUCTION

Oregon has been the major pumice producer in the United States for many years, followed by California, New Mexico, and Idaho. Currently, two operators are active in the state: Cascade Pumice Company and Central Oregon Pumice Company. Both mine the Bend pumice unit in and around the city of Bend in Deschutes County, and each has been in operation for over 40 years, producing lightweight aggregate and other products primarily for the Pacific Northwest region. The lightweight-aggregate market is sensitive to transportation distance, and competitive pumice producers are in northern California and southeastern Idaho. Pumice is also used for lightweight aggregate in the eastern states, but all of it is imported, mostly from Greece. Western United States producers shipping by rail cannot compete with pumice transported by ship from Europe.

The pumice produced by both Cascade Pumice Company and Central Oregon Pumice Company for lightweight aggregate is minus 5⁄16 in. Specific aggregate applications require mixes of various proportions through the entire range of sizes from coarse to fine particles, while pumice for horticultural use is preferred with few fines. Particle size and particle-size proportions are controlled by crushing and screening.

Cascade Pumice operates pits near Tumalo and a plant between Bend and Redmond. After primary crushing in the pit, pumice is transported by truck to the plant, where it is stockpiled and then crushed and screened to yield various grain size distributions for end uses that include lightweight aggregate, horticultural material, floor sweep, and pet litter (Figures 12 and 13). Cascade also produces a small amount of very coarse lump pumice from a pit near Beaver Marsh in Klamath County (see section on Mazama pumice). Large boulders up to 24 in. are crushed and screened to about 1 to 1½ in. for use in stonewashing. Product is shipped from the plant by both truck and rail.

Figure 13. Cascade Pumice Company plant with offloading ore truck, radial stacker, and stockpile.

Central Oregon Pumice has pits and a processing plant within the city of Bend (Figure 14). Pit-run material is transported by truck to the plant, where it is crushed, screened, and loaded on railroad cars (Figures 15 and 16). The company's primary products are various grades of aggregate pumice.

Both Cascade Pumice and Central Oregon Pumice are producing from pits within an area that is rapidly becoming urbanized. They must operate under strict noise and air-quality standards and must transport ore by truck through residential areas. Both companies continually reclaim as they mine, and both have won awards for their reclamation activities.

Figure 14. One of several pits of Central Oregon Pumice Company in Bend, Deschutes County. Overburden is removed by bulldozers and scrapers, and pumice is mined by front-end loader.

Figure 15. Crushing and screening plant of Central Oregon Pumice Company.

Figure 16. Rail-car loading facility, Central Oregon Pumice Company.

PREVIOUS INVESTIGATIONS IN OREGON

Little previous statewide work has been done on the economic aspects of pumice deposits in Oregon. Moore (1937, p. 149-175) presented descriptions of several deposits and grain size analyses for about 90 samples associated with Cascade volcanism between Bend and Klamath Falls. Pumice occurrences were noted in reports on the following counties: Deschutes (Peterson, and others, 1976), Douglas (Ramp, 1972), and Klamath (Peterson and McIntyre, 1970). Several pumices and pumicites were tested for their pozzolanic properties by Heath and Brandenburg (1953). Extensive academic studies have included several pumices in attempts to understand the petrogenesis and eruptive history of the Cascade Range, particularly Crater Lake and Newberry volcano. Representative papers will be cited in the following sections on specific deposits.

SAMPLING AND ANALYTICAL PROCEDURES

Sample locations are shown on Plate 1. Detailed descriptions, physical test data, and chemical analyses are presented on Plate 2. Approximately half a cubic foot of sample was taken from each location. Samples were taken from shallow pits, road cuts, and working faces. Where practical, a channel cut was made of appropriate width and depth through the exposed section, otherwise a pit 1 to 2 ft in depth was excavated. In nonindurated exposures, caution was exercised to avoid crushing the pumice particles and skewing the grain size data. Indurated exposures were collected with a pick and were not screened. Deposits composed of large lumps and blocks were sampled by hand-picking representative fragments. All samples were dried at 105°C to a constant weight, usually for 24 hours. While this is not a typical procedure for commercial pumice production, especially for aggregate or decorative uses, it is the only way to assure comparison of samples at uniform moisture levels.

Screen analyses were performed by hand to minimize particle size reduction by attrition. Where appropriate, the entire sample was screened, since no means were available to accurately split collections of particles ranging in size from inches down to sand and silt.

Colors of both particles and milled (powdered) samples were described and indexed by use of the Geological Society of America Munsell Rock Color Chart. Orthogonal flat surfaces were ground by hand with dry sandpaper on several larger fragments from each sample. Vesicle morphology was described and measured from these surfaces with the help of a calibrated binocular microscope. A qualitative abrasive hardness was estimated from the ease of grinding, and indentation hardness testing (see Appendix) was performed on each surface.

Particle specific gravity and water absorption were measured by an immersion method described in detail in the Appendix. Bulk specific gravity (bulk density) was determined by the weight of a known volume of the ¼- to ½-in. fraction.

DEPOSIT DESCRIPTIONS

Pyroclastic rocks of rhyolitic to dacitic composition (the typical range for pumice) occur widely from the Cascade Range to the eastern border of Oregon. Ash-flow units of large volume and great areal extent indicate large-scale explosive eruptions and suggest the possibility of voluminous air-fall units. However, except for the immediate area of the Cascade Range, most of the silicic volcanics are 3-15 million years old, and the ephemeral character of pumice has meant that few deposits have survived alteration, weathering, and erosion. Also, many areas are covered with younger basalts and sediments that limit exposure.

BEND PUMICE, DESCHUTES COUNTY (samples 1 and 2)

The Bend pumice, first distinguished by Taylor (1980), is a rhyodacite aphyric air-fall deposit composed of pumice lapilli usually of less than 2 in. in size and with a very low lithic fragment content. Mapping, grain size analysis, and chemical analysis were done by Hill (1985) in an attempt to define the petrology, source vent, and eruptive history of the Bend pumice and overlying Tumalo tuff. This and more recent work was summarized by Hill and Taylor (1990).

Chemistry, thickness, grain size variations, and lithic fragment size and content indicate a source in a belt of silicic volcanics referred to as the Tumalo volcanic center, 10 to 20 mi west of Bend. Radiometric dating has constrained the eruption to about 400,000 years before present (Hill and Taylor, 1990).

The Bend pumice and Tumalo tuff apparently were formed by a single eruptive event, as indicated by their chemical similarity and the lack of an erosional contact between them. The pumice is the air-fall component, and the tuff represents collapse of the eruptive column. Both units were partially covered by later volcanics and are now exposed only west of Bend. The thickness of the tuff ranges up to about 70 ft and of the pumice about 10 to 40 ft in exposures, although water-well records suggest a thickness in excess of 60 ft in some covered areas (Hill, 1985, p. 22). Despite its age, the pumice has been protected from weathering and erosion by the Tumalo tuff (Figure 17).

The commercial advantages offered by the Bend pumice include whiteness, low crystal and lithic content, lack of alteration or weathering, its proven performance in aggregate and horticultural applications, and its proximity to rail transportation and to markets that can be served by truck. The crystal-free nature suggests the possibility of producing granular abrasive, but processing equipment would require considerable capital investment. The low proportion of >¼-in. particles will limit the use of Bend pumice for stonewashing until the development of washing techniques that can utilize smaller sizes. Then, its bulk density and hardness would offer advantages over other pumices in the state. The most serious disadvantages of the Bend pumice are its limited exposure and its occurrence in a rapidly expanding urban area.

ROCK MESA PUMICE, LANE AND DESCHUTES COUNTIES (sample 3)

Rock Mesa is a rhyodacite dome and flow complex of lava, obsidian, and pumice straddling the boundary between Lane and Deschutes Counties on a southern flank of South Sister peak (Figure 18). It is the largest of several such domes in the South Sister-Devils Hill area that have been dated at 2,000 to 2,900 years before present (Taylor and others, 1987). Total surface area of the flow is about 2½ mi^2, nearly half of which is pumice (Fink and Manley, 1987). The surface is a jumbled mass of blocks up to several feet in dimension of material ranging from nonvesicular lava and obsidian to coarsely vesicular pumice. The deposit lies within the Three Sisters Wilderness.

The only other block pumice deposit comparable in block size, areal extent, and quality is at Mono Craters in east-central California, where U.S. Pumice Company has produced abrasive blocks, landscaping boulders, and facing veneers since the early 1940s. In 1962, that company acquired mining claims on Rock Mesa and began exploration of the property. The Three Sisters Wilderness was established in 1964, and there followed a protracted period of evaluation and litigation to determine ownership, quality, mineability, and marketability of the block pumice. These proceedings are documented in a series of unpublished reports, mineral investigations, exhibits, and rulings on file in the USDA Forest Service Region 6 office in Portland. The claims were eventually declared valid and immediately purchased by the federal government and placed in the wilderness area, thereby removing any possibility of production.

Figure 17. Cascade Pumice Company pit in Bend pumice unit near Tumalo, Deschutes County. Overlying Tumalo tuff, visible in background, has been removed just prior to mining pumice.

Figure 18. Rock Mesa, a block pumice flow in the Three Sisters Wilderness, on the southern flank of South Sister peak, Lane and Deschutes Counties.

NEWBERRY VOLCANO, DESCHUTES AND LAKE COUNTIES (samples 4-10)

Newberry volcano, about 20 mi southeast of Bend, is a complex pile of flows, pyroclastics, and epiclastic deposits of basaltic through andesitic and rhyolitic composition. The younger volcanics tend to be more silicic and include rhyolitic obsidian flows and ash flows and rhyolitic pumice flows, cones, and air-fall deposits. The most recent activity was the eruption of the Big Obsidian Flow dated about 1,300 years before present (MacLeod and others, 1982, p. 6). Numerous pumice occurrences are associated with various units in the Newberry complex. Three were selected for sampling on the basis of thickness, areal extent, and accessibility. While this study was in progress, the central portion of the area was designated as the Newberry National Volcanic Monument. Much of the pumice now lies within the monument boundaries and is closed to development.

Central Pumice Cone (samples 4-6)

The center of Newberry volcano is a collapse caldera in which two lakes, Paulina Lake and East Lake, are separated by a small pumice and obsidian cone named the Central Pumice Cone. Dated about 6,700 years before present (MacLeod and others, 1982), the cone is about 4,000 ft in diameter and 600 ft high and is composed of obsidian flows and aphyric pumice, ash, lapilli, and blocks up to 2 or 3 ft in diameter. Vesiculation is variable, ranging from glass with thick-walled vesicles several millimeters in dimension to finely vesicular fibrous pumice. The large pumice blocks are supported by a matrix of smaller pumice fragments. Most of the pumice occurs as talus slopes on the cone flanks, often intermixed with 2 to 5 percent obsidian fragments ranging from small flakes to large boulders (Figure 19).

Mining claims were staked on the east half of the Central Pumice Cone on the southwest shore of East Lake prior to 1945, after which time no further staking was permitted. Block pumice has been produced sporadically from the claims for nearly fifty years, primarily for abrasive uses. The total production has been small, and potentially a large reserve of block pumice remains. The claims are patented, remaining as a privately owned enclave within the area of the Newberry National Volcanic Monument. Any future production from these claims, however, is problematic, particularly at high enough volumes to be economic. At over 6,000 ft in elevation, the area is snow free only about three months of the year. Any larger scale mining will generate an obvious visual impact, and present county zoning restricts the volume of truck traffic on the access highway.

East flank pumice fall (samples 7-9)

The youngest and one of the most spectacular eruptive features in the Newberry volcano complex is the Big Obsidian Flow dated about 1,300 years before present (MacLeod and others, 1982). A few hundred years earlier, probably about 1,600 years before present, an eruption of identical chemical composition from the same vent produced a plume of aphyric pumice lapilli extending several miles to the east, as illustrated on Plate 1.

MacLeod and others (1982) documented a progressive decrease in thickness and grain size downwind. About 3 mi east of the vent, outside of the monument boundary, the air-fall deposit is over 10 ft thick; and 10 mi east, north of

Figure 19. Pumice blocks exposed in pit face on south flank of Central Pumice Cone in Newberry volcano between Paulina Lake and East Lake, Deschutes County. Large obsidian fragment is exposed immediately above hammer head.

China Hat, it is about 4 ft thick. Samples collected for this study range from 30 percent plus ¾-in. particles to 5 percent plus ¾-in. particles at distances from the vent of 6 mi and 9 mi, respectively.

The lithic content of the deposit frequently exceeds 10 percent by volume and includes fragments of lava, obsidian, and cinders. The pumice itself is aphyric with no nonglass fragments detected in counts of several thousand grains. There is no overburden other than a thin forest soil covering of a few inches, but the entire thickness lies within vegetation root zone.

There has been no production from this deposit, probably due in large part to its isolation and limited access. However, the coarser particles may have some potential for garment washing, probably for stonewashing rather than acid washing. While the pumice is hard enough for aggregate use, the lithic content and organic content may be prohibitive. The completely aphyric nature of the pumice suggests some potential for fine abrasives, if lithics and organic debris could be removed easily.

Poly Top Butte (sample 10)

Older deposits (Pleistocene) mapped by MacLeod and others (1982) as undifferentiated sediments and interbedded pyroclastics are exposed on the northern and eastern flanks of Newberry volcano. Thick pumice lapilli deposits were noted south of China Hat, and one sample was taken for this study from that area near Poly Top Butte. The pumice itself is aphyric, but the sample contains about 5 percent lithic fragments. Nearly 20 percent of the sample is plus ¾ in., but this represents only a 4-ft channel taken from near the top of what appears to be a thicker but poorly exposed bed. Within the exposure is a marked gradation of coarser particles near the top. Based on only one sample, the unit would appear to have limited economic potential. While it does contain some particles that are large enough for garment washing and has low density and a high absorption rate, the Poly Top Butte pumice is extremely soft, probably too soft for either washing or aggregate use.

MAZAMA (CRATER LAKE) CLIMACTIC PUMICE, KLAMATH, DOUGLAS, AND JACKSON COUNTIES (samples 11-16)

Mount Mazama collapsed 6,845 ± 50 years before present (Bacon, 1983), forming the caldera now occupied in part by Crater Lake and generating a pumice and ash deposit over an enormous area of western North America. The Mazama ash bed is identifiable throughout the northwest quarter of the United States and in three Canadian provinces. A pumice air-fall lapilli deposit from the climactic eruption blankets an area of over 2,000 mi^2 with a thickness greater than 3 ft, and an area of over 350 mi^2 with a thickness greater than 10 ft. An isopach map of the air-fall material is presented by Sherrod and Smith (1989, p. 20). The first studies of the pumice characteristics were conducted by Moore (1937) and Williams (1942). Young (1990) recently documented the events of the climactic eruption with a detailed analysis of the air-fall deposits.

Figure 20. Air-fall pumice bed and overlying pyroclastic flow from the Mazama (Crater Lake) climactic eruption, exposed in a waste-disposal pit near Chemult, Klamath County.

The final eruption of Mount Mazama produced air-fall deposits and pyroclastic deposits with varying degrees of welding (Figure 20). The air-fall pumice plume extends to the northeast toward Newberry volcano and the city of Bend. Pyroclastic flows formed by the collapsing eruptive column were channelled by topography to move radially outward, including down the drainage of the North Umpqua River to the northwest and the Rogue River to the southwest, although these deposits may in part be epiclastic. Only a small portion of the climactic pumice lies within the Crater Lake National Park boundaries.

Particle sizes range from a few feet downward, with the larger sizes confined primarily to the flow deposits. Most of the air-fall pumice is less than 1 in. Compared to other pumices in the state, Mazama material tends to have lower density, higher absorption, and lower hardness. Lithic content of most of the deposit is low, and samples collected in this study contain 1 to 5 percent crystals, primarily feldspar with lesser amounts of pyroxenes and hornblende. Except where covered by climactic, welded pyroclastic-flow material, the pumice is exposed at the surface with no overburden other than forest vegetation.

Many attempts have been made to develop the Mazama pumice commercially, particularly in the Chemult area, which has deposits with thick sections and large particle sizes and is served by both a railroad and a major highway. To date, none of the attempts have been successful in producing lightweight aggregate in large volumes for long periods. Mazama pumice has not been able to compete successfully with Bend pumice, perhaps due in part to its lower strength and iron oxide alteration. For many years, small amounts of block pumice have been produced near Beaver Marsh (Figure 21). The boulders have been used for abrasive blocks, landscaping, and most recently for stonewashing.

The geometry of the Beaver Marsh deposit is not clear. It is probably a channel deposit with linear rather than lateral continuity. A covering of finer pumice masks the block pumice and therefore makes exploration for extensions or similar deposits difficult.

Fine-grained pumice was produced for many years from a pit near the Rogue River at McLeod for use as pozzolan in cement. Cement is no longer produced in Jackson County, and the pumice location is now submerged in the Lost Creek Reservoir.

Any comments on the economic potential of the Mazama climactic pumice must be generalizations. Large areas remain unstudied in sufficient detail to document lateral and vertical variations, including degree and type of alteration, that could define exploration targets or the lack of them.

BEATTY/BLY AREA PUMICITE, KLAMATH COUNTY (samples 17-20)

A pumicite bed is exposed at various points in the Sprague River valley below Quaternary basalt flows and above a Tertiary unit of volcaniclastic sediments (unit Tst of Peterson and McIntyre, 1970). The pumicite is not mapped separately, and no work has been done on petrography, source, thickness, or areal extent. Exposures sampled for this study were over 20 mi apart. The bed is composed of well-rounded pellets of pumice, most less than 2 mm. in diameter. Screen analyses are presented in Table 2. Over 75 percent of the particles are minus 32 mesh plus 100 mesh (Tyler Standard) or between 0.50 and 0.15 mm. Free crystals of feldspar, pyroxene, and magnetite, most minus 60 mesh, make up 5 to 10 percent of the grains. Both vertical

Figure 21. Block pumice flow and overlying finer pumice bed from the Mazama (Crater Lake) climactic eruption, exposed in a pit face near Beaver Marsh, Klamath County.

Table 2. *Screen analyses of samples 17-20, expressed as weight percent retained on respective screen sizes (Tyler Standard Series)*

	Screen analyses							Cumulative totals						
	Mesh size							Mesh size						
Sample no.	16	32	60	100	150	200	minus 200	16	32	60	100	150	200	minus 200
17	6.0	30.4	42.8	10.4	3.1	1.9	5.4	6.0	36.4	79.2	89.6	92.7	94.6	100
18	8.8	36.0	44.2	5.9	1.4	0.8	3.0	8.8	44.8	89.0	94.9	96.3	97.1	100
19	6.2	36.0	39.2	13.0	2.3	1.2	2.1	6.2	42.2	81.4	94.4	96.7	97.9	100
20	3.1	63.0	25.6	4.9	1.1	0.7	1.7	3.1	66.1	91.7	96.6	97.7	98.4	100

and lateral variations were evident. Samples 17 and 18 were collected from the lower and upper portions, respectively, of a 50-ft-thick exposure sampled on the eastern edge of Knot Tableland. The lower sample has a higher nonpumice content. Samples 19 and 20 from near Bly have a low nonpumice content and a much lower bulk density.

Peterson and McIntyre (1970, page 59) report earlier limited production for plaster and mortar aggregate and for soil conditioner, but there has been no recent production. The fine particle size of the Beatty/Bly pumicite makes it unsuitable for concrete aggregate, but the pellet shape could possibly impart smooth working and finishing characteristics to plaster and stucco. Removal of the nonpumice grains by screening or air separation could produce a clean, fine-grained pumice with a potential for high-value applications such as paints and abrasives that could justify the expense of processing and transportation.

BURNS PUMICE, HARNEY COUNTY (samples 21-23)

Burns Butte about 3 mi west of Hines was the eruptive center for a sequence of pyroclastics named the tuff of Wheeler Springs by Brown (1982). The Hotchkiss lapilli member exposed on Burns Butte and on its flanks up to 4 mi to the south consists of pumice flows and falls from at least 20 discrete eruptive events. Pumice layers are separated by soil horizons, ash beds, and cinder beds (Figure 22). The pumice beds contain variable amounts of lithic and obsidian fragments visually estimated at 2 to 5 percent. Several prospect and production pits are located in the area, and the exposures range from friable to well indurated. Less than 10 percent of the friable beds are plus ¾-in. particles. Brown reported thicknesses in excess of 150 ft.

Figure 22. Pumice pit face on Burns Butte, Harney County. This deposit is the result of multiple eruptive events, as indicated by soil horizons, interlayered ash and cinder beds, and abrupt changes in color and induration.

Currently, no pumice is produced from the area, although aggregate for concrete blocks was produced in the late 1940s and the early 1950s. The economic potential of this deposit is limited by its lithic content, the interlayered nonpumice beds, the small size of the local market, and the isolation of the location from larger markets.

NEW PRINCETON PUMICE, HARNEY COUNTY (sample 24-25)

About 4 mi north of New Princeton and 6 mi south of Crane, a small amount of pumice has been produced from private land for local use. Greene and others (1972) mapped the unit as tuffaceous sedimetary rocks underlying the Devine Canyon welded tuff. No recent mapping has been done in the area to subdivide the unit or to further define its relationships.

A small pit has been opened, and the pumice has been used to surface ranch roads. The deposit is fairly fine grained with over 90 percent of the pumice fragments less than ½ in., a size range suitable for aggregate. Larger grains are surrounded by a matrix of fines forming a compact hard bed in excess of 10 ft thick with a low lithic content. Its areal extent is unclear, but pumice that may have been from the same bed was encountered in a water well over a mile to the west. The pumice fragments have high indentation hardness, a low nonpumice fraction, but a higher density than other pumices in the state.

DISCUSSION AND SUMMARY

Currently, the principal markets for Oregon pumice are lightweight aggregate followed by horticultural uses. None is processed for traditional abrasives, either lump or granular, and only a small amount is sold for stonewashing. Granular abrasive production requires considerable capital investment and clean hard pumice, both crystal-free and lithic free. The Bend pumice, the Newberry volcano east flank pumice, and the New Princeton pumice bear further testing for this application. However, the granular-pumice abrasive market is limited, especially for optical polishing, and a superior product and an energetic marketing effort would be required to displace current producers elsewhere in the United States. Plus ¾-in. particles now required by launderers are not a major component of most Oregon pumices, although deposits in some areas of the Newberry volcano east-flank fall and the climactic Mazama fall are suitable.

The Bend pumice remains the premier pumice in the state for the markets it serves. No other deposit can match its proven performance as lightweight aggregate or its favorable location on transportation routes. However, exposures are limited, and access is becoming increasingly restricted. It may well be possible to define additional covered reserves by detailed mapping and by analysis of water-well data. Some of these may be far enough removed from developed housing and have overburden thin enough to make removal economical. One operator currently strips up to 70 ft of Tumalo tuff, and the other has stripped basalt flows and produced crushed aggregate to reach the underlying pumice.

Of the Newberry volcano pumices, large-scale production seems possible only from the east-flank deposit. Although the thickest and largest grain size portion now lies within the National Monument boundary, it has sufficient thickness and areal extent outside to justify further testing.

The economic potential of Mazama climactic pumice remains an enigma. Much of it may be too soft for aggregate, but it is not clear whether this is an alteration or weathering effect. The effects of weathering may decrease with a depth; in other areas, the pumice lapilli bed may be protected by overlying welded tuff from the same eruption. Portions are coarse enough for laundry material, but their spatial geometry is not clear, and it is not apparent what prospecting technique would be effective to rapidly evaluate large areas to depths of several tens of feet. The large areal extent offers considerable potential but is in itself part of the difficulty.

The Beatty/Bly pumicite is unique in its sharply limited grain size distribution and its likely susceptibility to relatively simple beneficiation. The resulting product could have direct applications as a texturizing or a nonskid agent or could serve as a feedstock for finely ground filler or abrasive production.

The pumice resources of Oregon are very large, and the state has historically been the largest producer in the United States. Production is almost exclusively from one unit, the Bend pumice. Continued long-term production from that unit will require identifying more reserves outside the urban areas. Other pumices have potential for lightweight aggregate as well as other end uses, but some are isolated from transportation routes and all require more detailed study to define those portions suitable for various markets.

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APPENDIX

SAMPLE PREPARATION AND TESTING METHODS

All samples were first dried to a constant weight at 105°C. To produce material for testing, block pumice samples were hand picked, coarse granular samples were screened as reported in Plate 2, and fine granular samples (less than ¼ in.) were screened as reported in Table 2.

Water absorption was measured on plus 1-in. fragments. A collection of 8 to 10 particles was weighed dry and then immersed in water with aid of a weighted screen. After five minutes, the particles were removed, lightly patted with a paper towel to remove surface moisture, and weighed. Samples were then immersed again and reweighed after an additional five minutes. Water absorption at the two time increments is reported as weight percent increase calculated as follows:

$$Absorption = \frac{(weight\ after\ immersion - dry\ weight)}{dry\ weight} \times 100.$$

Particle specific gravity was measured on the same collections of fragments as those used for water absorption. Volume of each collection that had been immersed for 10 minutes was measured by placing it in a large graduated cylinder with a known volume of water and holding it under with a wire plunger. In the brief time required to read the displaced volume, no significant additional absorption could occur to distort the reading. Specific gravity was calculated from the dry weight and the displaced volume.

Bulk specific gravity was measured on minus ½-in. plus ¼-in. fraction obtained by screening granular samples or by crushing and screening block samples. The fraction was lightly tamped into a 3,000-cc container and weighed. Bulk specific gravity of the fine granular samples (17 through 20) was measured on unscreened material. Bulk density reported as pounds per cubic foot was calculated from bulk specific gravity.

Particle counts were made on the minus ½-in. plus ¼-in. fraction of granular samples. From 500 to 800 particles were counted for each sample. Grain counts were made on a minus 60 plus 200 mesh fraction obtained by hand crushing and screening about 10 minus ½-in. plus ¼-in. fragments. From 1,000 to 1,500 grains were counted for each sample.

A device was constructed to compare the relative particle hardness of various pumices collected (Figure 23). A penetrometer with a 60° conical tip and a total weight of 3,000 g was constructed from 1½ x 6-in. pipe nipple, end caps, steel rod, and lead.

Figure 23. Device built to determine the relative indentation hardness of pumice as measured by the hole diameter produced when the point is supported on a flat surface ground on pumice particles.

Orthogonal flat surfaces were ground with sandpaper on pumice particles, and the tip of the penetrometer was gently lowered until its full weight was supported by the pumice. The diameter of the resulting indentation was measured with a comparator or with a calibrated microscope. The same number of indentations (usually 6 or 10) was made on each set of perpendicular surfaces, and the diameter measurements were averaged. The value reported is the average of three to six particles so measured. Mutually perpendicular surfaces were tested to minimize the effects of vesicle lineation, since most samples with elongated vesicles were harder on surfaces transverse to the direction of elongation. A total weight of 3,000 g was used, after preliminary testing with that approximate weight produced indentation diameters ranging from 0.5 mm to 5.5 mm on the hardest and softest samples collected.

Samples for whole-rock chemical analysis (Plate 2) were crushed to minus ¼ in. in a steel-jawed chipmunk jaw crusher, reduced to about minus 10 mesh in a cone crusher, and split in a Jones-type splitter. A 100-g split of each sample was milled to about minus 200 mesh in corundum milling media. Samples for trace-element analysis (Plate 2) were crushed and split as above, and a 250-g split was milled to about minus 200 mesh in chrome-steel milling media. All sample preparation was performed in the Oregon Department of Geology and Mineral Industries laboratory.

Whole-rock X-ray fluorescence (XRF) analyses were performed by X-ray Assay Laboratories (XRAL) of Don Mills, Ontario, Canada. XRAL used a fused button for its analyses (1.3 g of sample roasted at 950°C for one hour, fused with 5 g of lithium tetraborate, and the melt cast into a button). Loss on ignition (LOI) was determined by weight loss during roasting.

Geochemical Services, Inc. (GSI), of Rocklin, California, performed trace-element analyses for 15 elements. The method employed a proprietary acid digestion/organic extraction on a 5-g sample. Gold was determined by graphite furnace atomic absorption (GFAA). The finish for the other 14 elements was by induction coupled (ICP) spectrometry. GSI considers the digestion to provide total metal contents except for gallium and thallium.

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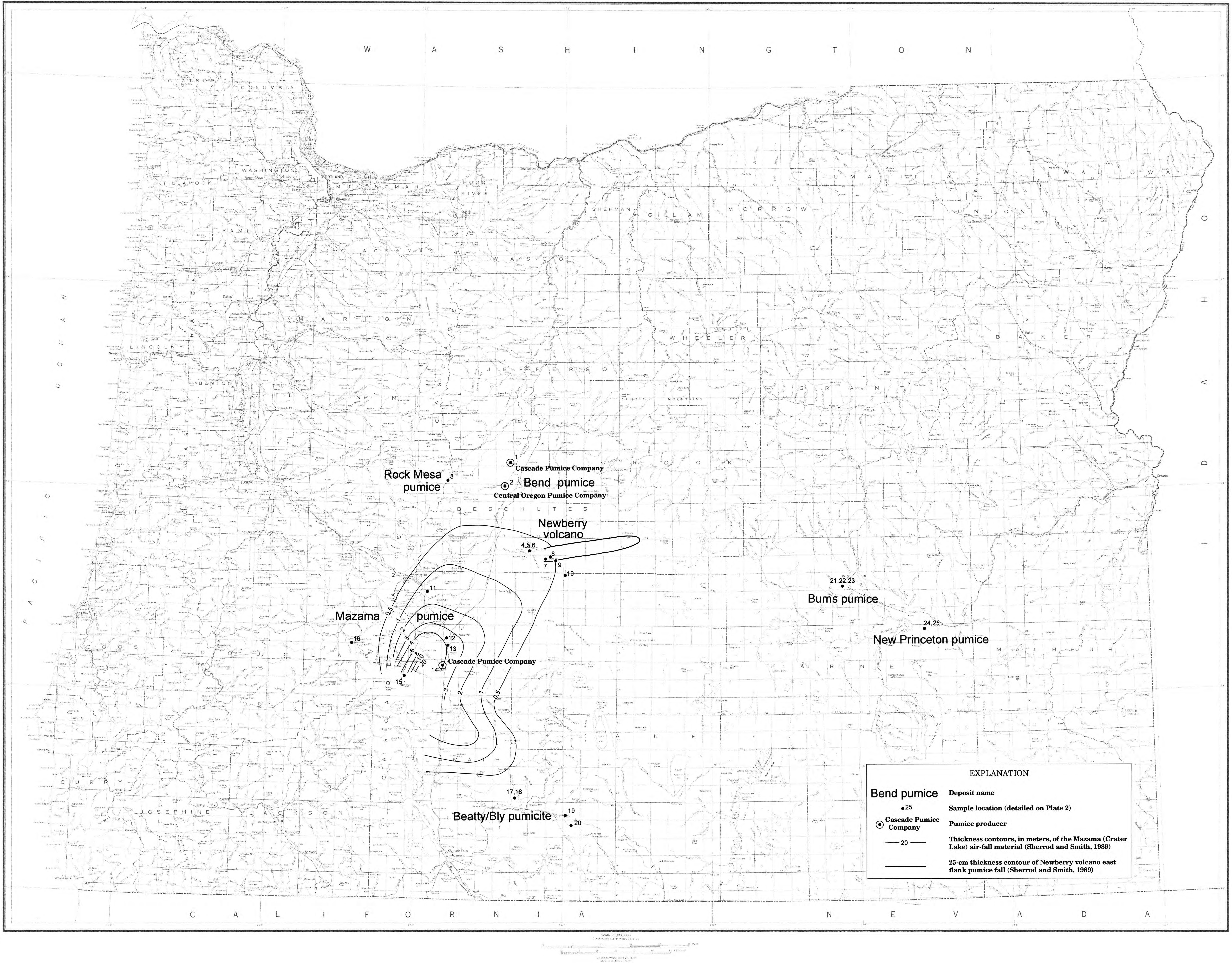
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

INDEX MAP OF PUMICE SAMPLE LOCALITIES
1992

Special Paper 25
Pumice in Oregon
By Ronald P. Geitgey
Plate 1



Scale 1:1,000,000
1 inch equals approximately 16 miles

Lambert conformal conic projection
Standard parallels 33° and 45°

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STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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LOCATIONS, DESCRIPTIONS, AND ANALYTICAL DATA FOR PUMICE SAMPLES

1992

Special Paper 25
Pumice in Oregon
By Ronald P. Geitgey
Plate 2

Locations and descriptions of pumice samples

Sample number	¼	¼	Sec.	T. S.	R. E.	County	Area	7½′ Quadrangle	Deposit type	Geologic unit	References
1	SE	SE	35	16	11	Deschutes	Bend	Tumalo	Air fall	Bend pumice (Qbp)	Hill (1985)
2	NW	NE	10	18	11	Deschutes	Bend	Shevlin Park	Air fall	Bend pumice (Qbp)	Hill (1985)
3	SE	NE	32	17	8	Deschutes	Rock Mesa	South Sister	Flow top	Young rhyodacite flows (Qyr)	Taylor and others (1987)
4	SE	SE	25	21	12	Deschutes	Newberry Crater	East Lake	Flow	Central Pumice Cone (QHp_1)	MacLeod and others (1982)
5	NE	SW	30	21	13	Deschutes	Newberry Crater	East Lake	Flow/air fall	Central Pumice Cone (QHp_1)	MacLeod and others (1982)
6	SE	SW	30	21	13	Deschutes	Newberry Crater	East Lake	Flow/air fall	Central Pumice Cone (QHp_1)	MacLeod and others (1982)
7	NE	NE	12	22	13	Deschutes	Pumice Butte	China Hat	Air fall	Rhyolitic pumice fall (QHt)	MacLeod and others (1982)
8	NE	SW	6	22	14	Deschutes	Pumice Butte	China Hat	Air fall	Rhyolitic pumice fall (QHt)	MacLeod and others (1982)
9	NE	NE	9	22	14	Deschutes	China Hat	China Hat	Air fall	Rhyolitic pumice fall (QHt)	MacLeod and others (1982)
10	SW	SW	2	23	14	Lake	Poly Top Butte	South Ice Cave	Air fall	Undiff. flank deposits (Qsu)	MacLeod and others (1982)
11	SE	NW	7	24	7	Klamath	Crescent Lake Jct.	Crescent Lake	Air fall	Mazama climactic pumice	Bacon (1983)
12	NW	NW	32	26	8	Klamath	Corral Spring	Muttonchop Butte	Air fall	Mazama climactic pumice	Bacon (1983)
13	NE	NE	17	27	8	Klamath	Chemult	Chemult	Air fall	Mazama climactic pumice	Bacon (1983)
14	NE	NW	18	28	8	Klamath	Beaver Marsh	Chemult	Pyroclastic flow	Mazama ash flow	Bacon (1983)
15	NE	SW	36	28	5½	Klamath	Summit Rock quarry	Pumice Desert East	Air fall	Mazama ash flow (Qaf)	Sherrod (1991)
16	NW	SE	35	26	3	Douglas	Clearwater	Toketee Falls	Pyroclastic flow	Mazama ash flow (Qaf)	Sherrod (1991)
17	NE	NE	29	35	12	Klamath	Beatty	Spodue Mtn.	Epiclastic	Tuffaceous sediments (Tst)	Peterson and McIntyre (1970)
18	NE	NE	29	35	12	Klamath	Beatty	Spodue Mtn.	Epiclastic	Tuffaceous sediments (Tst)	Peterson and McIntyre (1970)
19	SE	SE	19	36	15	Klamath	Bly	Campbell Reservoir	Epiclastic	Pumice and pumicite	Peterson and McIntyre (1970)
20	SW	SE	15	37	15	Klamath	Bly	Paradise Mountain	Epiclastic	Pumice and pumicite	Peterson and McIntyre (1970)
21	SW	NW	34	23	30	Harney	Burns	Burns	Flow/fall	Hotchkiss lapilli member (Tmlh)	Brown (1982)
22	SW	NE	3	24	30	Harney	Burns	Burns	Flow/fall	Hotchkiss lapilli member (Tmlh)	Brown (1982)
23	SW	NE	3	24	30	Harney	Burns	Burns	Flow/fall	Hotchkiss lapilli member (Tmlh)	Brown (1982)
24	SW	SW	5	26	34	Harney	New Princeton	New Princeton	Pyroclastic flow?	Tuffaceous sediment. rocks (Tts)	Greene and others (1972)
25	SW	SW	5	26	34	Harney	New Princeton	New Princeton	Pyroclastic flow?	Tuffaceous sediment. rocks (Tts)	Greene and others (1972)

Descriptions of pumice samples: Color, vesicles

Sample number	Particle color[1]	Particle color index[2]	Powder color[1]	Powder color index[2]	Vesicle morphology	Vesicle size (mm)
1	V. lt. gray	N 8	V. lt. gray	N 8	Irregular to spherical to fibrous	0.1-1.0
2	V. lt. gray	N 8	V. lt. gray	N 8	Irregular to spherical to fibrous	0.1-1.0
3	Med. lt. gray	N 6	——	——	Fibrous, ropy, walls up to 0.05mm	1-5
4	Lt. olive gray	5 Y 6/1	——	——	Fibrous, ropy, walls up to 0.2mm	0.2-10
5	Lt. gray	N 7	V. lt. gray	N 8	Fibrous, lineated	0.05-0.2
6	Yellowish gray	5 Y 8/1	V. lt. gray	N 8	Fibrous, lineated	0.05-0.2
7	Yellowish gray	5 Y 8/1	——	——	Fibrous	0.05-0.5
8	V. lt. gray to yellowish gray	N 8 to 5 Y 8/1	Pinkish gray	5 YR 8/1	Spherical to irregular to fibrous	0.05-0.5
9	Yellowish gray	5 Y 8/1	Pinkish gray	5 YR 8/1	Irregular to fibrous	0.02-0.2
10	V. pale orange	10 YR 8/2	Grayish orange pink	5 YR 7/2	Fibrous	0.02-0.2
11	V. pale orange	10 YR 8/2	Pinkish gray	5 YR 8/1	Spherical to elongate	0.05-0.5
12	Pinkish gray	5 YR 8/1	——	——	Spherical to elongate to irregular	0.05-1
13	Yellowish gray	5 Y 8/1	Pinkish gray	5 YR 8/1	Spherical to elongate	0.05-1
14	Grayish orange pink	5 YR 7/2	Grayish pink	5 YR 8/2	Fibrous	0.05-2
15	Pinkish gray	5 YR 8/1	Pinkish gray	5 YR 8/1	Fibrous	0.05-2
16	Pale yellowish orange	10 YR 8/6	Grayish orange pink	5 YR 7/2	Highly fibrous, lineated	0.1-2
17	Yellowish gray	5 Y 8/1	——	——	Spherical pellets up to 2.5mm	0.02-0.2
18	Yellowish gray	5 Y 8/1	——	——	Spherical pellets up to 2.5mm	0.02-0.2
19	Pinkish gray	5 YR 8/1	——	——	Spherical pellets up to 1.5mm	0.02-0.2
20	Pinkish gray	5 YR 8/1	V. lt. gray	N 8	Spherical pellets up to 1.5mm	0.02-0.2
21	V. lt. gray	N 8	V. lt. gray	N 8	Highly fibrous, lineated	0.05-0.2
22	V. lt. gray	N 8	——	——	Highly fibrous, lineated	0.02-0.1
23	Grayish pink	5 R 8/2	——	——	Highly fibrous, lineated	0.02-0.1
24	V. lt. gray to lt. gray	N 8 to N 7	——	——	Spherical to elongate, some fibrous	0.05-0.2
25	V. lt. gray to lt. gray	N 8 to N 7	V. lt. gray	N 8	Spherical to elongate, some fibrous	0.05-0.2

[1] Abbreviations used: lt = light, med. = medium, v. = very.
[2] Color index according to GSA Munsell Rock Color Chart.

Analytical data of pumice samples: Physical characteristics

Sample number	Particle specific gravity	Bulk specific gravity	Bulk density (lb/ft³)	Water absorption (weight-percent increase) 5 min.	Water absorption (weight-percent increase) 10 min.	Abrasion hardness	Indentation hardness (diameter in mm)	Pumice	Particle counts (percent, ¼-½ in.) Obsidian	Particle counts (percent, ¼-½ in.) Cinder	Lithic	Grain counts (percent, 60/200 mesh) Glass	Grain counts (percent, 60/200 mesh) Nonglass
1	0.65	0.36	22.5	22	23	Hard	1.0	99.7	——	——	0.3	98.4	1.6
2	0.56	0.34	21.2	34	36	Medium	1.3	99.9	——	——	0.1	99.5	0.5
3	0.56	0.32[1]	20.0	67	67	Very hard	——	——	——	——	——	80.6	19.4
4	0.67	0.45[1]	28.1	35	37	Very hard	——	——	——	——	——	99.7	0.3
5	0.57	0.34	21.2	42	43	Soft	1.1	——	——	——	——	100	0.0
6	0.58	0.36[1]	22.5	51	51	Soft	1.7	——	——	——	——	99.2	0.8
7	0.51	0.39	24.3	39	41	Soft	1.4	88.0	——	——	12.0	100	0.0
8	0.57	0.39	24.3	20	34	Soft	1.1	86.8	0.2	1.5	11.4	100	0.0
9	0.42	0.37	23.1	45	48	Soft	1.5	94.1	——	0.9	5.0	100	0.0
10	0.44	0.29	18.1	90	90	Very soft	2.3	94.4	——	——	5.6	100	0.0
11	0.42	0.26	16.2	89	89	Very soft	1.6	100.0	——	——	——	97.4	2.6
12	0.50	0.28	17.5	85	85	Medium	1.8	98.9	——	——	1.1	98.5	1.5
13	0.52	0.30	18.8	62	62	Soft	1.6	98.1	——	0.3	1.6	98.0	2.0
14	0.37	0.18	11.2	92	94	Soft	1.8	——	——	——	——	94.4	5.6
15	0.54	0.36	22.5	26	28	Soft	1.4	98.9	——	——	1.1	97.7	2.3
16	0.45	0.34	21.2	90	90	Very soft	2.0	88.5	——	——	11.5	97.5	2.5
17	——	0.91[2]	56.8	—	—	——	——	——	——	——	——	96.1	3.9
18	——	1.00[2]	62.4	—	—	——	——	——	——	——	——	99.4	0.6
19	——	0.67[2]	41.8	—	—	——	——	——	——	——	——	99.1	0.9
20	——	0.40[2]	25.0	—	—	——	——	——	——	——	——	98.1	1.9
21	0.66	0.44	27.5	26	28	Hard	1.2	95.3	2.7	——	2.1	84.4	15.6
22	0.56	0.38	23.7	55	71	Very hard	1.5	——	——	——	——	99.4	0.6
23	0.82	0.35	21.8	20	20	Hard	1.2	——	——	——	——	99.6	0.4
24	0.78	0.48	30.0	25	27	Hard	1.1	——	——	——	——	99.5	0.5
25	0.78	0.48	30.0	25	29	Hard	1.1	99.0	——	——	1.0	99.1	0.9

[1] Minus ½-in. plus ¼-in. fraction of crushed sample.
[2] Bulk sample; entire sample is minus ¼ in.

Analytical data of pumice samples: Screen analyses (Expressed as weight percent retained on respective screen sizes)

Analytical data of pumice samples: Screen analyses, cumulative totals (Expressed as weight percent retained on respective screen sizes)

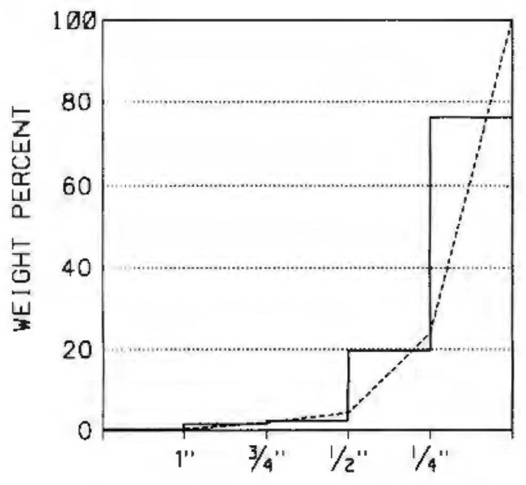
	Screen analyses						Cumulative totals				
Sample number	1″	¾″	½″	¼″	<¼″	Comments	1″	¾″	½″	¼″	<¼″
1	0.3	1.5	2.4	19.7	76.1	——	0.3	1.9	4.2	24.0	100.0
2	1.3	2.4	8.7	22.8	64.8	——	1.3	3.7	12.4	35.2	100.0
3	——	——	——	——	——	Large blocks.	——	——	——	——	——
4	——	——	——	——	——	Blocks and boulders.	——	——	——	——	——
5	——	——	——	——	——	Talus.	——	——	——	——	——
6	——	——	——	——	——	Boulders.	——	——	——	——	——
7	15.8	15.4	20.9	23.5	24.3	——	15.8	31.3	52.1	75.7	100.0
8	5.7	8.3	16.8	28.8	40.4	——	5.7	14.0	30.8	59.6	100.0
9	1.3	4.2	19.3	26.3	48.9	——	1.3	5.5	24.8	51.1	100.0
10	8.3	10.5	14.8	22.8	43.7	——	8.3	18.8	33.6	56.3	100.0
11	——	——	——	2.6	97.4	——	——	——	——	2.6	100.0
12	2.9	1.7	3.2	14.0	78.2	——	2.9	4.7	7.9	21.9	100.0
13	3.6	3.5	7.5	20.0	65.4	——	3.6	7.1	14.6	34.7	100.0
14	——	——	——	——	——	Boulders.	——	——	——	——	——
15	3.8	2.1	5.4	11.4	77.4	——	3.8	5.8	11.2	22.6	100.0
16	13.8	8.3	9.5	15.9	52.6	——	13.8	22.0	31.5	47.4	100.0
17	——	——	——	——	100.0	Screen analysis in text.	——	——	——	——	——
18	——	——	——	——	100.0	Screen analysis in text.	——	——	——	——	——
19	——	——	——	——	100.0	Screen analysis in text.	——	——	——	——	——
20	——	——	——	——	100.0	Screen analysis in text.	——	——	——	——	——
21	2.1	6.6	21.9	27.8	41.7	——	2.1	8.6	30.5	58.4	100.0
22	——	——	——	——	——	Indurated.	——	——	——	——	——
23	——	——	——	——	——	Indurated.	——	——	——	——	——
24	0.2	0.8	4.4	19.0	75.5	——	0.2	1.0	5.4	24.5	100.0
25	0.5	1.3	6.6	29.5	62.1	——	0.5	1.8	8.4	37.9	100.0

Chemical analyses of selected samples: X-ray fluorescence analyses by XRAL

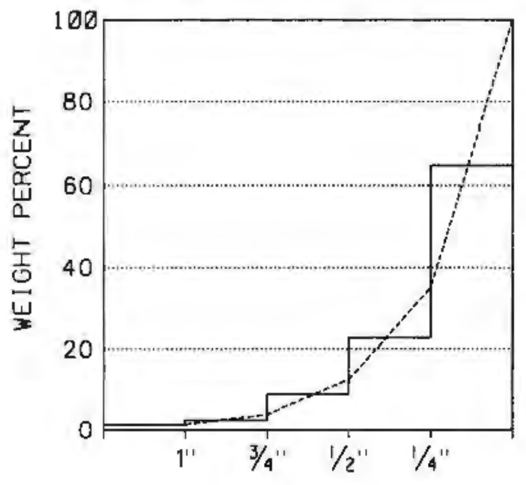
Sample number	SiO_2 (wt. %)	Al_2O_3 (wt. %)	CaO (wt. %)	MgO (wt. %)	Na_2O (wt. %)	K_2O (wt. %)	FE_2O_3 (wt. %)	MnO (wt. %)	TiO_2 (wt. %)	P_2O_5 (wt. %)	LOI (wt. %)	Cr (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Ba (ppm)	Total
1	69.0	14.1	1.31	0.33	5.70	2.92	2.12	0.08	0.21	0.04	4.16	40	77	152	52	242	32	954	100.2
2	68.4	14.3	1.25	0.33	5.29	3.22	2.09	0.07	0.20	0.04	4.62	27	82	162	43	249	20	866	100.0
5	70.3	13.5	0.93	0.26	5.07	4.11	1.75	0.05	0.23	0.04	3.31	18	133	72	28	277	28	1010	99.7
6	71.3	14.0	0.93	0.27	5.14	4.13	1.84	0.06	0.24	0.04	2.16	29	128	67	34	280	27	971	100.3
8	69.2	14.5	1.56	0.63	5.17	3.53	3.19	0.08	0.42	0.07	2.23	38	105	145	50	318	32	877	100.8
9	67.1	14.3	1.50	0.71	5.11	3.57	3.21	0.08	0.41	0.07	3.08	39	110	108	36	330	23	879	99.3
10	62.0	16.1	2.49	1.07	4.37	1.90	5.40	0.13	0.64	0.08	5.16	39	65	331	51	289	18	755	99.5
11	60.3	18.0	4.60	1.81	5.04	1.50	4.68	0.10	0.63	0.13	3.23	60	33	857	17	133	21	644	100.2
13	63.4	16.4	3.48	1.21	5.15	2.04	3.52	0.08	0.53	0.12	3.85	55	45	668	14	177	14	695	100.0
14	67.6	15.1	2.41	0.85	5.38	2.47	2.78	0.07	0.49	0.10	3.23	31	55	506	27	232	14	851	100.7
15	64.9	15.7	3.30	1.31	4.91	2.22	3.67	0.08	0.56	0.11	2.93	43	60	641	19	195	15	717	99.9
16	62.2	16.8	3.12	1.33	4.77	2.07	3.93	0.08	0.61	0.13	4.85	45	67	566	13	212	22	756	100.1
20	67.5	14.9	2.38	0.82	5.48	2.44	2.67	0.07	0.49	0.09	3.23	24	56	490	45	227	10	875	100.3
21	70.0	13.1	0.68	0.28	3.52	5.40	1.47	0.05	0.21	0.03	5.23	22	100	41	53	262	32	741	100.1
25	69.7	10.3	0.71	1.79	2.97	4.59	3.20	0.07	0.22	0.04	6.39	77	148	32	184	1230	75	94	100.2

Trace-element analysis of selected samples: Atomic absorption and induction coupled spectrometry by GSI

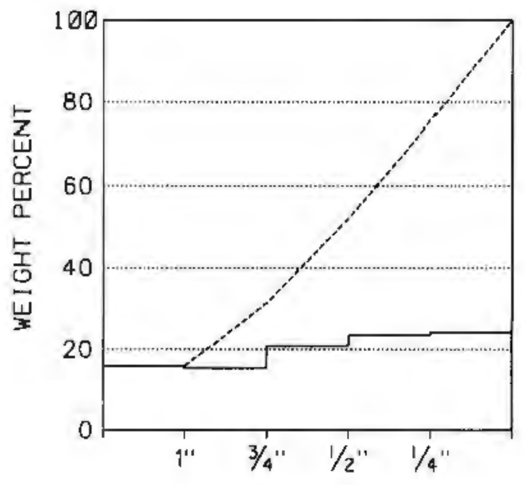
Sample number	Ag (ppm)	As (ppm)	Au (ppm)	Cu (ppm)	Hg (ppm)	Mo (ppm)	Pb (ppm)	Sb (ppm)	Tl (ppm)	Zn (ppm)	Bi (ppm)	Cd (ppm)	Ga (ppm)	Se (ppm)	Te (ppm)
1	0.053	<0.993	0.016	6.18	<0.099	0.630	0.544	<0.248	<0.497	5.98	<0.248	<0.099	0.709	<0.993	<0.497
2	0.025	<0.988	0.002	4.58	<0.099	0.414	0.891	<0.247	<0.494	6.17	<0.247	<0.099	0.931	<0.988	<0.494
5	<0.015	<0.995	0.003	1.96	<0.099	0.310	0.415	<0.249	<0.497	1.17	<0.249	<0.099	<0.497	<0.995	<0.497
6	0.02	0.98	0.015	2.97	<0.098	0.558	0.806	<0.245	<0.49	1.16	<0.245	<0.098	0.573	<0.98	<0.49
8	0.019	1.44	0.001	8.86	<0.098	0.789	10.25	<0.245	<0.49	16.1	<0.245	<0.098	1.36	<0.98	<0.49
9	0.023	1.26	0.004	9.61	<0.099	0.722	10.67	<0.249	<0.497	17.0	<0.249	<0.099	1.65	<0.994	<0.497
10	0.03	1.23	0.003	13.9	<0.099	0.472	30.61	<0.248	<0.496	31.5	<0.248	<0.099	5.37	<0.991	<0.496
11	0.021	1.73	0.002	13.8	<0.099	0.613	10.91	<0.247	<0.494	25.0	<0.247	<0.099	3.41	<0.987	<0.494
13	0.022	<0.989	0.007	9.71	<0.099	0.689	30.10	<0.247	<0.495	14.2	<0.247	<0.099	2.28	<0.989	<0.495
14	0.025	0.975	0.004	20.0	<0.097	0.391	10.33	<0.244	<0.487	16.2	<0.244	<0.097	1.59	<0.975	<0.487
15	0.019	<0.991	0.002	14.9	<0.099	0.379	0.954	<0.248	0.496	11.8	<0.248	0.099	1.12	<0.991	<0.496
16	0.026	1.17	0.003	15.8	<0.098	0.550	20.53	0.246	<0.491	18.3	<0.246	<0.098	3.80	<0.983	<0.491
20	0.02	<0.989	0.008	4.14	<0.099	0.373	0.935	<0.247	<0.494	6.84	<0.247	<0.099	1.06	<0.989	<0.494
21	0.02	<0.987	0.015	6.31	<0.099	0.500	10.19	<0.247	<0.494	4.29	<0.247	<0.099	0.790	<0.987	<0.494
25	0.019	2.28	0.003	7.94	0.099	0.947	60.81	<0.247	<0.494	43.6	<0.247	<0.099	3.73	<0.987	<0.494



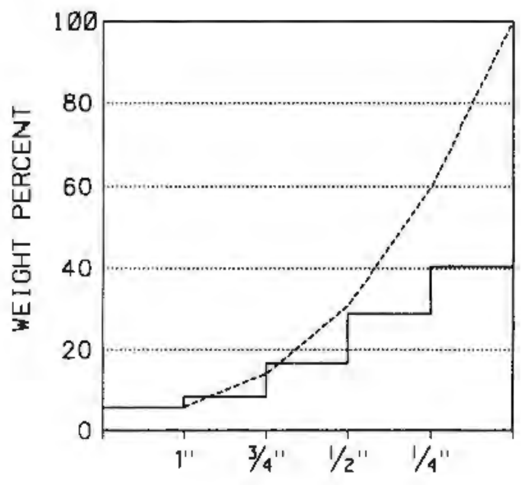
Sample Number: 1
Area: Bend
County: Deschutes



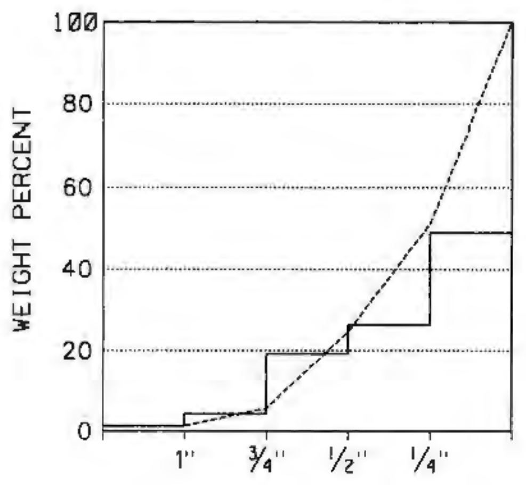
Sample Number: 2
Area: Bend
County: Deschutes



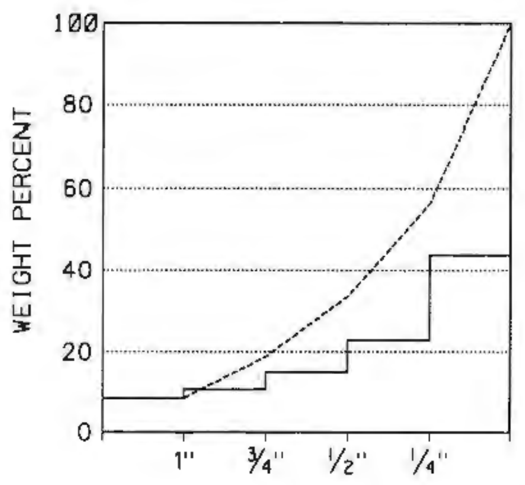
Sample Number: 7
Area: Pumice Butte
County: Deschutes



Sample Number: 8
Area: Pumice Butte
County: Deschutes



Sample Number: 9
Area: China Hat
County: Deschutes



Sample Number: 10
Area: Poly Top Butte
County: Lake

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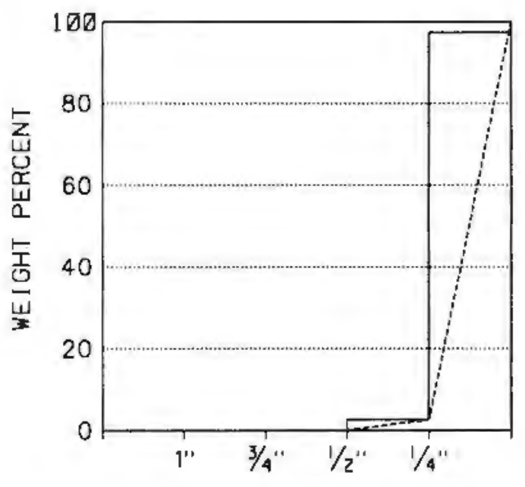
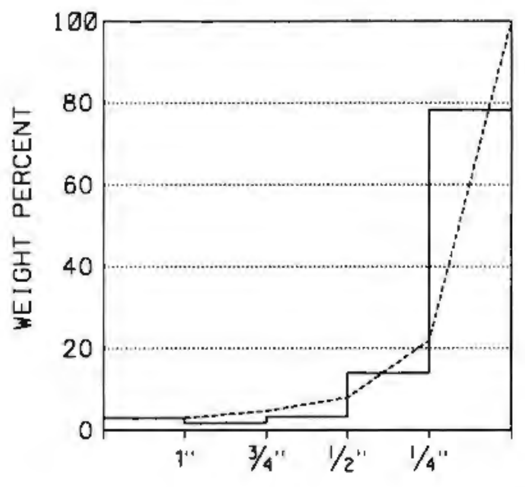
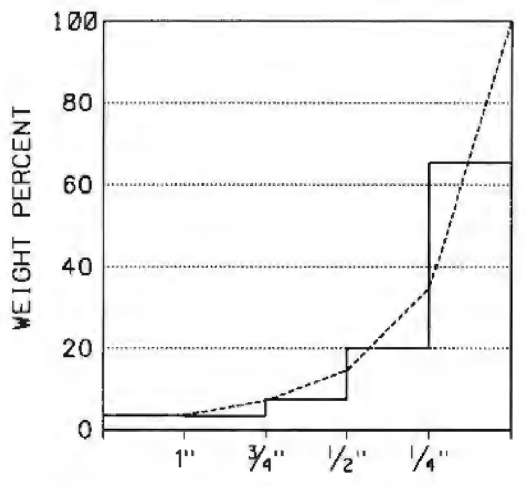


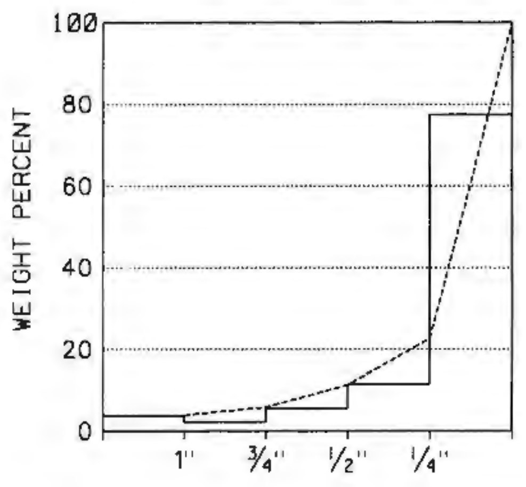
Sample Number: 11
Area: Crescent Lake Jct.
County: Klamath



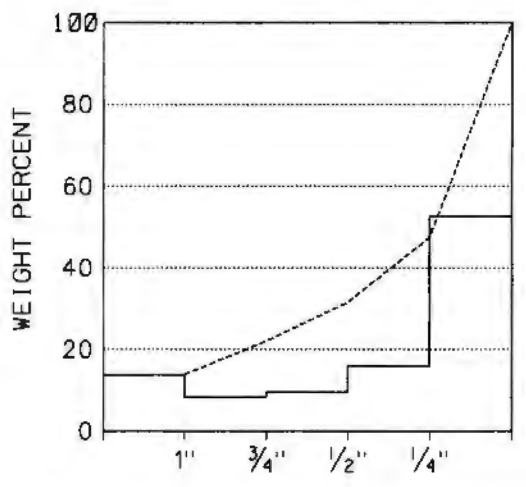
Sample Number: 12
Area: Corral Spring
County: Klamath



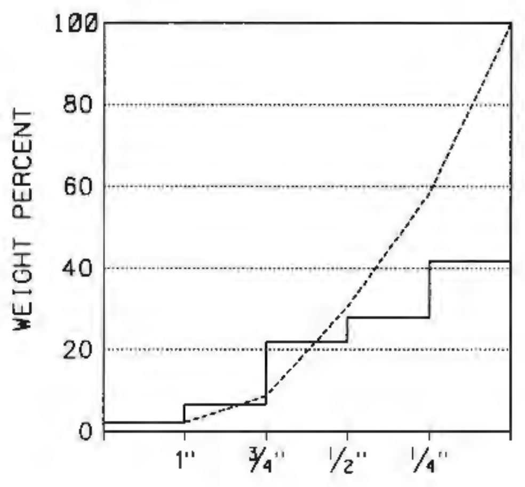
Sample Number: 13
Area: Chemult
County: Klamath



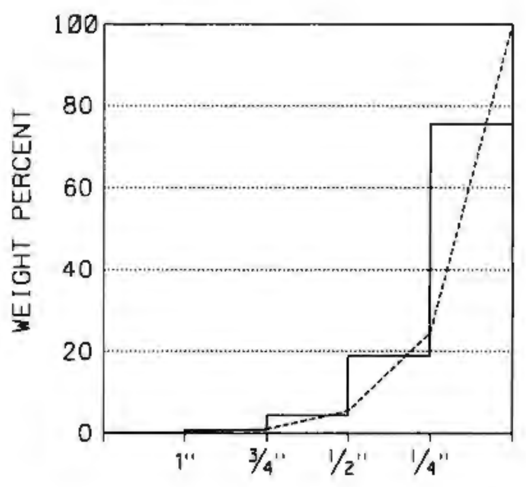
Sample Number: 15
Area: Summit Rock quarry
County: Klamath



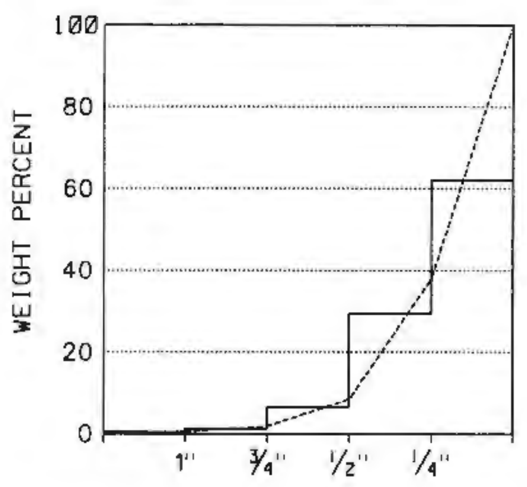
Sample Number: 16
Area: Clearwater
County: Douglas



Sample Number: 21
Area: Burns
County: Harney



Sample Number: 24
Area: New Princeton
County: Harney



Sample Number: 25
Area: New Princeton
County: Harney