PUMICE AND PUMICITE IN ARIZONA

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ABSTRACT

Arizona contains an abundance of pumiceous materials. Although only one active mine is currently producing pumice and pumicite, over 50 occurrences have been documented within the state.

From 1980 to 1989 Arizona has produced approximately 18,140 mt (20,000 st) of pumiceous materials valued at $104,000. In 1990 Arizona ranked fourth in the amount of pumice used or sold in this U.S. It is anticipated that the state's production should increase in the near future because of the increasing demand for lump pumice in the production of stonewashed fabrics.

The principal domestic uses of pumiceous materials include concrete admixtures and aggregates, light-weight building blocks, abrasives and landscaping. In 1990, over 90% of the production was used for building blocks and abrasives. The fastest growing use of pumice is its use as an abrasive for the production of designer jeans. In 1986 abrasive use was 3% of the U.S. consumption; but in 1990, it increased to 14% -- an increase of nearly 400%.

The principal pumiceous deposits in Arizona occur within the silicic volcanic units of the San Francisco volcanic field in Coconino County. Present production comes from the ash-fall deposits on the White Vulcan claims north of Flagstaff. Arizona Tufflite, Inc. produces approximately 4590 m^3 (6000 yd^3) per month from this deposit for use in the construction and laundry industries. Other significant, but undeveloped, pumiceous deposits occur at Bill Williams Mountain and Deadman Flat.

Physical properties of the Arizona pumiceous materials indicate they are suitable for use in concrete aggregate, light-weight building blocks, and as abrasives. The pumice lumps from the White Vulcan claims and Deadman Flat area are the best suited for laundry use.

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INTRODUCTION

Terminology and Origin

Pumice and pumicite are pyroclastic materials produced by the rapid expansion of dissolved gases in a viscous siliceous magma of rhyolite to dacite composition. This group of pyroclasts is distinctive because they are glassy with the occurrence of a cellular structure composed of numerous thin-walled vesicles. A useful classification of pyroclastic and pumiceous fragments, based upon size (Fisher, 1961), is in Table 1.

Table 1. Classification of pyroclastic and pumiceous fragments

Clast Size (mm)	(in)	Pyroclastic Fragments	Pumiceous Fragments
> 64 mm	> 2.6	Bombs, Blocks	Lump Pumice
64 - 4	2.6-0.16	Lapilli	Pumice
< 4	< 0.16	Ash	Pumicite

The term lump pumice is used for pumiceous fragments greater than 64 mm (2.6 in) diameter; pumice 4-64 mm (0.16-2.6 in) in size and pumicite to those less than 4 mm (0.16 in). Pumice contains abundant equidimensional to elongate vesicles whereas pumicite is composed of vesiculated to nonvesiculated fragments derived from rupturing of vesicle walls.

Pumicite originates when dissolved gases in the viscous magma produce a froth or a large quantity of bubbles in a short period of time followed by rapid rupture of the vesicles. If fewer bubbles develop in the magma and the glass vesicle walls are allowed to solidify rapidly enough to prevent collapse, then pumice will form (Verhoogen, 1951; Chesterman, 1956).

Studies on the pore size distribution of vesicles have shed some new light on the origin of pumice. Sparks and Brazier (1982) have reported that pore size of pumice vesicles are polymodal and occur in three distinct populations; they include vesicle diameters of: 1) 15-184, 2) 3-23, and 3) 0.5-4.0 microns (Whitham and Sparks, 1986).

The three pore size populations are interpreted as representing degassing of silicic magma at three different times. The coarse population represents slow vesiculation within the magma chamber over periods ranging from weeks to years. The intermediate populations occur during magma ascent over periods of time from minutes to hours. The smallest vesicle represent bubbles formed during explosive discharge of the magma at the surface over periods of a few seconds (Sparks and Brazier, 1982).

Block pumice has commonly been used to refer to lump pumice; however, the term block has been defined legally as a pumice fragment possessing one dimension equal to or exceeding 51 mm (2 in) (Federal Register, 1990) (see Appendix I).

The laundry industry utilizes only coarse pumice ranging from 19 to 76 mm (3/4 to 3 in) in diameter. The amount of coarse pumice in a typical pumiceous deposit is generally less than 10%. A survey of 58 deposits in the western United States shows that over 30% contain no pumice fragments coarser than 19 mm (3/4 in). The average > 19 mm (> 3/4 in) fraction for all of the deposits is 7.1% (Hoffer, 1991).

Geologic Setting and Occurrence

Pumiceous materials are formed from areas of explosive volcanism in which high-silica materials (65 to 75% SiO_2) have erupted. Such areas occur only in the western United States and include the active volcanoes of the Cascade Mountains in northern California, Oregon, and Washington. In addition, numerous deposits have been produced from recent siliceous calderas or dome complexes in California, Nevada, Arizona, New Mexico, and Idaho.

All glasses are amorphous and are therefore unstable in nature over geologic time. Pumice and pumicite, which are natural glasses, are susceptible to alteration by chemical weathering at the earth's surface over a relatively short period of geologic time. Weathering of the pumiceous minerals will devitrify the glass to clay minerals, and thus destroy the physical properties that make the pumice useful as an aggregate and abrasive. Therefore, fresh, unaltered pumice and pumicite are generally restricted only to strata of mid-Tertiary to Quaternary age.

Physical and Chemical Properties

Pumice and pumicite are either vesicular volcanic glass or fragments of such glass. Vesicles can range in size from less than 0.01 mm (0.0004 in) to more than 20 mm (0.8 in), but commonly range from 0.1 to 0.6 mm (0.004 to 0.024 in) in diameter with equidimensional to highly elongate shape. Pumice has a white streak and a Mohs hardness of 6.0. The fracture is irregular and the tenacity is generally brittle. Pumice has a silky luster whereas pumicite is more earthy (Williamson and Burgin, 1960). Pumice and pumicite are light colored, commonly light gray to white with shades of light buff, brown, and pink are not uncommon. The density of the pumiceous materials is about 2.5 g/cm^3 (156 lbs/ft^3) but because of their cellular structure, the apparent density is generally less than 1.0 g/cm^3 (62.4 lbs/ft^3). Apparent density measurements of more than 250 pumice samples show a range from 0.35 to 1.20 g/cm^3 (21.8 to 74.9 lbs/ft^3) with an average of 0.70 g/cm^3 (43.7 lbs/ft^3) (Hoffer, 1989).

Phenocrysts and fragments of quartz, feldspar, hornblende, biotite, augite, and magnetite are commonly found in pumice and pumicite. Generally, these crystals are most abundant in pumice with high density.

Pumiceous materials are composed primarily of SiO_2. Williamson and Burgin (1960) reported that the SiO_2 content of 92 pumice and pumicite samples ranged from 54 to 77.6% with a median of 71.3% Chesterman (1956), based on chemical analyses of 80 pumice samples, states that the average SiO_2 value is approximately 70.4%. Typically, pumiceous materials contain from 65 to 75% SiO_2. The second most abundant compound is Al_2O_3, followed by the alkali oxides of potassium and sodium (Table 2).

Table 2. Chemical composition (weight percent) of the average pumice and Arizona pumice (1 - data from Chesterman, 1956; 2 - data from Arizona Department Mines and Mineral Resources files, 1957, 1989; Kiersch and Haff, 1955; Wolf et al., 1987; Ulrich and Bailey, 1987; Newhall et al., 1987; Holm, 1988; nr = not reported).

	Average Pumice (80 samples)[1]	Arizona Pumice (10 samples)[2]
SiO_2	70.38%	70.65%
TiO_2	n.r.	0.26
Al_2O_2	15.82	14.52
FeO	2.92	2.07
MgO	0.48	0.72
CaO	1.56	1.86
Na_2O	3.70	4.11
K_2O	4.10	3.86
MnO	n.r.	0.08
P_2O_5	n.r.	0.09
LOI	0.53	3.00
TOTAL	99.49	101.22

The chemical analyses of Arizona pumice samples, which are from the pumice deposits of the San Francisco Peaks and Bill Williams Mountain areas, are comparable to those of average pumice. The loss on ignition (LOI) values of Arizona pumice is much higher than average pumice; LOI represents the liberation of volatiles such as H_2O and CO_2 during heating.

Deposits

Pumice and pumicite deposits can be classified on the basis of mode of deposition and origin. A working classification, modified from Chesterman (1956), is given in Table 3.

Pyroclastic fall deposits are formed after material has been explosively ejected from a vent into the atmosphere and then falls to the earth's surface under the influence of gravity. Fall deposits

Table 3 Classification of pumiceous deposits (modified from Chesterman, 1956)

Origin	Mode of Deposition	Example
Subaerial		
Pyroclastic Fall	Gravity	Sugarloaf Mtn., and White Vulcan, AZ
Pyroclastic Flow	Laminar Flow	Upper Bandelier Tuff, NM; Mt. St. Helens, 1980
Pyroclastic Surge	Turbulent Flow	Sugarloaf Mtn., tuff ring, AZ
Flow and Dome	Vesiculation	Glass Mtn. and Mono Craters, CA
Subaqueous	Fall, Flow, or Surge (?)	Japan, Grenada Basin, Krakatoa, Philippines
Epiclastic	Mainly water, but may include mass movements, ice or wind	Pumicite layers in upper Bidaahochi Fm. northeastern AZ; Bagdad, AZ

locally maintain. a uniform thickness over the topography and are generally well sorted with the majority of the fragments between 1 to 8 mm (0.04 to 0.32 in) in diameter (Fig. 1). Near the vent some fall deposits are welded (Cas and Wright, 1987).

Pyroclastic flow deposits result from hot laminar surface flow of pyroclastic debris and gas which travel as a high particle concentration medium. The deposits are topographically controlled and fill valleys and depressions (Fig. 1). The pyroclastic units are generally massive and poorly sorted. The individual clasts may show rounding and the effects of abrasion. In addition, lithic fragments show normal grading whereas pumice clasts display inverse grading (Hickson and Barnes,

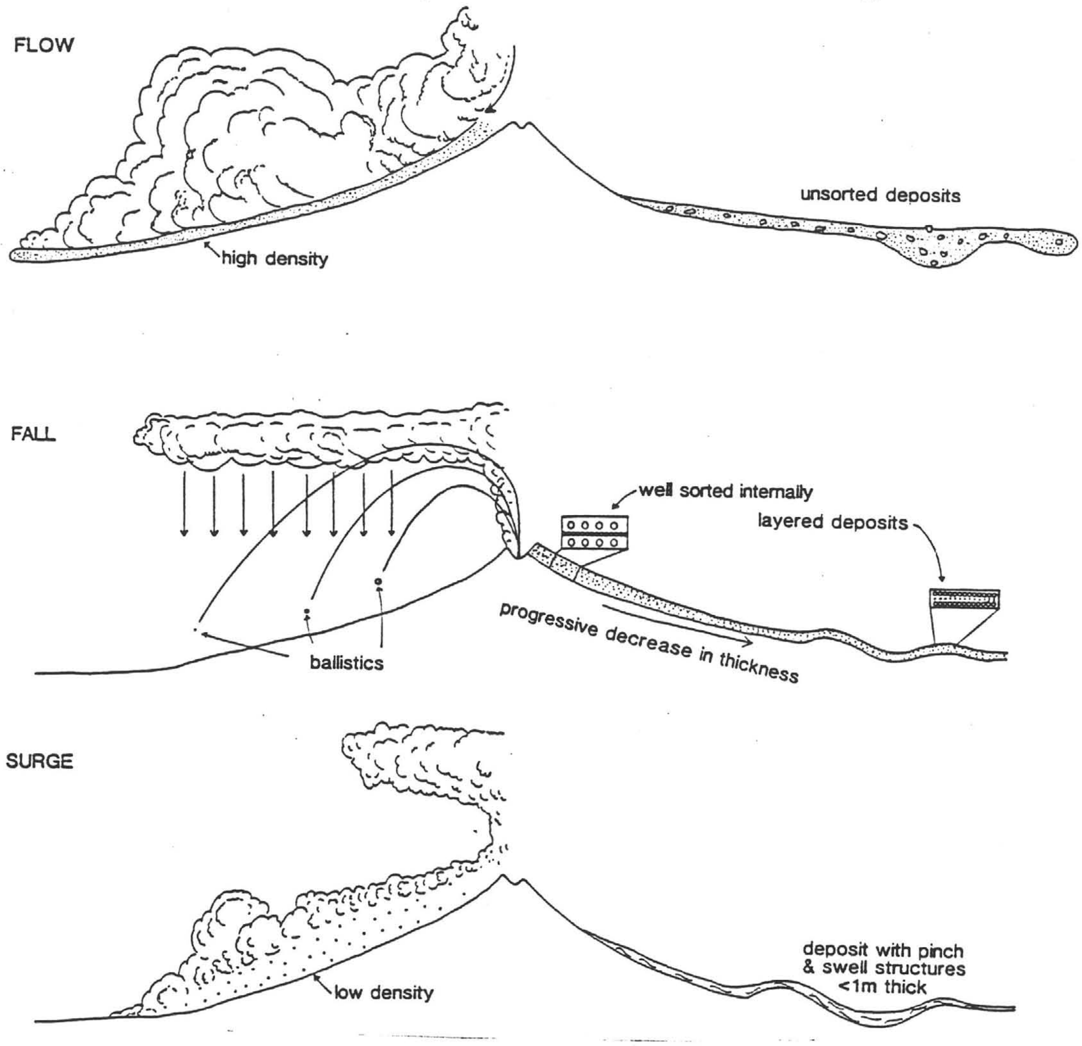
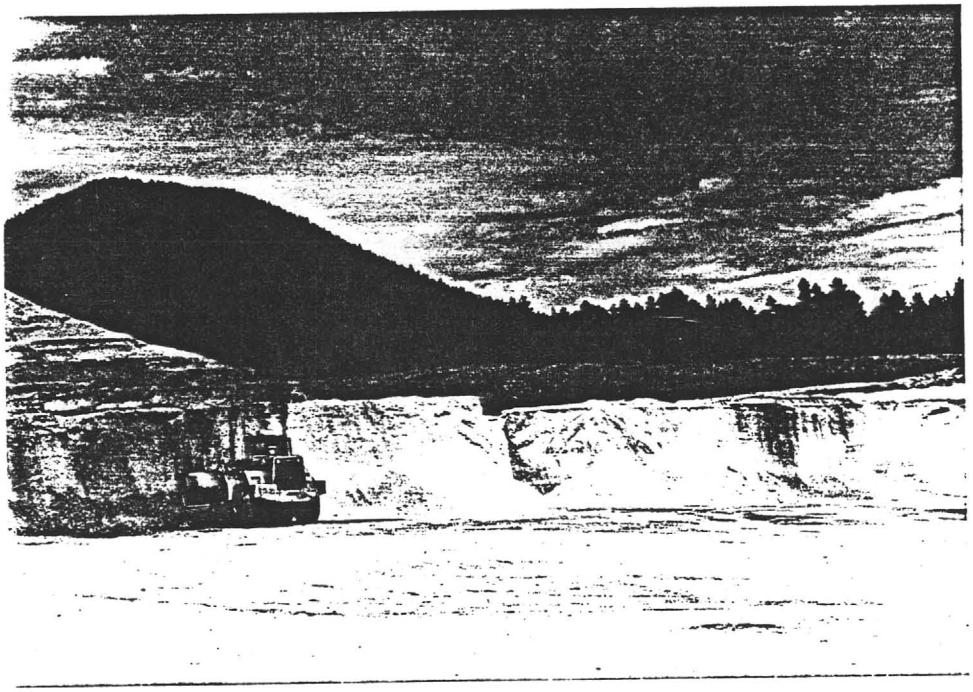


Figure 1. Mode of formation and characteristics of the main types of pyroclastic deposits. (Note: the ballistic trajectories are independent of the eruption column), (from Smith and Roobol, 1990).



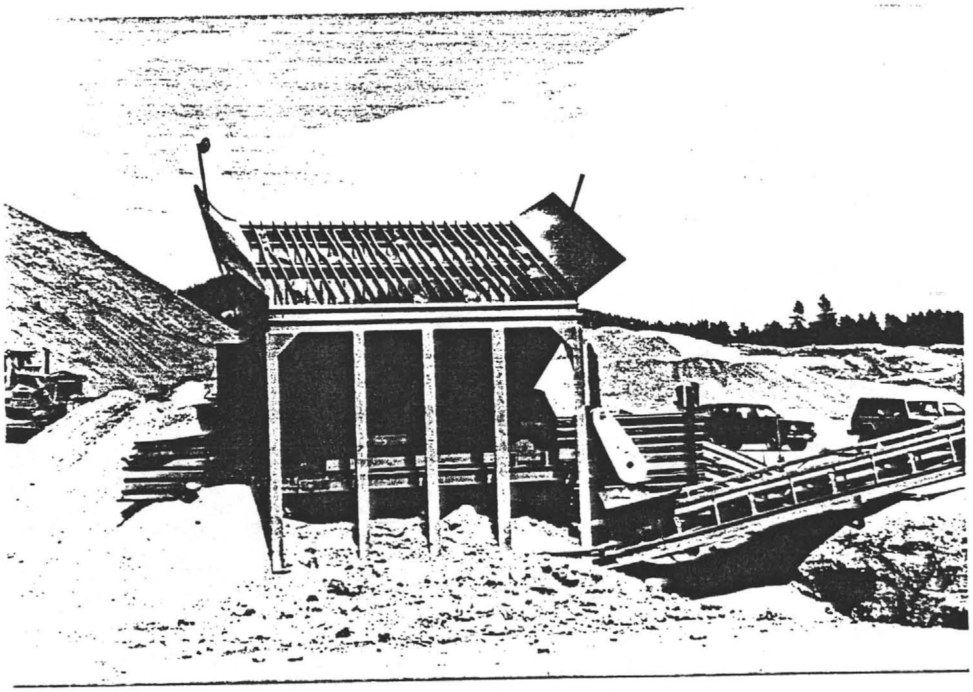
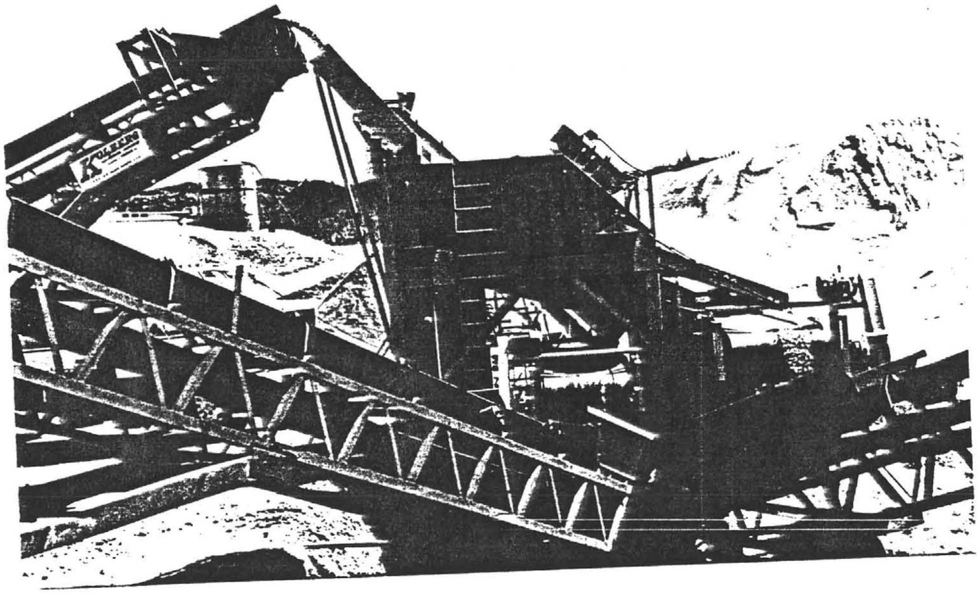


Plate 1. Arizona Tufflite pumice mine sec. 19, T23 N. R8E. Coconino County. Top - pumice is removed from the quarry face (Sugarloaf Mountain in background). Bottom - pumice is then dumped into a separator which removes rock and obsidian fragments and the clean fraction is moved by a conveyor to a grizzly for screening.



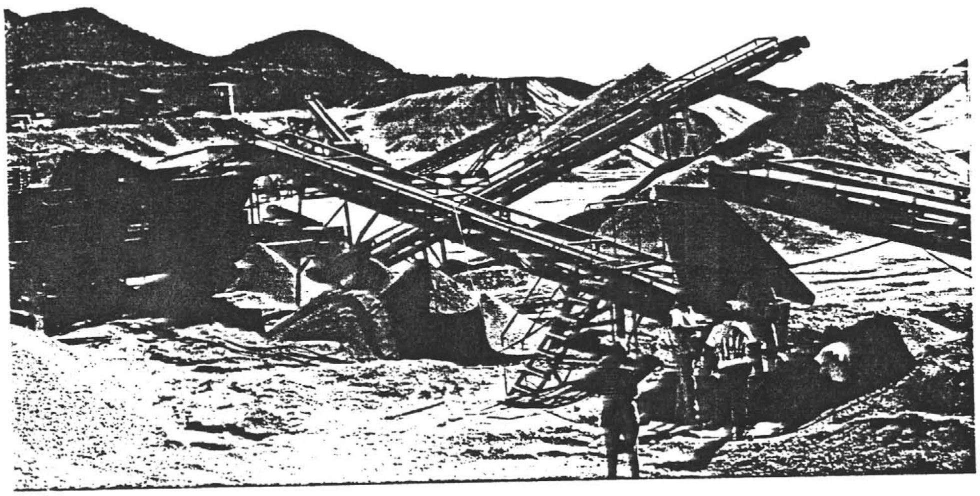


Plate 1 (cont). Converger (top-left) dumps the pumice into a grizzly (center) which screens the materials into 2.5-6.5 cm (1-2.5 in), 2.5 cm (1 in), 1.2 cm (0.5 in), 1 cm (-3/8 in) fractions. The two largest sizes are for laundry use, 1.2 cm (0.5 in) for concrete aggregate, and 1 cm (3/8 in) for cinder blocks. Minus 1 cm (3/8 in) fraction is currently being rescreened into 0.8 cm (5/16 in), 0.3 cm (1/2 in), and 0.2 cm (3/32 in) for use in horticulture, planting and ballfield coverings, and roofing tiles, respectively.

1986). Units formed by pyroclastic flows are commonly referred to as ignimbrites, ash flows, or welded tuffs.

Surge deposits are emplaced as a cool turbulent mixture of gas and clasts. The resulting deposits mantle the topography but are generally thicker in valleys and in depressions and usually contain abundant lithic fragments (Cas and Wright, 1987). Characteristically, the units show directional sedimentary bed forms such as low-angle cross-bedding and dune and anti-dune forms (Fig. 1).

Pumice deposits that exist as vesiculated surfaces of obsidian flows and domes have been observed at Glass Mountain and Mono Craters in California (Chesterman, 1956). The pumice formed by quiet vesiculation of viscous glassy lava as it rose to the surface. The pumice occurs in lumps 5.1 cm to 1.7 m (2 in to 5.2 ft) in diameter and grades downward into obsidian.

Subaqueous pyroclastic deposits can form in both marine and lacustrine enviroments from accumulation of ejecta from subaerial and submarine eruptions. Typical features associcated with subaerial eruptions include plane-parallel beds, normal grading from crystal- and lithic-rich bases to shard-rich tops, pumice inversely graded, and good to poor sorting (Fisher and Schmincke, 1984). Submarine eruptions which consist mainly of pyroclastic flow debris, are characterized by a massive to poorly bedded and poorly sorted lower unit and an upper thinly bedded unit. When present, pumice is inversely graded in the lower layer (Fisher and Schmincke, 1984).

Submarine ash-fall deposits, based upon the recent studies of Cashman and Fisher (1991), are commonly bimodal in particle diameters with the pumice fragments 5 to 10 times as large as the codeposited lithic fragments. Similar subaerial deposits show pumice diameters are only 2 to 3 times as large as the lithics.

Epiclastic deposits represent any of the above materials that have been eroded, transported and redeposited by running water, glaciers, mass movements, or wind. Reworked materials deposited by streams commonly show many of the same features as fluvial clastic sedimentary rocks.

Such features inlcude cross-bedding, interbedded non-pyroclastic materials, and rounding of fragments.

PRODUCTION

Most pumiceous deposits are unconsolidated and have a minimum of overburden. Mining is by open pit and can easily be carried out with conventional loading equipment. The material is removed in bulk and then screened on site into various size fractions required in the construction and laundry industries (Plate 1). Pumice, after separation from the pumicite, may undergo a gravity separation to remove pumiceous fragments that contain lithics and/or obsidian.

Although the reserves of pumiceous materials in Arizona are significant, the state has produced very limited amounts during the 1980's. From 1980 to 1989 Arizona produced approximately 18,140 mt (20,000 st) of pumiceous materials valued at $104,000. The largest production was in 1980 when 8163 mt (9000 st) of pumice and pumicite were mined; this represents less than 2% of the total U.S. production (Table 4). From 1981 through 1989 production has ranged from only 907 to 1814 mt (1,000 to 2,000 st) per year.

In 1990, the leading states in the amount of pumice used or sold were Oregon, California, New Mexico, Arizona and Idaho in order of decreasing production (Bolen, 1991).

It is anticipated that Arizona's pumice production should increase in the next several years for two reasons. One, the demand for lump pumice has increased significantly since 1987 for the production of stonewashed jeans. The major laundry centers in the U.S. are located in nearby Los Angeles, California and El Paso, Texas. Second, at the end of 1989, 43% of the U.S. pumice consumption was supplied by imports from Greece, Turkey, Guatemala, and Italy. Because of the additional transportation costs to U.S. markets from foreign sources, Arizona pumice should be able to compete very favorably with the imports.

Table 4. Arizona production of pumiceous materials 1980-1990 (thousand metric and short tons and thousand dollars; data from Meisenger, 1983, 1988; and Bolen, 1990, 1991; nr = not reported).

Year	Quantity (10^3 mt)	Quantity (10^3 st)	Value (10^3 \$)	U.S. Production and Arizona Percentage (10^3 mt)	(10^3 st)	(%)
1980	8	9	13	493	543	1.7
1981	0.9	1	7	453	499	0.2
1982	0.9	1	3	377	416	0.2
1983	1.8	2	15	407	449	0.5
1984	1.8	2	15	455	502	0.4
1985	nr	nr	nr	461	508	nr
1986	1.8	2	30	503	554	0.4
1987	0.9	1	7	356	392	0.3
1988	0.9	1	7	353	389	0.3
1989	0.9	1	7	423	466	0.2
1990	nr	nr	nr	442	487	nr

CONSUMPTION AND USE

Introduction

The principal domestic uses of pumiceous materials include concrete admixtures and aggregates, building block, abrasives, and as landscaping materials; minor uses include road materials, carriers of fertilizers and pesticides, and insulators. A summary of the industrial uses of pumiceous materials are shown in Table 5.

The major consumers of pumice from 1981 to 1990 are shown in Figure 2. In 1981, approximately 85% of the pumiceous materials were utilized in concrete aggregates. This use fell steadily from 1981 to 1985 when it consumed only 45% of the pumice market. In 1990, over 80% of the production was used for light-weight building blocks and as an abrasive.

Table 5. Summary of industrial uses of pumiceous materials (modified from McMichael, 1990)

Size	Use
Extra Coarse > 76 mm (> 3.0 in)	Decorative stone (up to 5 ft); scouring blocks (4x4x8 in or 3x3x6 in); stone washing (up to 4 in); landscaping (3 to 5 in)
Coarse 76-1.5 mm (3.0-0.06 in)	Acid and stone washing (0.75-3.0 in); barbeque stones (2 in); soil additives (0.2 in); pet litter (0.12 to 0.15 in); aggregate for concrete (0.75 to 0.31 in); plaster (0.12 to 0.06 in); and stucco (< 0.125 in); chemical carriers, filtration media; accoustical paints and non-skid coatings; (<0.2 in) building blocks.
Intermediate 1.5-0.30 mm (0.06-0.012 in)	Powdered handsoaps (0.02 to 0.004 in), metal and plastic finishing, fillers for textured paints.
Fine 0.30-0.076 mm (0.012-0.003 in)	Polishing natural teeth and dentures (0.003 to 0.007 in), glass polishing (0.006 to 0.01 in), electro-plating; TV tube processing
Extra Fine < 0.076 mm (< 0.003 in)	Portland pozzolan cements; furniture polishing and finishing; cleaning electronic circuit finishing; flattening agents; glass cleaners; mold release agents.

The fastest growing use of pumiceous materials is its use as an abrasive. In 1986 abrasive use of pumice was 15,419 mt (17,000 st) or 3% of the U.S. consumption. In 1990, abrasive use had increased to 61,676 mt (68,000 st) to 14%, an increase of nearly 400%. The primary reason for the increase as an abrasive is in the production of designer jeans (Bolen, 1991). Laundry pumice was formerly included under the abrasive category by the U.S. Bureau of Mines, but in 1990 it was reported as a separate listing. The 1990 consumption of laundry pumice was reported at 39,001 mt (43,000 st) (Bolen, 1991).

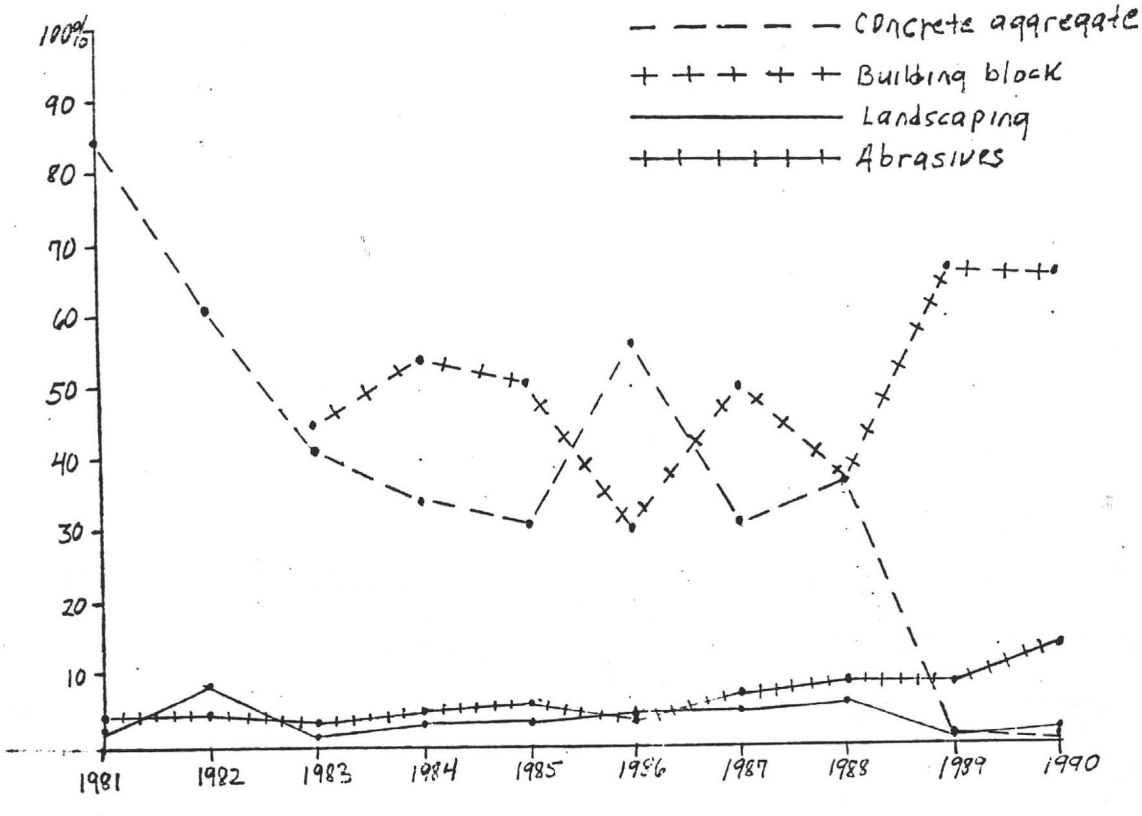


Figure 2. Consumption trends of pumiceous materials; 1981 to 1990 (data from Meisinger, 1983 and 1988); Bolen (1990 and 1991).

Major Uses and Specifications

Concrete Aggregates and Admixtures

In the construction industry, pumice and pumicite are used primarily to produce light-weight concrete aggregate. The major advantages of pumice concrete include:

1. Light weight -- pumice weighs one-third to two-thirds as much as quartz sand, gravel, or crushed stone, thereby decreasing the need for structural steel;
2. High insulation value -- pumice concrete is six times more efficient as a heat insulator than ordinary concrete;
3. High elasticity -- pumice concrete is six times as resilient as ordinary concrete and is therefore more resistant to earthquakes and other shocks; and
4. Heat resistance -- pumice undergoes no volume change below 760°C (1400° F) and therefore no spalling or structural damage occurs during building fires (Chesterman, 1956, 1966).

Major disadvantages of pumice concrete include minor moisture absorption and volume change and significant lower compressive strength than ordinary concrete (Bates, 1960).

Pumice used for light-weight aggregate should possess vesicles of uniform size and shape which should not be interconnected. The pumice fragments should be inert and free of contaminating substances such as clay minerals, organic materials, chemical salts, and amorphous silica (Walker, 1951). The aggregate should be well sorted with fragments ranging in size from 0.16 to 0.64 cm (0.063 to 0.25 in).

When fine-grained siliceous material is added to portland cement, it forms a pozzolan. The siliceous fragments, in the presence of water, combine with calcium hydroxide that is liberated from the cement to form compounds with additional cementious properties (Harben and Bates, 1990).

Natural pozzolanic materials are classified according to their mineralogical composition; the classification, in descending order of activity, includes: 1) pumice-pumicite and volcanic glass, 2) opal and diatomaceous earth; 3) clay minerals (kaolinite, montmorillonite, and illite clays, palygorskate and mixed clays with altered vermiculite); 4) zeolites; and 5) hydrous aluminum oxides (Mielenz et al., 1951). Artificial pozzolan includes fly ash, which is produced as a by-product from the burning of coal. In Arizona, over 907 mt (100 st) of fly ash are produced each week at the Arizona Public Service Company Cholla power plant at Joseph City (Williams, 1966).

The primary product of the pozzolanic reaction is the formation of an insoluble hydrous calcium silicate which reduces the overall porosity and permeability of the concrete and thereby prevents deterioration by chloride or sulfate salt solutions or acid waters (Bates, 1960; U.S. Bureau of Mines, 1969). In addtion, the effect of alkali reactions in the concrete are reduced, which will cause it to eventually expand and crack. In the U.S., portland pozzolan cements have been used in the construction of concrete dams, canals, tunnels, reservoirs, and other structures exposed to corrosive waters. Examples of major pozzolan-cement structures in the southwest include the Elephant Butte and Glen Canyon dams in New Mexico and Arizona, respectively.

The major advantages of utilizing pozzolanic materials in concrete products includes the following (Williams, 1966).

1. Pozzolans cost less than portland cement.
2. Impovement of plasticity of the fresh cement, thereby reducing finishing time;
3. Reduction of aggregate segregation and "bleeding" of water in concrete slurries;
4. Reduced porosity and permeability in the hardened concrete;
5. Reduced deterioration by sulfate waters and alkali reactions; and
6. Improved concrete tensile and compressive strength and reduced heat by hydration.

Disadvantages of pozzolan concretes include a slower curing time for the concrete, impeded rate of development of compressive strength, and the dry shrinkage of the hardened concrete may be increased (Williams, 1966).

The physical and chemical specifications for natural pozzolanic materials have been defined by the American Society for Testing and Materials (ASTM C618, Class N) and are summarized below:

Physical Properties

1. Density = 2.3-2.8 g/cm^3 (143.5-174.7lbs/ft^3)

2. Size = maximum of 12% retained when wet-sieved on No. 325 sieve; mean particle diameter, maximum = 9 microns

3. Water requirements = 115% of that required for normal portland cement

4. Dry shrinkage = 0.03% at 28 days

5. Autoclave expansion = 0.8% maximum.

Chemical Properties

1. $SiO_2 + Al_2O_2 + Fe_2O_3$ = 70.0% minimum

2. MgO = 5.0% maximum

3. SO_3 = 3.0% maximum

4. Moisture content = 3.0% maximum

5. Loss of ignition = 10.0% maximum

6. Available alkalies (optional) = 1.5 maximum

A summary of Arizona pumice and pumicite deposits tested for pozzolan specifications are included in Table 6.

The relative abundance and current low price of fly ash has replaced the use of pumiceous materials in pozzolans.

Building Blocks, Decorative Stone and Landscaping

In 1990 the principal use of pumice was in the manufacturing of building blocks. In addition, many of the larger pumice blocks, up to 1.6 m (5.2 ft) or more in diameter, are sold either rough or with one or two edges sawed. These blocks are used for wall or other surface coverings such as suspended ceilings.

Table 6. Evaluation of Arizona pumice-pumicite deposits for pozzolan (nd = not determined, * = evaluation based upon the solubility and activity of the materials (Moran and Gilliland, 1951).

Deposit Area, Location	Rock Type	Chemical Analyses (%) $SiO+$ Al_2O_3+ Fe_2O_3	MgO	SO_3	Na_2O	LOI	Physical Property Tests Moisture (%)	(p=passed; f=failed)	Reference
Bidahochi, Navajo County T45, R22E	pumicite	82.2	1.38	0.00	nd	7.33	1.79	F	Williams, 1966
Greasewood Apache County T25, R24E	pumicite	78.3	1.79	0.03	1.19	9.33	2.89	F P*	Williams, 1966 Kiersch and Haff, 1955
Wide Ruin-Tanner Springs, Apache Co. T7S, R26E	pumicite	79.3	2.63	0.56	nd	10.0	3.64	F P*	Williams, 1966; Kiersch and Haff, 1955
Sanders, Apache Co. T5S, R28E	pumicite	84.3	0.77	0.00	nd	5.89	0.83	F	Williams, 1966
Canyon Lake, Maricopa Co., T2N, R8E	pumice	87.7	0.16	0.16	0.33	4.44	4.73	P	Williams, 1966; U.S.B.M., 1969
Pena Blanca, Santa Cruz, Co. T23S, R12E	pumicite	88.5	0.36	0.03	0.08	3.68	3.24	F (failed compression test)	Williams, 1966 U.S.B.M., 1969
West of Kingman, Mohave Co., T21N, R20W	pumicite	nd	nd	nd	nd	nd	nd	P	U.S.B.M., 1969
Bagdad, Yavapai Co. Sec 30, T5N, R8W	pumice	83.60	0.70	nd	nd	15.7	nd	F (failed compression test)	ADMMR File, 1964
Sugarloaf Peak, Coconino Co., Secs 13, 14, 23, 24, T23N, R7E	pumice	88.0	0.40	0.05	1.30	1.39	0.26	P	Williams, 1966

Deposit Area, Location	Rock Type	Chemical Analyses (%) $SiO+$ Al_2O_3 Fe_2O_3	MgO	SO_3	Na_2O	LOI	Physical Property Tests Moisture (%)	(p=passed; f=failed)	Reference
Arizona Mine, Williams-Coconino Co. Sec 3 and 4, T21N, R2E	pumice	78.7	1.44	trace	1.06	3.43	0.16	P	Williams, 1966
Bosley Deposit, Flagstaff, Coconino Co., Sec 31, T23N, R8E	pumice	86.2	0.21	0.04	1.26	5.05	0.58	P	Williams, 1966
Blackbird Deposit Yuma Co. Secs 24 & 25, T7N, R17W	pumicite	85.7	0.51	0.14	0.75	5.30	1.70	F (3 tests) F	Williams, 1966 (U.S.B.M., 1969)
Hope Deposit Yuma Co., Sec 31, T5N, R14W	pumicite	83.0	1.03	0.15	1.46	4.27	1.20	P (all but 1 test)	Williams, 1966
Gila Valley, Graham Co., Secs 28 & 29, T6S, R29E	pumicite	80% SiO_2 (petrography)	nd	nd	nd	nd	nd	P (all but 1 test)	Williams, 1966
Hope, Yuma Co., Sec 1, T4N, R13W	pumicite	nd	nd	nd	nd	nd	nd	P	U.S.B.M., 1969
Nogales Santa Cruz Co. Sec 8, T24S, R14E	pumice-pumicite	87.3	0.73	0.05	0.10	5.37	4.36	P	U.S.B.M., 1969; Williams, 1966

The rough, uncut blocks are often used in landscaping and for sculptured pieces (Peterson and Mason, 1974). The low specific gravity of lump pumice makes it easy to transport large boulders, 1.0-1.3 m (3.3 to 4.3 ft) in diameter and emplace them by hand.

Abrasives

Pumice and pumicite have been used as abrasives for nearly 90 years; prior to 1940, this was their chief use. High-quality pumiceous materials, free of crystals (quartz, feldspar, etc.) and alteration products (clays and iron oxides), have been used for scouring and fine-polishing operations. Pumice use for abrasives should be uniform in texture and particle size; the size and shape of the vesicles should also be uniform (Walker, 1951).

Since about 1985, clean lump pumice has been employed as an abrasive in the production of designer jeans; the process is referred to as stonewashing. From 1986 to 1987, pumice utilized as an abrasive increased 71% primarily because of the demand in the laundry industry to produce faded denim fabrics (Meisinger, 1988). In El Paso, alone, over 2268 mt (2500 st) of lump pumice are consumed in laundries each month.

As an abrasive in the laundry industry, pumice is utilized in two distinct processes: acid-washing and stone-washing (Plates 3 and 4). In the former, pumice is impregnated with oxidizing chemicals and then tumbled dry with the denim fabric. The chemicals are slowly released from the pumice and bleach the fabric. In stone-washing, the pumice (unimpregnated with chemicals) is tumbled with the fabric and water and the bleached look is produced by the abrasion of the outer surface of the fabric. The net result of both processes is to soften the denim fabric and impart a worn look to the garment. There are a multitude of looks that can be produced by the pumice ranging from a splotchy pattern of high contrast to an even finish of light blue to nearly white.

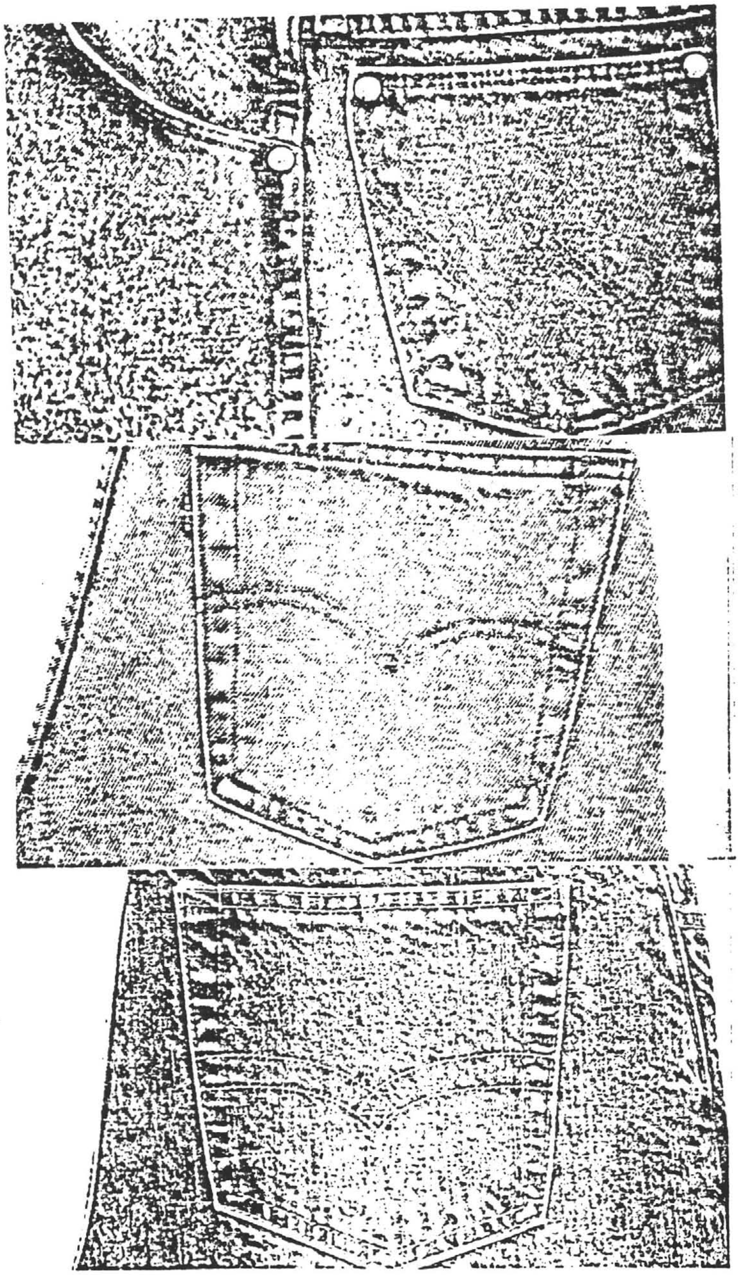


Plate 2. Top, acid-washed denim with high contrast which was produced by tumbling of potassium permanganate impregnated pumice with denim; middle, acid-washed denim with less contrast from longer tumbling time; bottom, stone-washed denim produced from abrasion of unimpregnated pumice during wet tumbling.

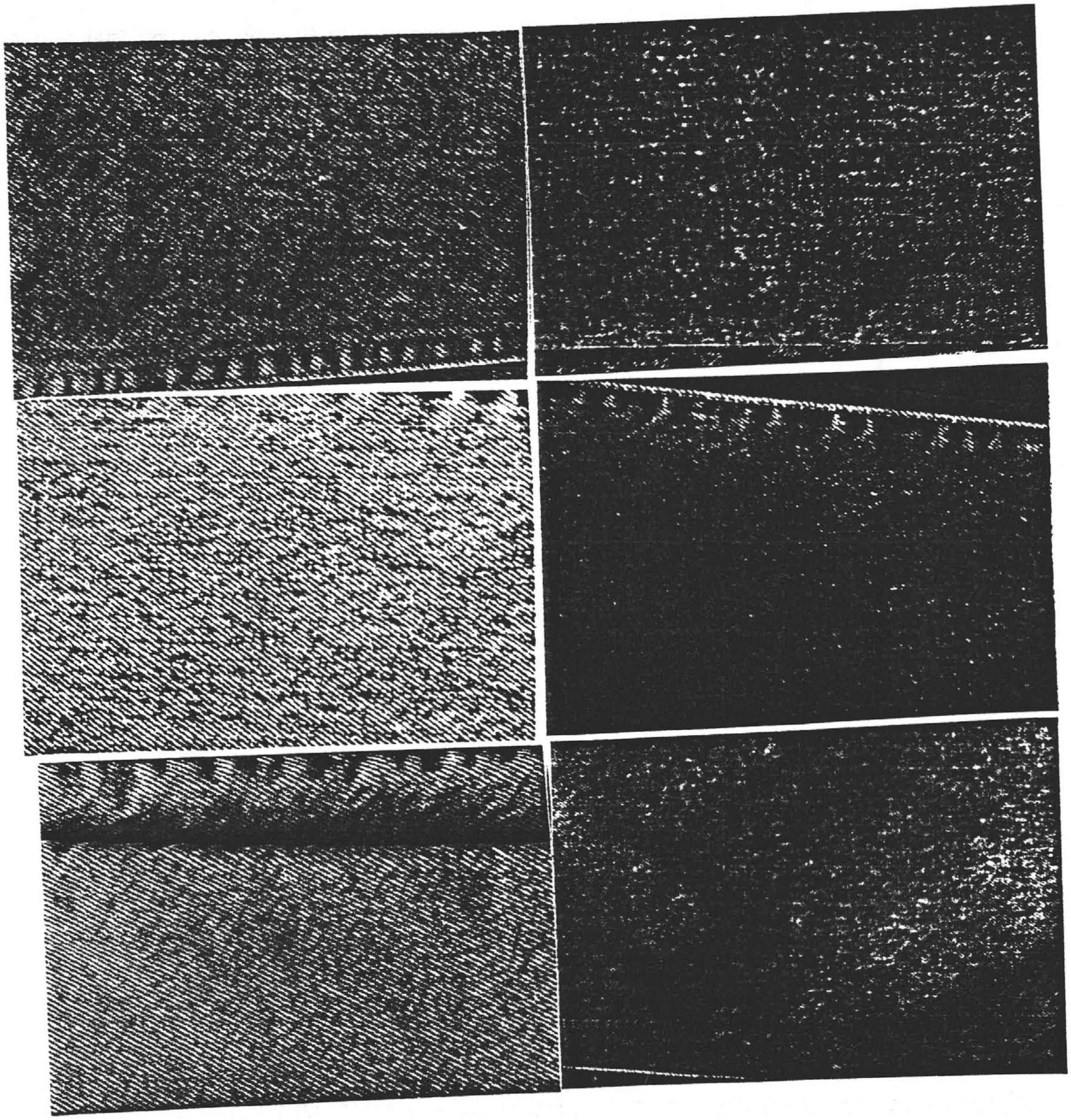


Plate 3. Acid- and stone-washed denim fabrics (black bar = 1 cm). Left (top): normal acid-wash with bleach; (middle): close-up of normal acid-wash with bleach; (bottom): long cycle acid-wash with bleach. Right (top): normal stone-wash; (middle): light stone-wash; (bottom): light stone-wash and sandblasting (light areas).

Prior to mid-1988, no specifications existed that would aid in the identification of pumice suitable for jeans washing; acceptable pumice was determined in the industry by trial and error. Since late 1988, the author has tested over 300 pumice samples from the United States (California, Oregon, Hawaii, Arizona, and New Mexico), Indonesia, Turkey, Ecuador, Guatemala, and Mexico in order to develop a set of physical property specifications that could be used to identify suitable pumice for acid- and stone-washing. The major physical properties that were found to be useful in selecting a specific pumice for washing use include: 1) surface fines and coloration, 2) apparent density, 3) abrasion loss, 4) absorption capacity, and 5) impregnation rate (Hoffer, 1989).

In addition to these physical properties, pumice size is a significant factor. Pumice fragments in the industry are referred to as small (1.9-3.2 cm, 0-.75-1.25 in diameter), medium (3.2-5.1 cm, 1.25-2.00 in, diameter), or large (5.1-7.6 cm, 2.0-3.0 in diameter). The small diameter fragments, when tumbled with denim fabric, will produce a more even worn look whereas the coarser fragments will produce a more splotchy pattern.

PUMICE PROPERTIES AND LAUNDRY USE

The required physical properties are not of equal importance in evaluating a pumice for washing use. Absorption, apparent density, and abrasion loss are overall the most useful in identifying a suitable pumice.

Another point to consider in evaluating a pumice is its intended use. If the pumice is to be used for stone-washing, abrasion loss and apparent density are most important. Absorption and impregnation rate are not factors because the pumice carries no chemicals. If the pumice is used in acid-washing, then absorption and impregnation rate are the important properties.

The specific procedures for determining the following physical properties of pumice are given in Hoffer (1991).

Surface Fines and Coloration

Surface fines include fine-grained glass fragments or clay minerals that adhere to the outer surface of the pumice (Plate 4). The glass fragments result from fragmentation of the vesicle walls and, when abundant, tend to plug the vesicles and reduce the absorption and hence the amount of chemical the pumice can carry. Alteration products such as smectitic clay minerals occasionally adhere to the outer surface of the pumice. The clay particles not only reduces the pumice absorption, but in acid-washing, it will absorb the oxidizing chemical and release it faster than pumice alone during contact with a garment. The result is a highly bleached streak across the fabric which will cause the garment to be rejected (Hoffer, 1989). If surface fines exceed 5%, they should be removed by washing the pumice prior to its use.

Pumices that contain over 5% yellowish- or reddish-brown iron oxides should be avoided. These iron oxides become mobilized during acid washing and are subsequently deposited on the garment during tumbling (Plate 5). The result is a light yellow or brown color on the finished garment which will cause it to be rejected.

Apparent Density

Although the true density of pumice is about 2.5 g/cm^3 (156 lb/ft^3), its cellular structure gives it an apparent value of less than 1.0 g/cm^3 (62.4 lbs/ft^3). A wide range of densities can be tolerated in the washing process, but the most acceptable densities are those between 0.50 and 0.85 g/cm^3 (31.2 and 53 lbs/ft^3). Pumice densities greater than 0.85 g/cm^3 (53 lbs/ft^3) have low absorption and are unsuitable for acid-washing. In addition, they will generally increase in apparent density to over 1.0 g/cm^3 (62.4 lbs/ft^3) as they absorb water during washing and will sink. Low density pumices, less than 0.50 g/cm^3 (32 lbs/ft^3), will generally produce only a small amount of abrasion and are undesirable for stone-washing.

In addition, the pumice should be free of abundant crystals or obsidian fragments which will increase the overall density of the pumice. Greater than 10% crystals or obsidian will cause the

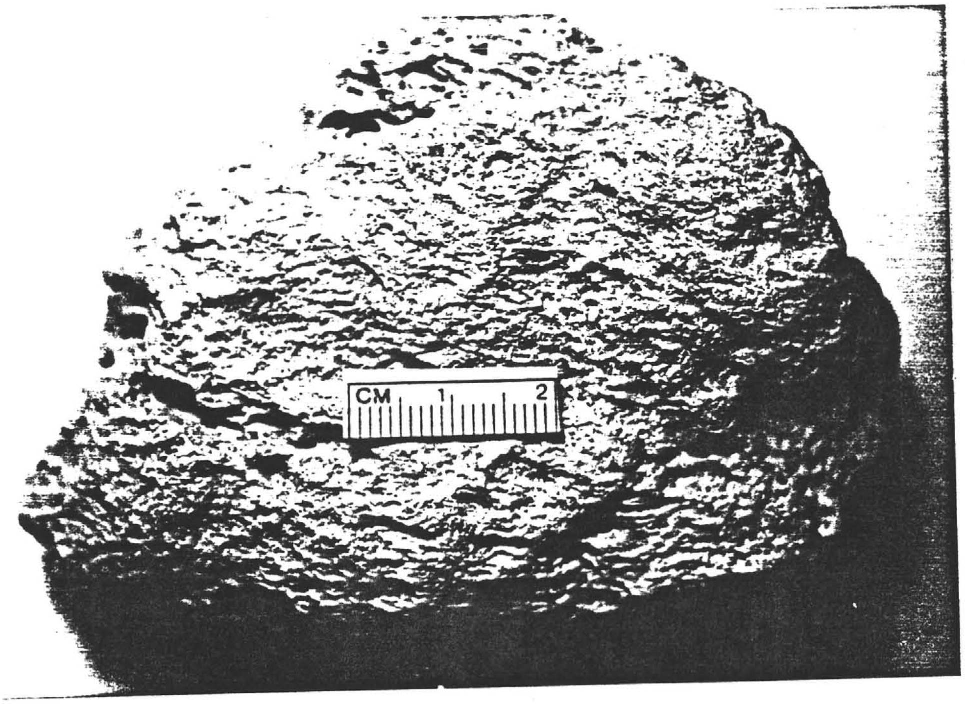
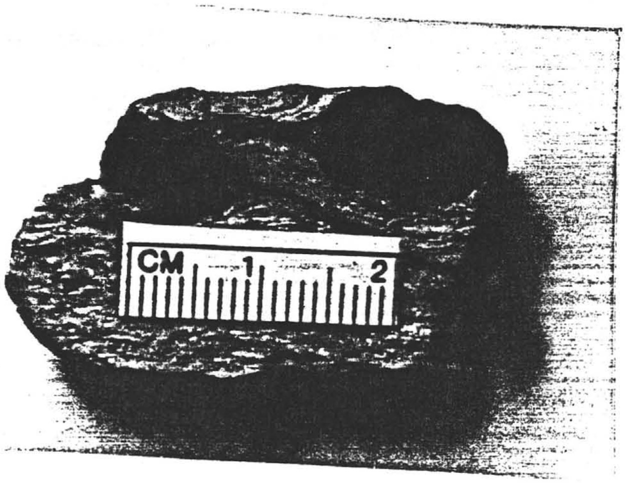


Plate 4. Abundant surface fines on pumice fragment, which effectively plug a majority of the vesicles.



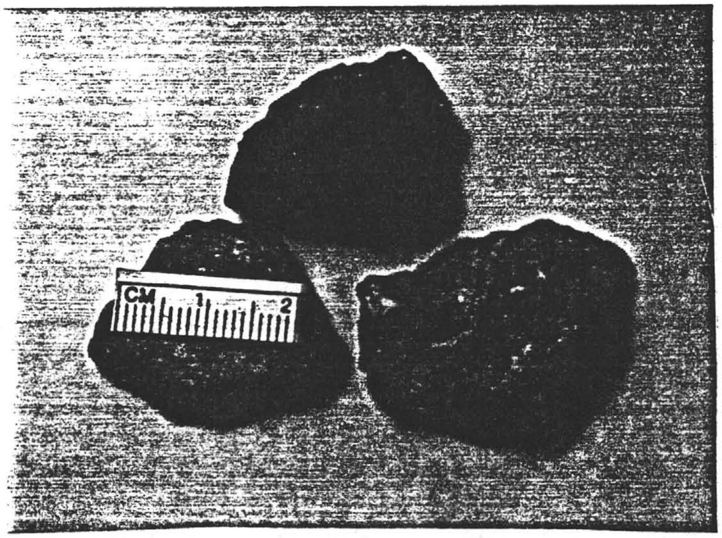


Plate 5. Top, obsidian inclusions in pumice fragments; bottom, rock fragments that have been found mixed with pumice, top, black fragment of obsidian.

pumice to sink during stone-washing, which is undesirable. Also, abundant obsidian inclusions or fragments will produce garment damage during tumbling (Plate 5).

Tested pumice apparent densities range from 0.39 to 1.14 g/cm³ (24.3 to 71.1 lbs/ft³); the average value is 0.70 g/cm³ (43.7 lbs/ft³) (Hoffer, 1989). Approximately 62% of the apparent densities measured occur within the interval of 0.50 to 0.80 g/cm³ (31.2 to 49.9 lbs/ft³). A classification of pumice apparent densities is included in Table 7.

Abrasion Loss

The rate of disintegration of the pumice fragments during tumbling is referred to as the abrasion loss. The pumice fragments are weighed before and after 30 minutes of tumbling and the loss of weight is reported as a percentage. Low abrasion loss values indicate slow disintegration, whereas high values indicate more rapid disintegration during the washing process. Measured abrasion losses range from 0.4 to 13.2%; the average, based upon more than 150 samples, is 4.6% (Hoffer, 1989). A classification of pumice abrasion loss is shown in Table 7.

Table 7. Classification of pumice physical properties; see text for an explanation of each property (from Hoffer, 1989).

Classification	Surface Fine (%)	Apparent Density (g/cm³)	Abrasion Loss (-%)	Absorption Capacity (%)	Impregnation Rate (%/min.)
High	> 6.0	> 1.0	> 6.0	> 30	> 5.5
Medium High	4.0-5.9	0.85-1.00	5.0-6.0	25-30	4.5-5.5
Medium	3.0-3.9	0.60-0.84	4.0-4.9	20-24	3.5-4.4
Medium Low	1.0-2.9	0.40-0.59	2.6-3.9	10-19	2.0-3.4
Low	< 1.0	< 0.40	< 2.6	< 10	<2.0
Number Tested	142	256	150	254	192

Absorption Capacity

The absorption of pumice is defined as the percentage of liquid that can be taken up during submergence of the pumice in a liquid. Factors that influence absorption include the size, shape, and the amount of vesicles in the pumice (Plate 6). In general, pumice with large vesicle diameters possess the highest absorption values. Absorption is very important in acid-washing because it determines the amount of oxidizing liquid, either potassium permanganate or bleach, that can be taken up and released onto the garment by the pumice. Absorptions values of 30% and above are preferred for the acid-washing. In general, high absorbing pumices are usually those of low apparent density, i.e. 0.60 g/cm^3 (< 37.4 lbs/ft^3). For stone-washing, pumice absorption is not a factor. Measured pumice absorption values from over 250 samples range from 1 to 56%, the average value is 23% (Hoffer, 1989). The classification of pumice absorption is shown in Table 7.

Impregnation Rate

The impregnation rate represents the rate of liquid absorption by the pumice. By knowing the amount and rate of liquid absorption, one can estimate the rate of chemical release from the pumice during acid-washing. Large vesicles and high absorption correlate with high impregnation rate.

The impregnation rate is estimated by calculating the percentage of weight gain from liquid absorption during a five minute period. Measurements from over 190 pumice samples show that the impregnation rates range from 0.6 to 11.3; the average is 3.9 (Hoffer, 1989). The classification of impregnation rates is included in Table 7.

The recommended physical properties for pumices utilized in acid- and stone-washing are summarized in Table 8. Once the physical properties of a pumice are determined, the table can be used to 1) determine if the pumice is suitable for washing use and 2) whether it is best suited for acid- or stone-washing.

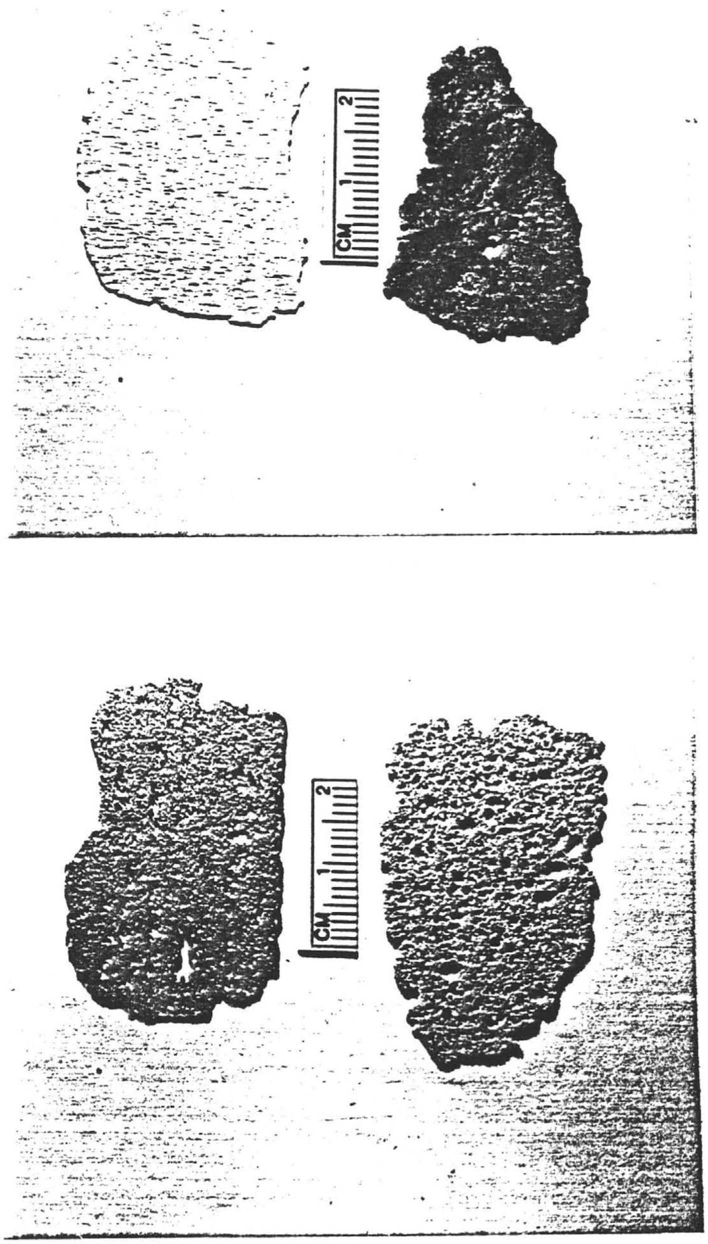


Plate 6. Pumice vesicularity and absorption capacity: Top, low absorptive pumice (left = 15%, right = 20%) and bottom, high absorptive pumice (left = 30%, right = 45%).

Table 8. Physical properties recommended for stonewashing pumice.

Properties	Acid-Wash	Stone-Wash
Apparent Density	0.50-0.70 g/cm^3 (31.2-43.7 lbs/ft^3)	0.70-0.85 g/cm^3 (43.7-53.1 lbs/ft^3)
Abrasion Loss	4-9%	< 4%
Absorption Capacity	30-45%	< 20%
Impregnation Rate	4.0-7.0% wt gain/min.	< 4.0% wt. gain/min.
Surface Fines and Coloration:	If fines exceed 5%, wash before use; reject if iron oxide stain exceeds 5% (source data from Hoffer, 1989)	

PUMICE AND PUMICITE DEPOSITS AND OCCURRENCES

Introduction

A summary of the active and inactive pumice and pumicite deposits in the state are given in Table 9 and Figure 3. Information is included on the location, name and address of the operators, current status, and where possible, the production and use of the pumiceous materials.

The state's principal pumice-pumicite deposits occur within the volcanic units associated with the San Francisco volcanic field in southern Coconino County of north-central Arizona (Fig. 4). The field includes the composite volcano San Fràncisco Mountain and four other centers of silicic to intermediate extrusive rocks, all of which are surrounded by Holocene basaltic flows and cones (Ulrich et al., 1989).

Three of the intermediate to silicic volcanic centers occur in the western portion of the field; they include, from southwest to northeast, Bill Williams Mountain (predominantly dacite, 4.2-2.9 Ma), Sitgreaves Mountain (predominantly rhyolite, 2.8-1.9 Ma), and Kendrick Peak (andesite to rhyolite, 2.7-

Table 9. Pumice and Pumicite Mines in Arizona (map number refers to location on Map 1).

County	Map No.	Location	Operators	Address	Status	Production and Use
Coconino	1	T23N, R8, sec. 19	Arizona Tufflite, Inc.	2432 W. Peoria, Suite 1081; Phoenix 85029; C.T. Morgan 602/931-3682	Active	6000 yd^3/mo; lt. weight aggregate, horticulture, and laundry use
Coconino	2	T21N, R2E, secs. 4 and 16	Mountain Mining, Inc.	2214 W. Mountain View; Phoenix 85021; D. Bellaire; 602/997-2013	Inactive since since early 1991	Primarily laundry use, no production data available
Coconino	3	T25N, R8E, secs. 27 28, 32 and 33 Deadman Flat	Unknown		Inactive	Pumice pits on east and west sides of U.S. 89
Graham	4	T6S, R29E, sec. 28-29	Gila Valley Block, Inc.	P.O. Box 465; Safford 85546; R. Solomon; 602/428-2360	Inactive since 1989	Pumice for lt. weight aggregate
Pinal	5	T1S, R10E, sec. 21	Arizona Rhyolite Co.	3435 E. Windrose; Phoenix; R. Erman 602/971-2388	Inactive since 1984	Pumice for lt. weight aggregate and pozzolan
Yavapai	6	T15N, R8W, secs. 19 and 30	Bagdad Pumice Co.	Agro-Lite Products, Inc.; H. McDaniel; 524 N. 42nd St; Phoenix	Inactive since 1975	Pumice for lt. weight aggregate and absorbent compounds
Maricopa	7	T2N, R9E, sec. 8	Concrete Industries, Inc.	Arizona Precast Co. 213 S Alma Rd.; Mesa C.L. Hodgert	Inactive	Pumice for lt. weight weight aggregate, 2000 tons/mo. in 1957

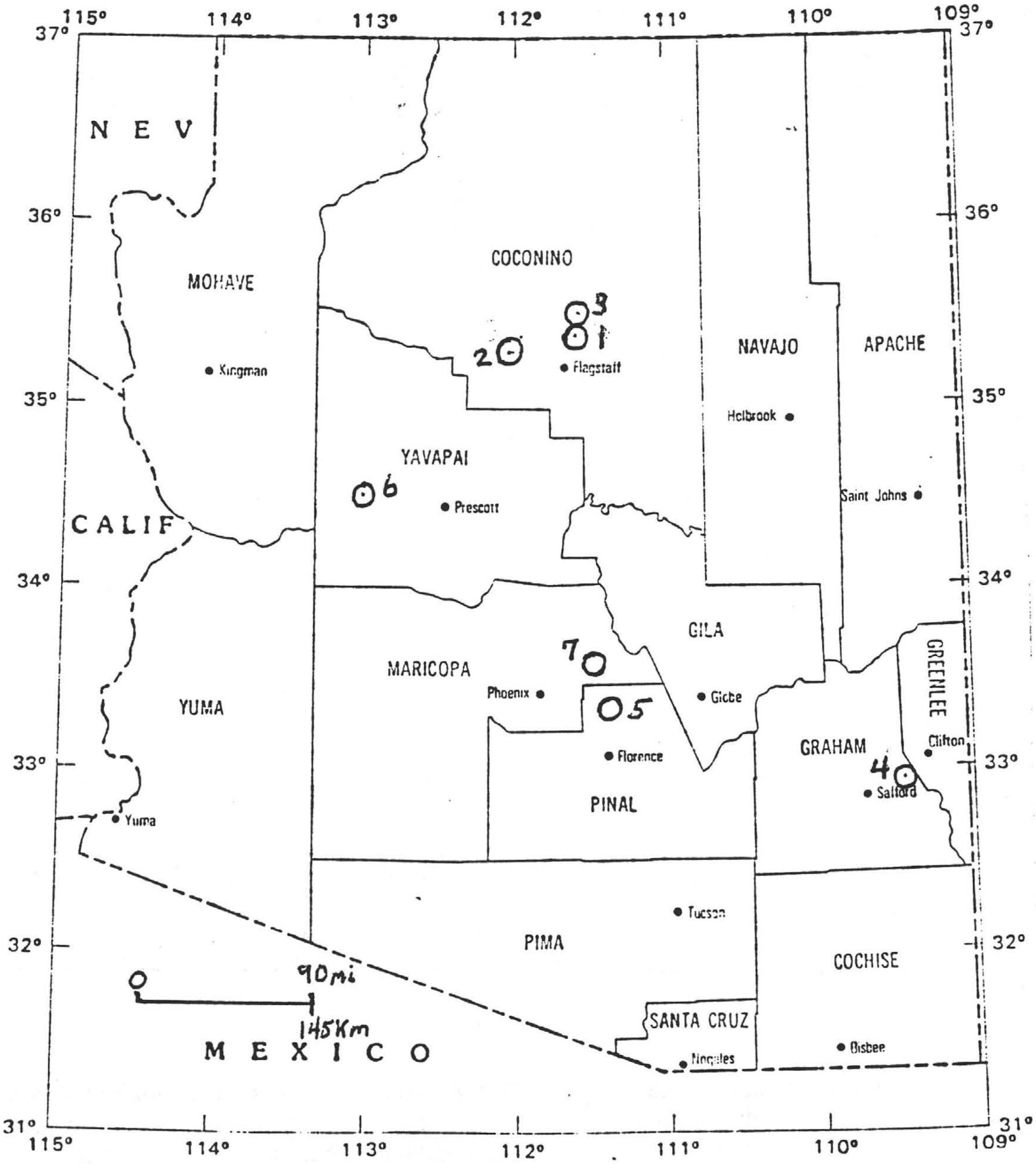


Figure 3. Location of areas within Arizona that have produced pumiceous materials (1 = White Vulcan, 2 = Bill Williams Mountain, 3 = Deadman Flat, 4 = Safford, 5 = Florence, 6 = Bagdad, and 7 = Mormon Flat).

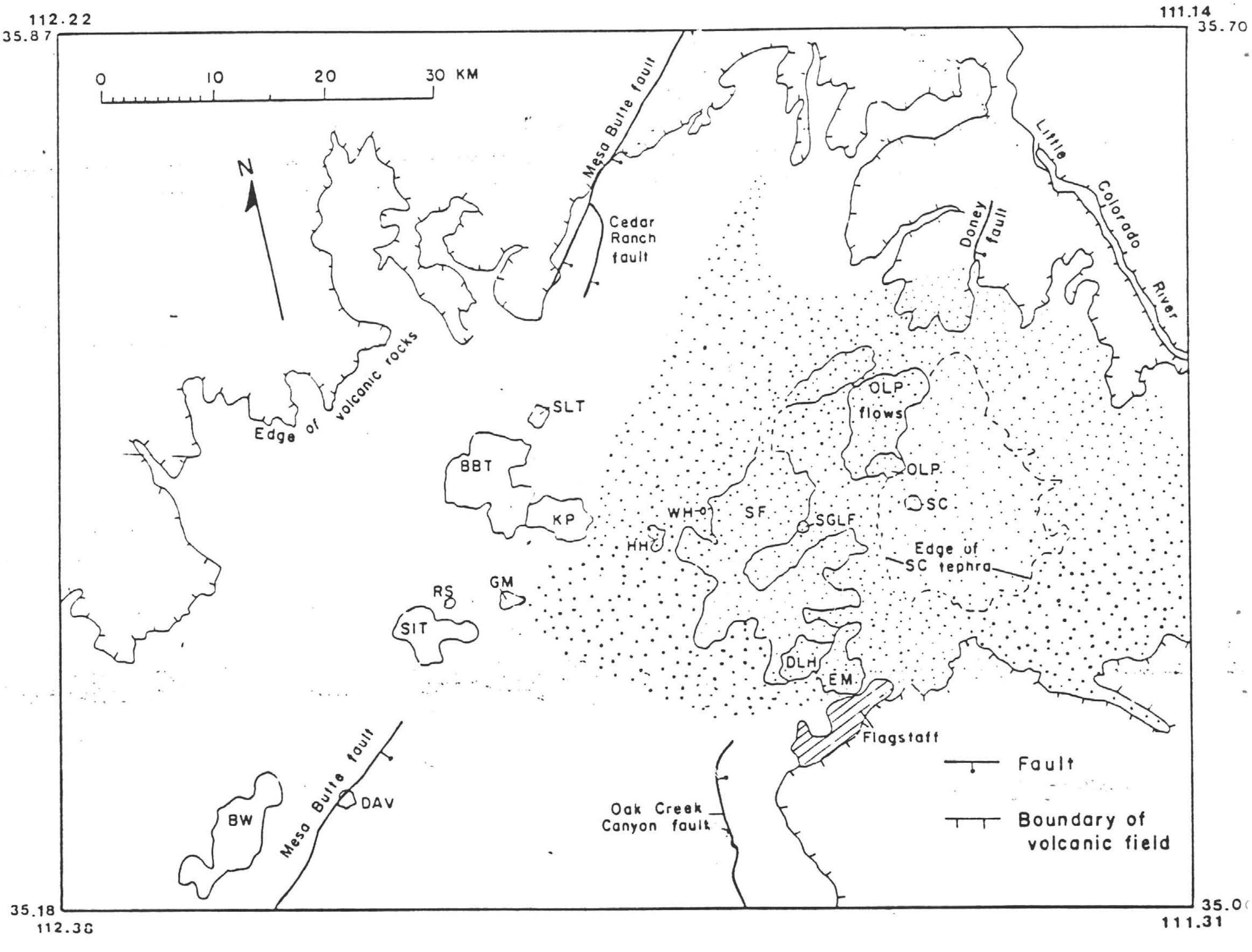


Figure 4. Volcanic features in the San Francisco volcanic field. Major western eruptive centers: BW - Bill Williams Mountain, SIT - Sitgreaves Mountain, KP - Kendrick Peak, and BBT - Bull Basin Mesa; major eastern eruptive centers: SF - San Francisco Mountains, and OLP - O'Leary Peak; dacite domes: DAV - Davenport Hill, DLH - Dry Lake Hills, EM - Eldon Mountain; rhyolite domes: RS - RS Hill, GM - Government Mountains, SLT - Slate Mountain, HH - Hochderffer Hills, WH - White Horse Hills, and SGLF - Sugarloaf; cinder cone: SC - Sunset Crater (from Ulrich, 1989).1.4 Ma) (Fig. 2) (Ulrich et al., 1989). In the eastern portion of the field occur San Francisco Mountains (andesite to dacite, 1.0-0.4 Ma), Sugarloaf (rhyolite, 0.2 Ma), and O'Leary Peak (andesite to rhyolite, 0.2 Ma) (Ulrich et al., 1989).

1.4 Ma) (Fig. 2) (Ulrich et al., 1989). In the eastern portion of the field occur San Francisco Mountain (andesite to dacite, 1.0-0.4 Ma), Sugarloaf (rhyolite, 0.2 Ma), and O'Leary Peak (andesite to rhyolite, 0.2 Ma) (Ulrich et al., 1989).

Additional areas in Arizona that have been mined for pumice and pumicite in the past include deposits in Graham County, near Safford, and in Yavapai County, near Bagdad; both of these deposits are of epiclastic origin. Large reserves of pumicite have been described in the northeastern portion of the state, Apache and Navajo counties, by Kiersch and Haff (1955). These deposits are of epiclastic origin and occur in the upper part of the widespread Bidahochi formation of late Cenozoic age.

Active and Inactive Mines and Deposits

San Francisco Volcanic Field

Sugarloaf Mountain and White Vulcan Pumice Claims

Sugarloaf Mountain is a young (0.22 ± 0.02 Ma) rhyolite dome located at the northeast base of San Francisco Mountain (Holm, 1988). The endogenous lava dome forms a symmetrical hill that rises about 150 m (492 ft) above the pre-existing topography and is surrounded by an inner tuff ring and an outer deposit of ash-fall tephra (Sheridan and Updike, 1975) (Figs. 5 and 6).

The tuff ring is composed of unconsolidated rhyolite tephra that was emplaced by phreato-magmatic pyroclastic base-surge during emplacement of the dome. The surge deposits consists of cross-bedded sand-wave beds, massive beds, and inversely graded plane beds (Sheridan and Updike, 1975). The tephra consists of mainly essential ash and lapilli of moderately vesicular pumiceous rhyolite.

The ash-fall tephra deposit forms a single poorly stratified layer extending northeast from the tuff ring. Sheridan and Updike (1975) report the thickness of the unit as ranging from a maximum of 10 m (32.8 ft) to less than 3 m (9.8 ft); locally it has been completely removed by erosion. Texturally, the deposit is massive and contains angular, highly vesiculated pumice lapilli.

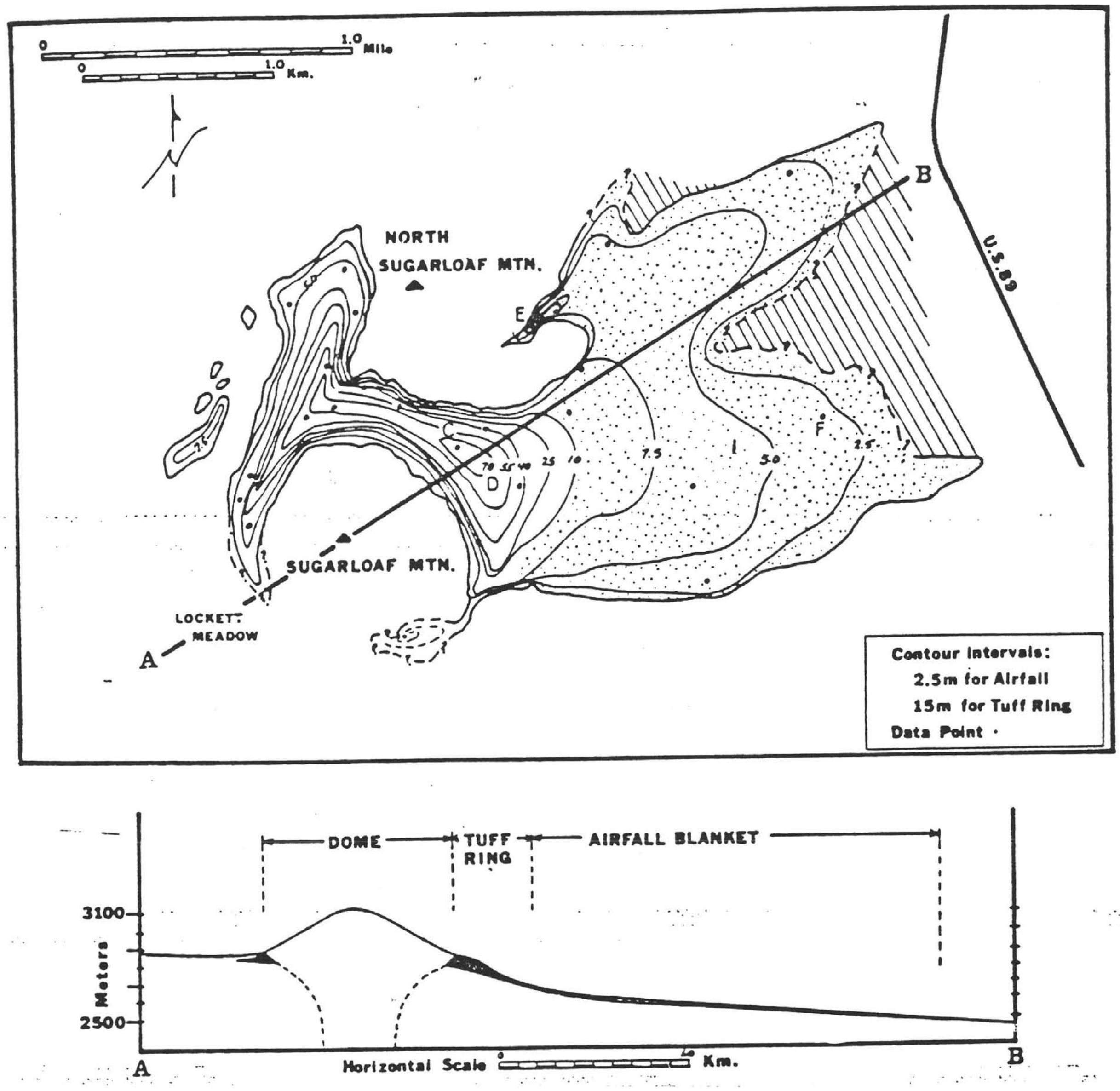
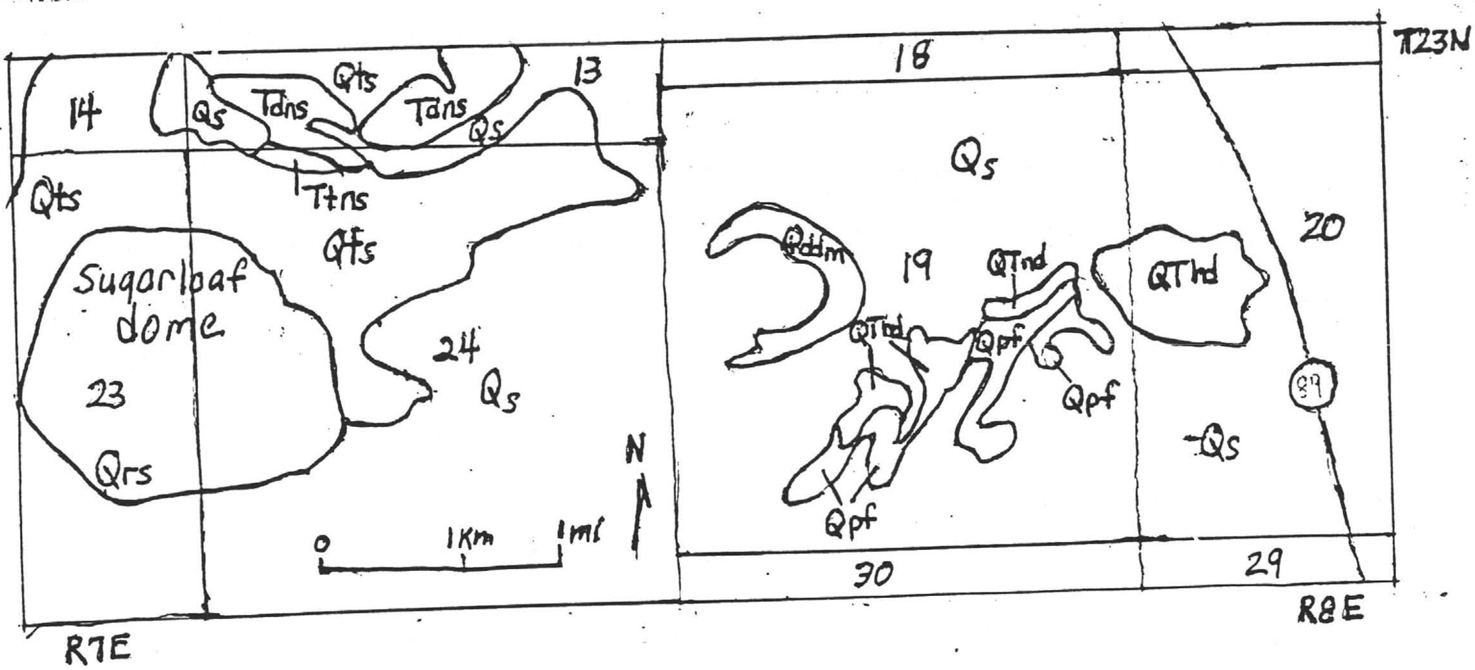


Figure 5. Sugarloaf Mountain and associated tuff ring and pyroclastic fall deposits (from Sheridan and Updike, 1975).



Quaternary
- Qs Surficial deposits
- Qrs Rhyolite of Sugarloaf, 0.22 ± 0.2 Ma
- Qts Tephra of Sugarloaf
- Qddm Middle dacite of Doyle Peak, 0.44 ± 0.3 Ma
- Qpf Pumice of Freemont Peak, 0.7 ± 0.17 Ma

Tertiary
- QThd Hornblende dacite, lava flow
- Ttns Tephra of north Sugarloaf, 2.78 ± 0.13 Ma
- Tdns Dacite of north Sugarloaf, 2.78 ± 0.13 Ma

Figure 6. Geologic map of Sugarloaf (secs 23-24, T23N, R7E) and Freemont Peak pumice deposits (sec 19, T23N, R8E) (modified from Holm, 1988 and Dennis, 1981) (White Vulcan claims No. 1 and 2 are located in in the western and eastern half of sec. 19, respectively).

Another pumice layer designated Pumice of Freemont Peak (0.75 $\pm$ 0.04 Ma) crops out approximately 2.5 km (1.6 mi) east of Sugarloaf on the White Vulcan pumice claims, and in pits along U.S. Highway 89 north of San Francisco Mountain (Dennis, 1981 and Holm, 1988) (Fig. 6). The pumice unit was probably emplaced during the early stage of dome emplacement on Freemont Peak 9 km (5.6 mi) west of Sugarloaf (Dennis, 1981). The pumice is massive with normal and reversely-graded beds with a minimum thickness of 15 m (49 ft) (Dennis, 1981). The ash-fall pumice deposit consists of unconsolidated tephra of angular lapilli to block-sized fragments of white to light-gray pumice (Plate 7).

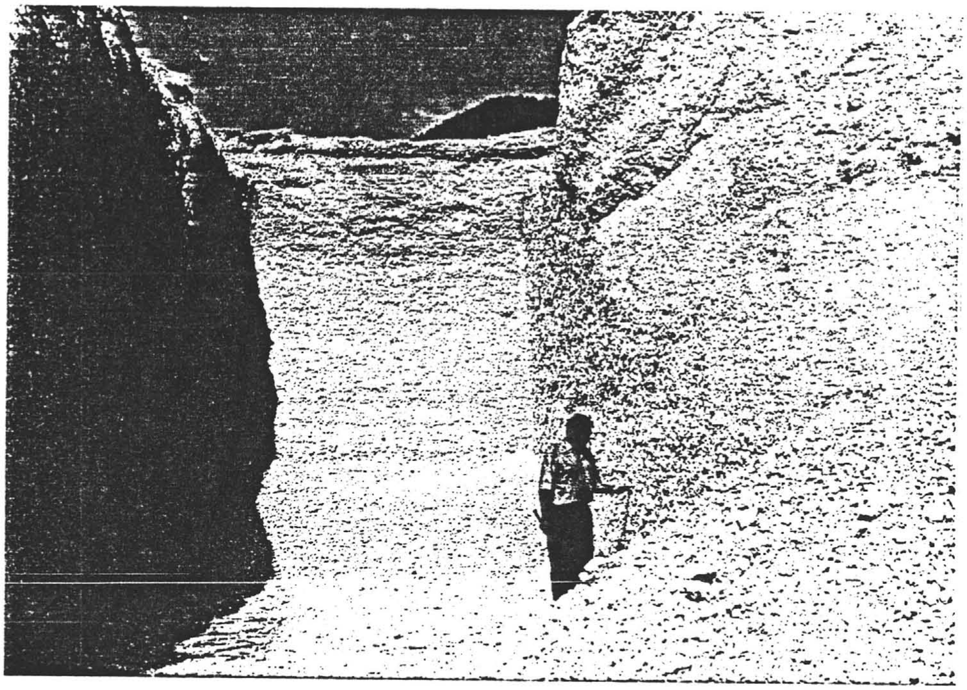
The lower beds of pumice are aphyric and of rhyolite composition, whereas the upper beds are porphyritic and of dacite composition; interlayered beds of basaltic scoria occur within the rhyolitic pumice (Holm, 1988). Numerous xenoliths from the underlying Precambrian units occur within the pumice beds and include fragments of slate, phyllite, schist, metagraywacke, and greenstone (Dennis, 1981).

Arizona Tufflite, Inc is currently mining the pumiceous materials from the Freemont Peak pumice, east of Sugarloaf (sec. 19, T23N, R8E, White Vulcan claim No. 2). Production is approximately 4590 m^3 (6000 yd^3) per month and the pumiceous materials are used for light-weight aggregate, horticulture, and for laundry applications (Phillips, 1988). The air-fall pumiceous materials associated with Sugarloaf are too small in diameter for laundry use (Sheridan and Updike (1975).

The estimated pumice-pumicite reserves of the White Vulcan, No. 2 deposit, based upon the geologic maps of Holm (1988) and Dennis (1981), are approximately 153 million m^3 (200 million/yds^3).

<u>Deadman Flat Area</u>

Approximately 40 km (24.8 mi) north of Flagstaff, on either side of U.S. 89, occurs an extensive deposit of pumice (Fig. 7). The rhyolite ash-fall material is termed the Pumice of San Francisco Mountain and is exposed in a series of pits in sections 27, 28, 32, and 33, T25N, R8E (Ulrich and Bailey, 1987).



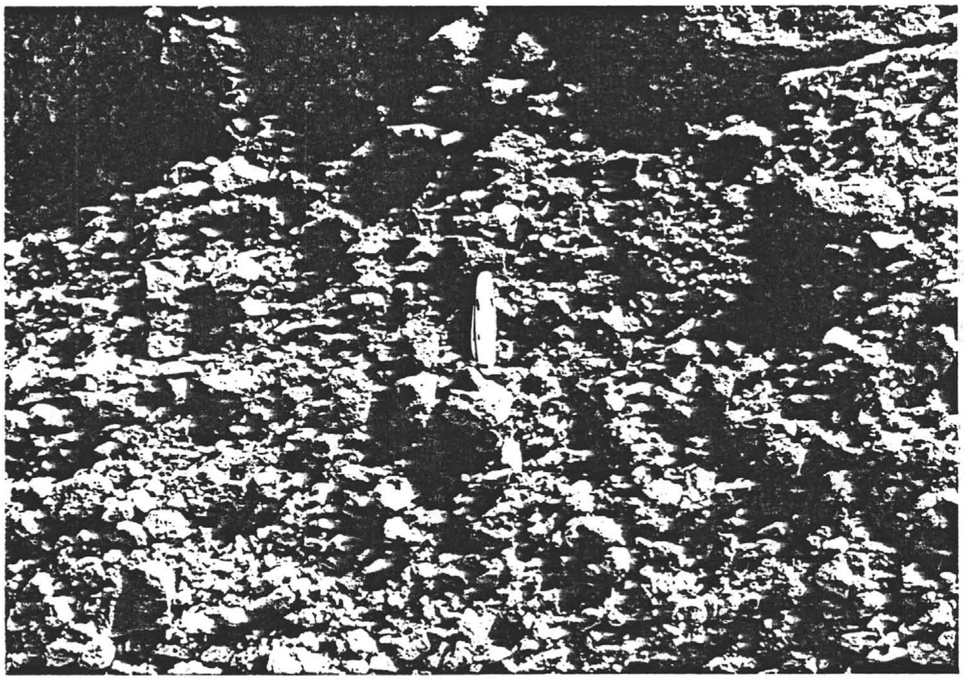
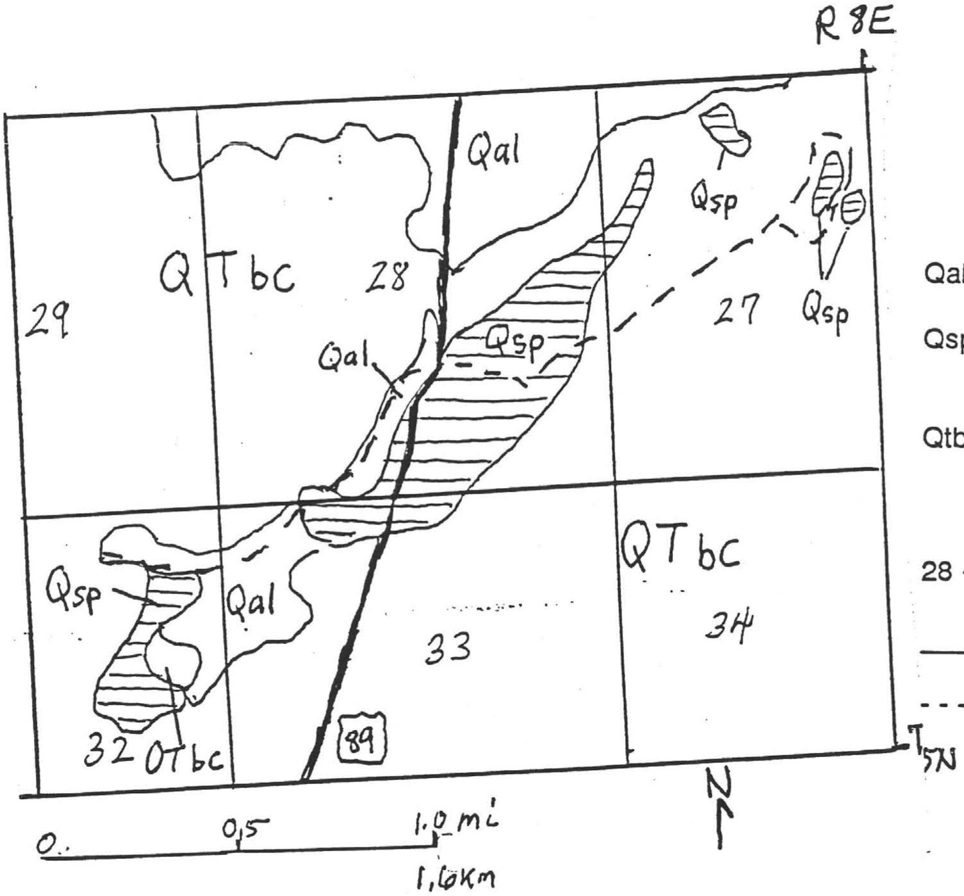


Plate 7. Top - lower rhyolite pumice beds on the White Vulcan claim No. 2; bottom - close-up of the lower pumice beds on the east side of the quarry. Lump pumice (> 9 mm, > 3/4 in) comprises approximately 28% of the pumiceous materials.



Qal - Quaternary Alluvium

Qsp - Quaternary Pumice of San Francisco Mountain

Qtbc - Quaternary-Tertiary (Pleistocene-Pliocene) basalt flow and cinder

28 - Section number

—— paved road

- - - unpaved road

Figure 7. Simplified geologic map of San Francisco Mountain pumice, Deadman Flat (modified from Ulrich and Bailey, 1987).

The unit is 3 to 5 m (9.8 to 16.4 ft) thick, poorly sorted, and the pumice fragments range from 2 to 70 mm (0.08 to 2.8 in) in diameter (Plate 8). The pumice is light gray to white, highly vesicular, and lacks visible crystals (Ulrich and Bailey, 1987). The pumiceous deposit contains xenoliths of greenschist and dense rhyolite.

The pumice unit is correlated with the lower aphyric pumice east of Sugarloaf on the White Vulcan claims based upon similarities in petrography, composition, and xenoliths (Dennis, 1981). Age of the pumice, based upon fission track age data on zircons by Naeser and Izett (1975, unpublished, in Dennis, 1981), is 0.80 $\pm$ 0.11 Ma.

Bill Williams Mountain

Bill Williams Mountain is located in the southwestern part of the San Francisco volcanic field just south of Williams (Fig. 8). Within this region of the field, basalt and basaltic andesite were extruded from numerous individual short-lived vents that produced an abundant number of cinder cones (Newhall et al., 1987). Other vents, erupting over more extended periods, form the much larger volcanic complexes of Bill Williams and Sitgreaves Mountains. Bill Williams Mountain is characterized by a cluster of dacite domes and flows and flanking andesite flows whereas Sitgreaves Mountain consists predominantly of rhyolite domes and flows (Newhall et al., 1987).

The central area of Bill Williams Mountain is composed of thick flows and intrusive rocks of porphyritic dacite (3.56 $\pm$ 0.38 Ma) (Fig. 8). The central dacite complex is flanked by a number of dacite domes (3.59 $\pm$ 0.13 to 4.22 $\pm$ 0.26 Ma). The domes are irregular to circular in plan view, 0.25 to 1.9 km (0.16 to 1.2 mi) in diameter, and 75 to 305 m (246 to 1100 ft) high (Newhall et al., 1987). Dacite and andesite lava flows occur outside the central complex; several of the flows appear to have been extruded from the base of the dacite domes.

Numerous dacite pyroclastic deposits of ash-fall occur on and around the mountain. They consist of pumiceous lapilli and fine ash and are distributed around the mountain as isolated outcrops, pyroclastic collars around dacite domes, and beneath dacite and andesite flows north and

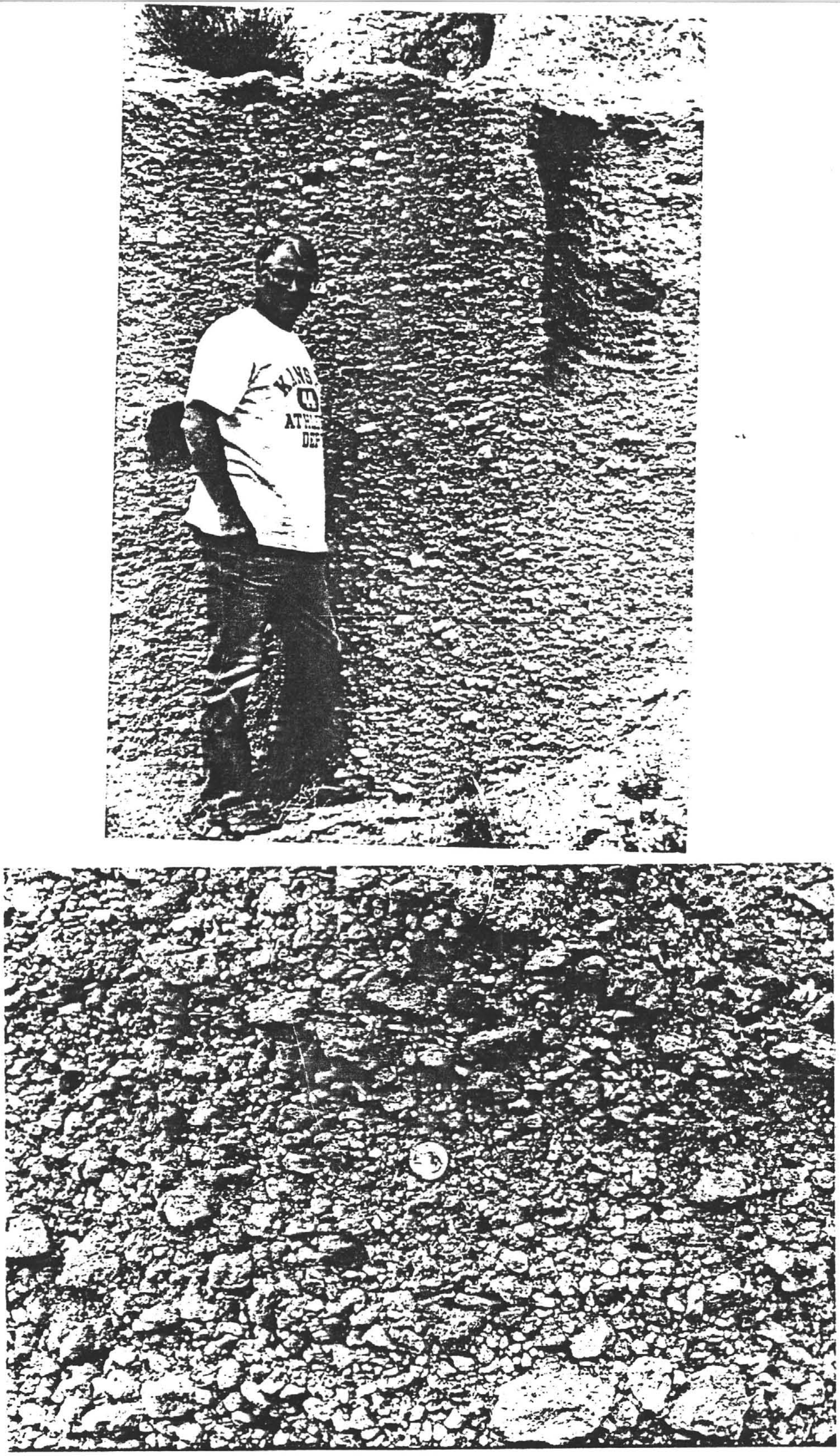
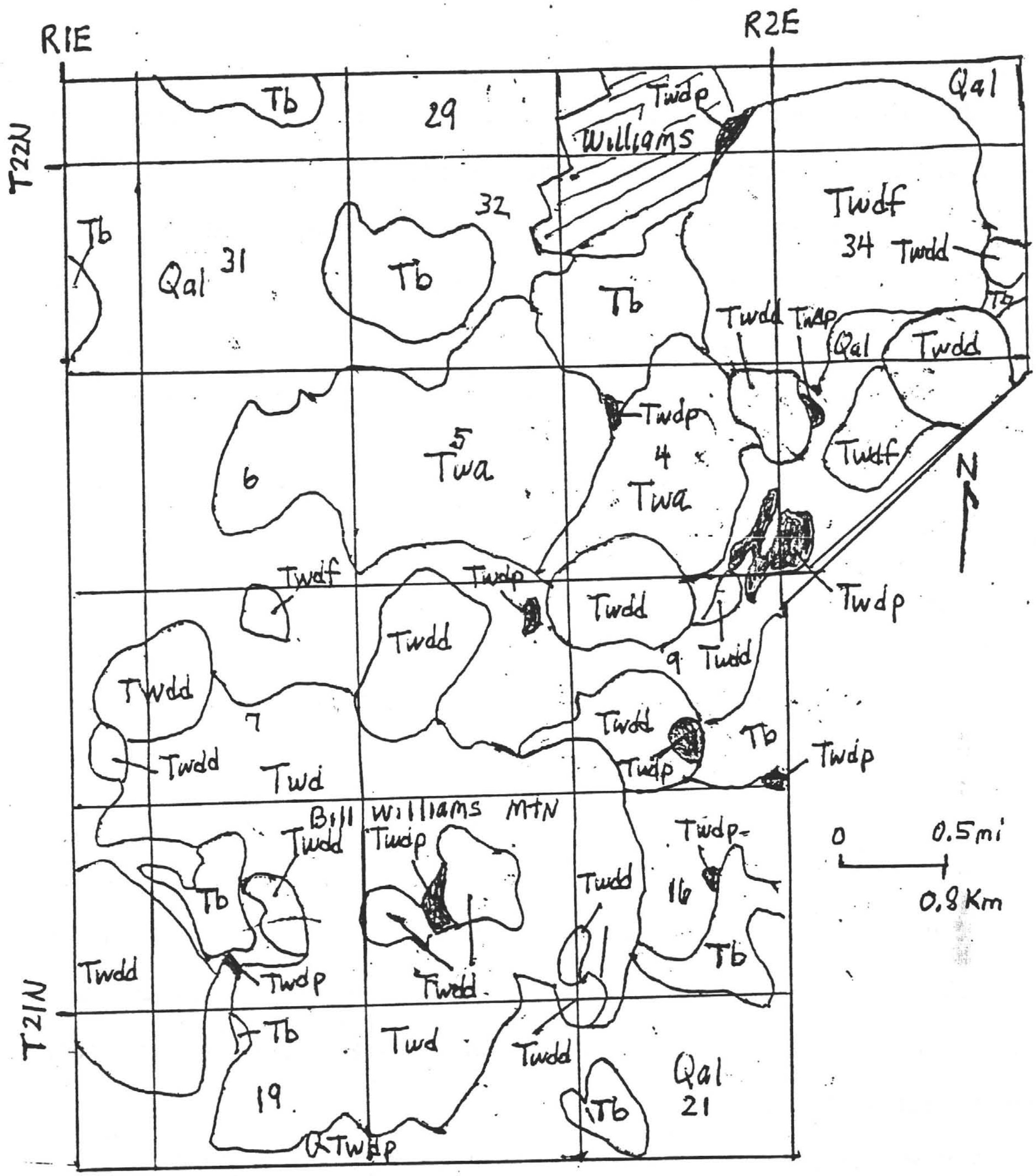


Plate 8. Deadman Flat (sec. 28, T25N, R8E); top - San Francisco Mountain pumice exposed in a pit east of highway 89, bottom - close-up view of lump pumice.



Qal Alluvial and colluvial deposits
Tb Basalt flows, cones and tuff, Pliocene-Miocene
Twa Andesite-flows and domes, Pliocene
Twd Dacite flows and intrusives, Pliocene
Twdd Dacite domes, Pliocene
Twdf Dacite flows, Pliocene
Twdp Dacite pyroclastic deposits, Pliocene

Figure 8. Geologic map of volcanic units at Bill Williams Mountain (modified from Newell et al., 1987).

south of the mountain, respectively (Newhall et al., 1987). Accidental clasts of Precambrian basement rocks which include gneiss, schist, mylonite, and orthoquartzite are locally common. A K-Ar age from one of the dacite fragments gives an age of 3.49 $\pm$ 0.06 Ma (Newhall et al., 1987).

Mountain Mining, Inc. was formerly mining pumiceous materials for laundry use from an ash-fall deposit, Moody pit, east of the mountain in late 1990 (sec. 4, T21N, R2E), and is currently trying to develop a second deposit associated with a nearby dome or flow (sec. 16, T21N, R2E) (Plate 9). At the present time, no production occurs from either of these two properties.

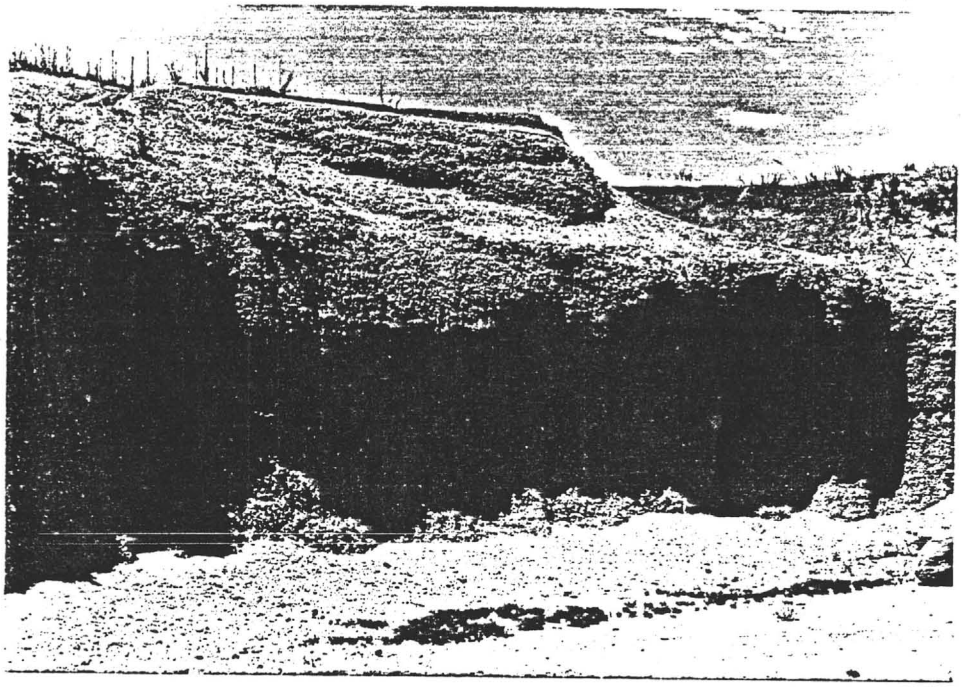
Bagdad Area

Rhyolite tuff beds crop out in a series of mesas in the vicinity of Bagdad. The pumiceous materials are interbedded or overlie the Gila (?) conglomerate and are capped by a late Cenozoic olivine basalt flow, the Saunders Basalt (Anderson et al., 1955). The basalt flow ranges in thickness from 0 to 17 m (0 to 55.8 ft) and where it is present, it is easily removed by ripping and dozing (Phillips, 1975).

The tuff beds range in thickness from 0.3 to 17 m (1 to 50 ft) but generally they average between 5 to 7 m (16.4 to 23.0 ft). Throughout the area the pumiceous tuff is poorly stratified and thinly bedded; the volcanic materials consist of white pumice lapilli and ash (Anderson et al., 1955). At several locations the tuff has been altered to clay or replaced by cavernous to dense opal (Anderson et al., 1955).

At Nelson Mesa, approximately 8 km (5 mi) northeast of Bagdad (sec. 30, T14, 5N, R8W), the tuff bed consists of 3 m (9.8 ft) of well sorted 2.5 to 2.9 cm (1.0 to 1.1 in) pumice fragments which is overlain by 1.7 m (5.6 ft) of pumicite (King, 1961) (Fig. 9). The pumiceous tuff is described as of exceptionally good grade, easily mineable, and epiclastic in origin (King, 1961).

From the early 1960's until 1975 Agro-Lite Product, Inc. (Bagdad Pumice) mined the pumiceous materials from the Nelson Mesa area. The tuff was quarried and then sized, dried, and



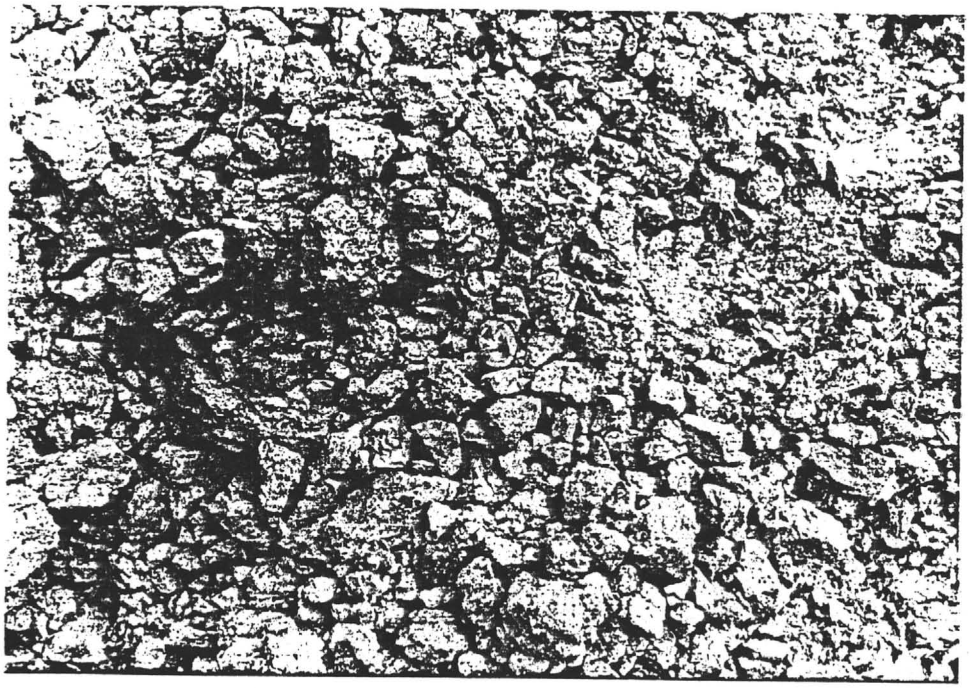


Plate 9. Top - Quarry face on the west side of the Moody pit (Sec. 4, T21N, R2E), Bill Williams Mountain, exposing approximately 12 m (36 ft) of pumice; bottom - closeup view of lump pumice, Moody pit.

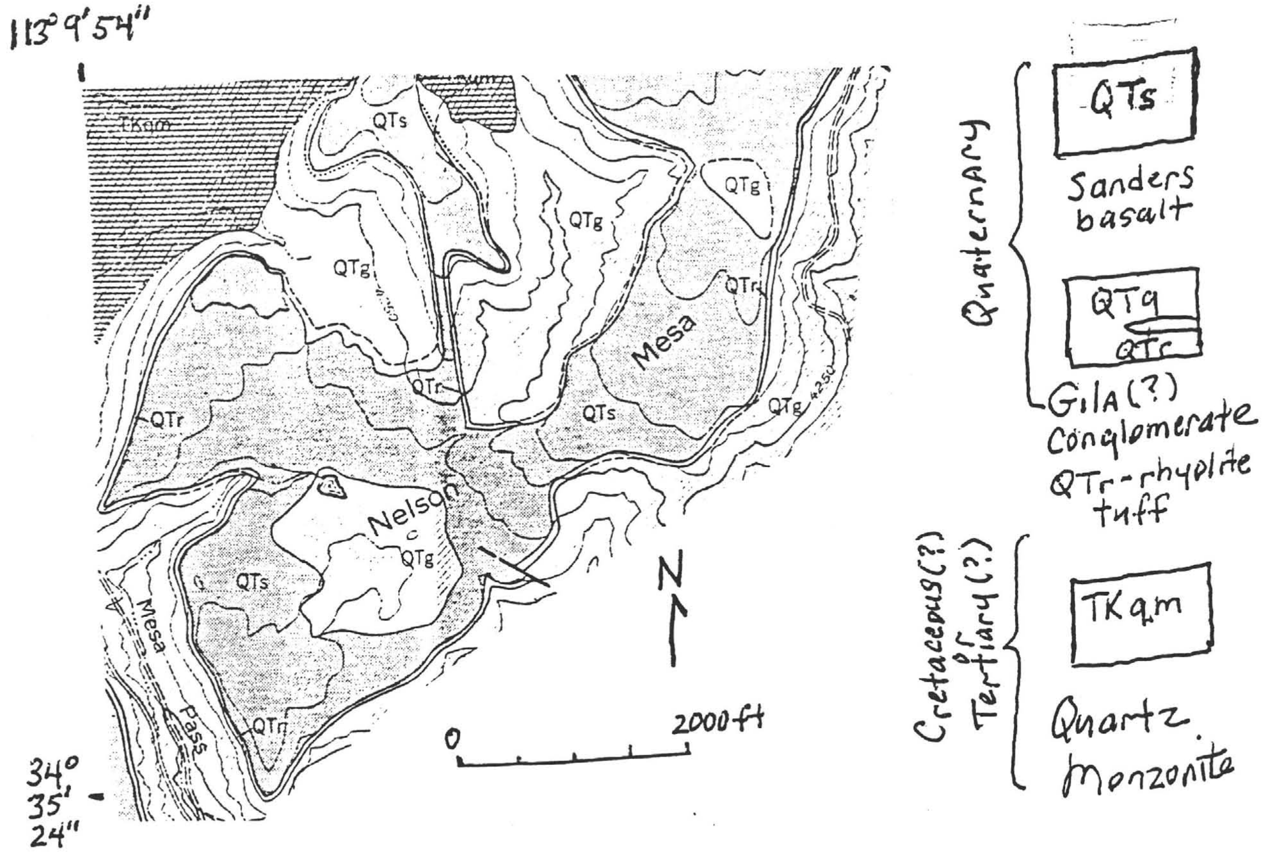


Figure 9. Geologic map of Nelson Mesa near Bagdad showing the distribution of the rhyolite tuff bed (Qtr) (from Anderson et al., 1955).

bagged for use as a floor sweep, oil and water absorbent, pet litter, insulation material, and as light-weight aggregate (Phillips, 1975).

The reserves of pumiceous materials in the Bagdad area are very large, probably in excess of 15.3 million m^3 (20 million yds^3). The reserves at Nelson Mesa are estimated at approximately 4.6 million m^3 (6 million yds^3).

Safford Area, Pumice Deposit

Both pumice and cinder have been mined recently, up until late 1990, from volcanic units in the Peloncillo Mountains in eastern Graham County by Gila Valley Block Company. The pumice, and cinder, occur in an andesite unit which includes basalt, basaltic andesite, and dacite flows and intercalations of silicic pyroclastic deposits and volcanoclastic rocks (Fig. 10) (Drewes et al., 1985) (Plate 10). The andesitic volcanic unit is Miocene-Oligocene (19.4-25.9 Ma) in age.

The mine, located in sec. 28, T6S, R29E, has quarried light-weight aggregate intermittently since at least 1955 and utilizes the pumice to produce light-weight cement blocks and as insulation. Two types of blocks were manufactured by the company, pumice blocks (20% pumice and 80% cinder) and cinder blocks (100% cinder and scoria). In 1963 production was 3825 m^3 (5000 yd^3) per year, 10% pumice and 90% cinder and scoria (ADMR, 1963).

Pumicite Deposits of Apache and Navajo Counties

Pumicite occurs mainly in northeastern Arizona within the Navajo-Hopi Indian Reservations. The epiclastic pumice deposits occur as thin beds of rhyolite tuff in the upper member of the Bidahochi Formation (middle Miocene to lower Pliocene, 4-15 Ma) (Kiersch and Haff, 1955). The tuff beds are rhyolitic in composition and range in thickness from 0.6 to over 3.7 m (2 to 11 ft); commonly, the tuffs are interbedded with claystone, clayey sandstone and tuffaceous sandstones (Plate 11). The tuff beds are generally horizontal and outcrop at or near the top of isolated mesas with little to no overburden (Fig. 11) (Kiersch and Haff, 1955).

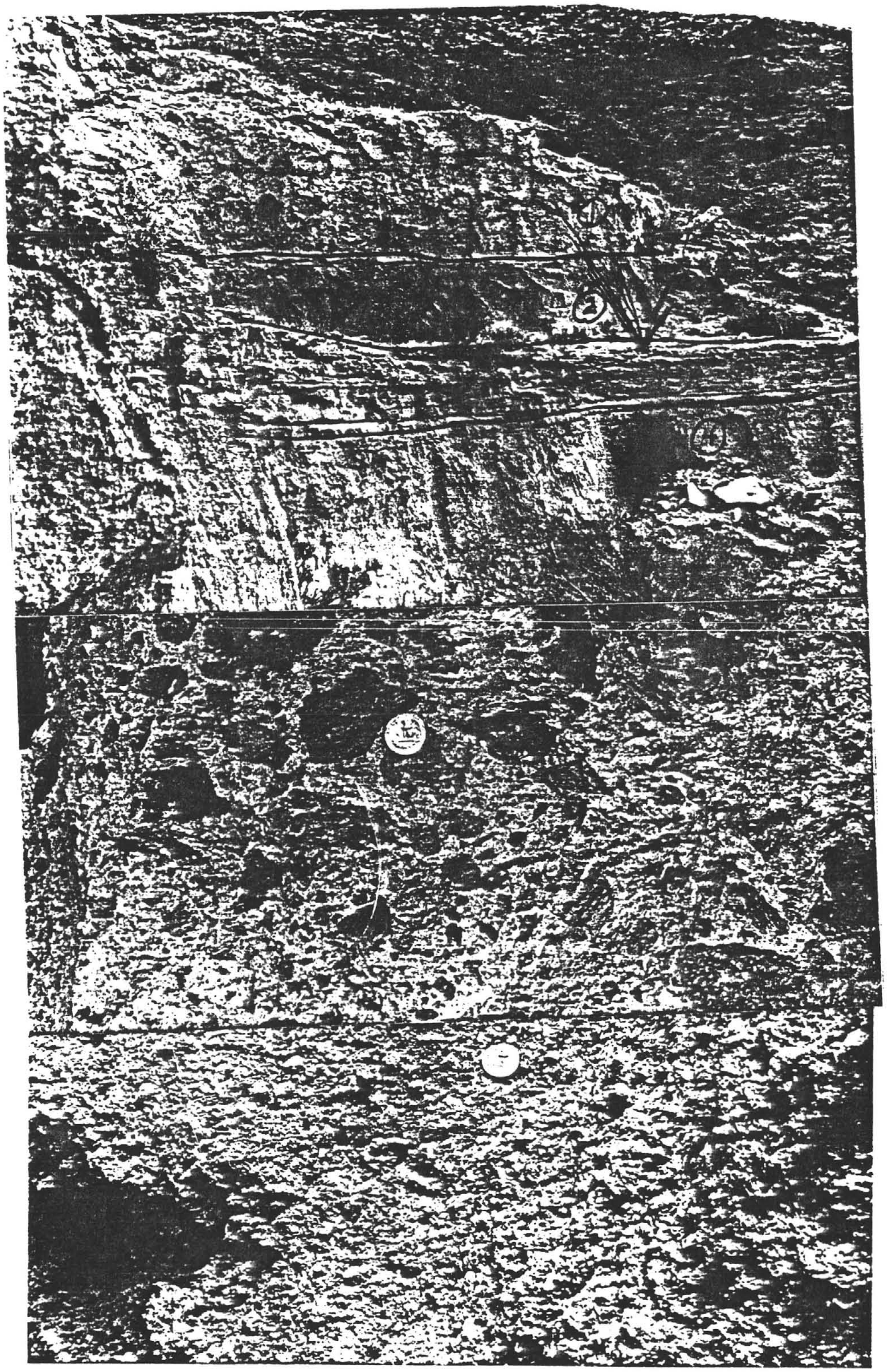
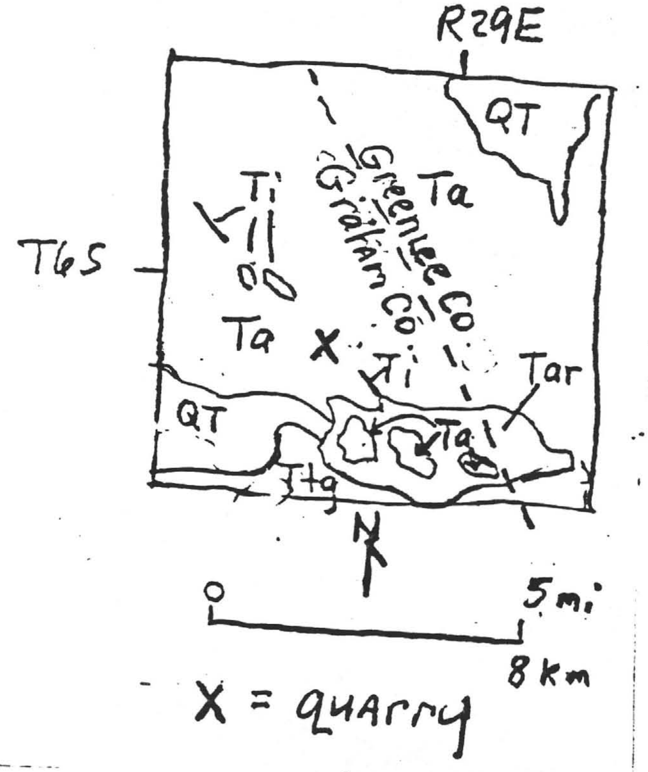
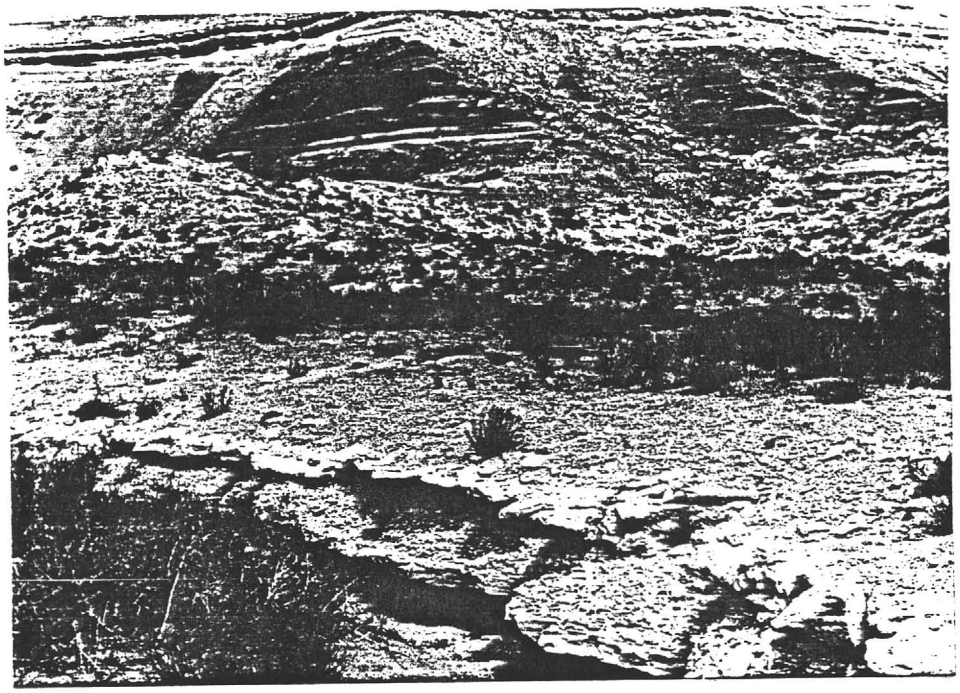


Plate 10. Top - Rhyolitic pyroclastic and volcanoclastic deposts exposed in quarry, east of Stafford (sec. 29, T6S, R29E), Graham County; 1 = pumiceous lapilli tuff; 2 = pumiceous ash-fall; 3 = bedded pumiceous tuff, epiclastic; and 4 = ash-fall pumice; middle = closeup of unit 1, lapilli to block-sized pumice fragments cemented by ash; bottom = lower ash-fall layer, unit 4.



QT -	Alluvial deposits
Ta -	Andesite, includes basalt-dacite flows and pyroclastic and volcanoclastic deposits, 19.4-26.1 Ma.
Ti -	Rhyolite dike and plugs, 22.8-27.0 Ma.
Ttg -	Rhyolite flows and domes (Tollgate Wash eruptive center).
Tar -	Rhyolite domes, flows, and pyroclastic deposits (Ash Peak-Rhyolite Peak eruptive center).

Figure 10. Geologic sketch map of pumice quarry east of Safford (modified from Drewes et al., 1985).



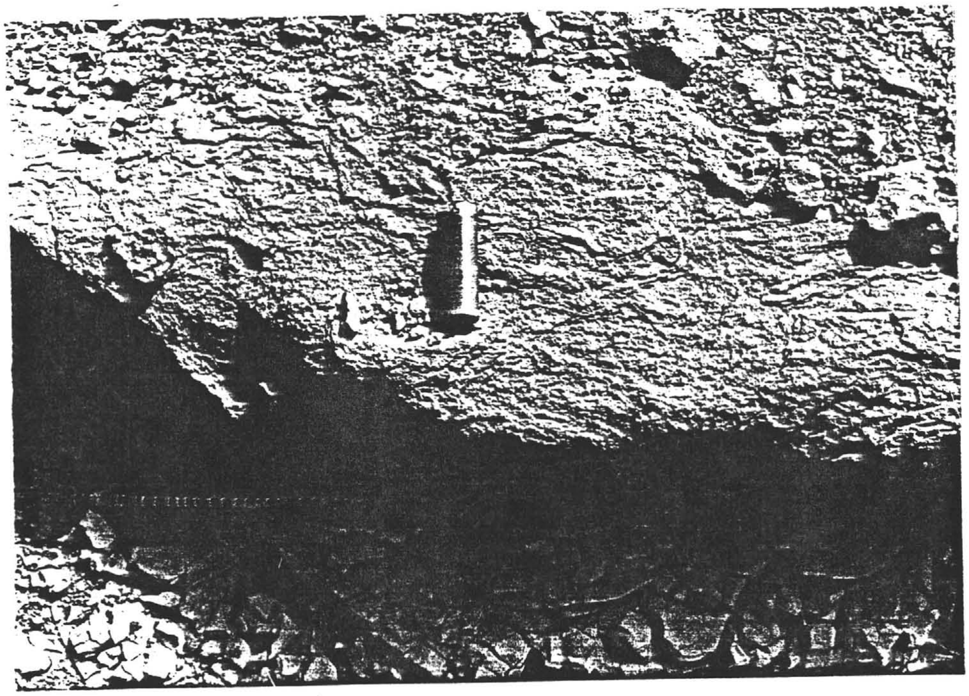


Plate 11. Top - Pumicite layer (Bidahochi Formation (second ledge from the bottom) exposed in arroyo 7 km (4 mi.) northeast of Greasewood, Apache County; Bottom - closeup view of the pumicite layer, overlying a light colored, blocky, clay unit.

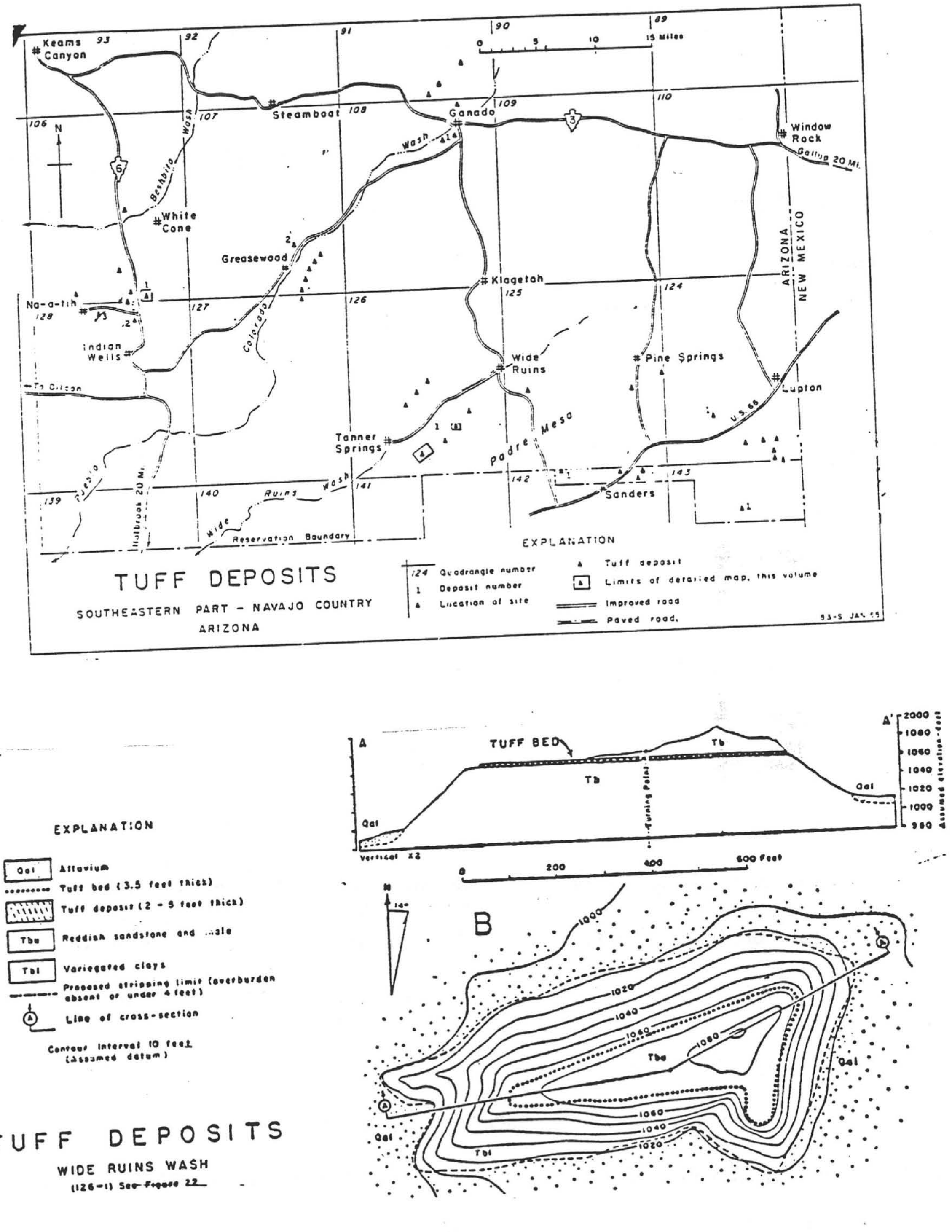


Figure 11. Top, index map showing location of pumicite occurrences, Navajo Reservation, Navajo County; bottom, tuff beds of pumicite in mesa east of Wide Ruins.

Sizeable deposits have been reported from Padre Mesa south of White Cone and in the Lupton-Chambers area. Keirsch and Haff (1955) have estimated the pumicite reserves in the Padre Mesa area at nearly 91,000 m^3 (120,000 yd^3) and indicate that the material is suitable as pozzolanic materials.

Keith (1969) in a survey of the industrial materials of the state, reports that the tuff beds of the Bidahochi Formation are generally are too thin or have too much admixed foreign matter to be a major source of commercial pumicite.

Reported Pumice and Pumicite Occurrences

In Table 10 is included a summary of all the known pumice or pumicite occurrences that have been reported in the literature or contained in the files of the Arizona Bureau. The occurrences are arranged alphabetically by county and are numbered; the numbers locate each occurrence on Map 1. Information included for each citation includes location (i.e. sec., township, and range), name of the corresponding topographic map, a brief description of the pumiceous materials, the literature reference, and, where possible, the inferred origin of the pumice or pumicite materials.

PHYSICAL PROPERTIES OF SELECTED ARIZONA PUMICE DEPOSITS

Introduction

A total of 28 pumice samples have been tested from five pumice deposits that include the White Vulcan claim, San Francisco Mountain (Deadman Flat), Bill Williams Mountain and Safford area. A summary of the pumice physical properties from each occurrence is given in Table 11.

White Vulcan Claim No. 2

The pumice of the White Vulcan deposit is of ash-fall origin and the lumps, comprising approximately 25% plus 19 mm (3/4 in), by weight, are light gray to white; occasionally yellow-brown stains of hydrated iron oxides are abundant.

Table 10. Arizona pumice-pumicite occurrences (map number refers to location on Map 1).

County	Map No.	Location	Area and Topographic Map	Reference and Description
APACHE				
	8	S1, 22N, 25E; S6, 22N, 26E S32, 23N, 26E	Tanner Springs-Wide Ruins (Padre Mesa), Q = Dipping Water Well, 7.5	Nine pumicite occurrences reported in upper rhyolite tuff, Bidahochi Formation; suitable for pozzolan (Kiersch and Haff, 1955) epiclastic
	9	S5, 21N, 28E; S7 21N, 29E S8, 21N, 29E; S9, 21N, 29E S19&14, 23N, 29E; S20, 22N, 30E; S29&32, 22N, 31E, S5, 21N, 31E; S36, 31N, 29E	Sanders-Pine Springs-Lupton Q=Tolapai Spring, 7.5	Fourteen pumicite occurrences reported in upper rhyolite tuff, Bidahochi Formation (Kiersch and Haff, 1955); epiclastic
	10	S29&31, 25N, 24E; S5, 24N, 24E	Greasewood, Q=Greasewood, 7.5	Four occurrences of pumcite reported in upper rhyolite tuff; Bidahochi Formation (Kiersch and Haff, 1955); epiclastic
	11	27N, 26E	North of Ganado, Q=Ganado, 7.5	Four pumicite occurrences in upper rhyolite tuff of the Bidahochi Formation (Kiersch and Haff, 1955); epiclastic
	12	S5, 10N, 24E	Bordshack Knoll pit, Q=Ortega Mtn., 7.5	Pumice occurrence (Phillips, 1987); epiclastic
COCHISE				
	13	S27, 17S, 20E	Benson, Q=Benson, 7.5	White to gray fine pumice (Phillips, 1987); epiclastic
	14	S25-26, 21S, 29E	Pedregosa Mtns., Q= Pedregosa Mtns., East 7.5	Gray pumice (Phillips, 1987); epiclastic
			Cameron, 15	

County	Map No.	Location	Area and Topographic Map	Reference and Description
COCONINO				
	15	S23, 30N, 9E	SE of Grand Canyon, Q =	Pumicite (Phillips, 1987)
	16	S26-29, 34-35, 23N, 4E	Sitgreaves Mtn., Q-Mt. Floyd, 7.5	Rhyolite pumice and ash (Newhall, et al., (1987); airfall
	17	S30, 25N, 6E	San Francisco volcanic field, Q=	Rhyolite pumice from airfall, fragments 1-5 cm (Wolfe et al., 1987)
	18	S10, 23N, 8E	O'Leary Peak; Q=O'Leary Peak, 7.5	Rhyolite pumice (Phillips, 1987); airfall
	19	S31, 23N, 8E	San Francisco volcanic field; Q=Sunset Crater, West; 7.5	Decomposed rhyolite pumice (Phillips, 1987)
	20	S13, 22N, 15E	Bird Springs; Q=Bird Springs Wash; 7.5	Pumicite (Phillips, 1987)
	21	S4&9, 23N, 8E	O'Leary Peak; Q=O'Leary Peak, 7.5	Pumice sand (Phillips, 1987); airfall
	22	S2, 3, 11, & 12, 24N, 8E	O'Leary Peak; Q=O'Leary Peak, 7.5	Pumice (Phillips, 1987); airfall
	23	S35, 25N, 9E	San Francisco volcanic field; Q=Wupatki SW, 7.5	White to gray pumice, less than 1 m (Moore et al., 1987); airfall
	24	S1, 24N, 9E	San Francisco volcanic field; Q=Strawberry Crater, 7.5'	White to gray pumice; less than 1 m (Moore et al., 1987); airfall
	25	S5, 22N, 7E	San Francisco Mtn.; Q= Humphreys Peak, 7.5	Lapilli and bombs of gray to pale yellow andesitic pumice (Holm, 1988); airfall
	26	S21, 23N, 7E	San Francisco Mtn.; Q= Humphreys Peak, 7.5	Light gray pumice lapilli and blocks up to 15 cm (Holm, 1988); airfall

County	Map No.	Location	Area and Topographic Map	Reference and Description
	27	S21, 23N, 4E	RS Hill; Q=Moritz Ridge, 7.5	Rhyolite pumice and ash associated with domes (Wolfe et al., 1987); airfall
	28	S3, 22N, 2E	Williams; Q=Williams, 15	Pumice (Phillips, 1987); airfall
GILA				
	29	S1, 1N, 18E, S2, 1S, 18E	San Carlos; Q=San Carlos, 7.5 and Natural Corral, 7.5	Pumiceous tuff (Phillips, 1987)
GRAHAM	30	S29, 6S, 29E	Safford area; Q=Guthrie, 15	Pumicite formerly mined for lt. weight aggregate (Phillips, 1987); tested positive for pozzolan (Williams, 1966); epiclastic
	31	S7, 7S, 29E	Safford area; Q=Guthrie, 15	Pumice (Phillips, 1987); epiclastic
GREENLEE				
	32	S20, 4S, 32E	Clifton area; Q=Big Lue Mtns., 15	Pumice outcrops (Phillips, 1987)
	33	S25, 4S, 31E	Clifton area; Q=Big Lue Mtns., 15	Pumice outcrops (Phillips, 1987)
	34	S29, 4S, 32E	Clifton area; Q=Big Lue Mtns., 15	Pumice outcrops (Phillips, 1987)
LA PAZ				
	35	S24&25, 7N, 17W	Northwest of Hope; Q=Uttin, 15	Past production of pumicite (Phillips, 1987); maximum thickness 30 ft.; tested positive for pozzolan (Williams, 1966)
	36	S1, 4N, 15W	West of Hope 4 mi.; Q= Vicksburg, 15	Gray pumicite (Phillips, 1987)

County	Map No.	Location	Area and Topographic Map	Reference and Description
MARICOPA				
	37	S30, 7N, 6W; S24 & 25, 7N, 7W	Vulture Mtns.; Q-Vulture Mtns., 15	Pumice interbedded with perlitic welded tuff (Phillips, 1987); pyroclastic flow/surge
	38	S3, 2N, 8W	Big Horn Mtns.; Q-Big Horn Mtns., 15	Pumicite (Phillips, 1987); tested positive for pozzolan except for alkali reactivity (Williams, 1966)
	39	S23, 6N, 1W	Baldy Mtn.; Q=Baldy Mtn., 7.5	Pumiceous rhyolite (Phillips 1987)
	40	S31, 5N, 4W	Northwest of Phoenix; Q= Wickenburg Sw, 7.5	Pumicite, 40 ft thick; possible for pozzolan (Williams, 1966)
MOJAVE				
	41	S7, 17N, 18W	5 mi west of Yucca; Q=Gene Wash, 7.5	Pumicite (Williams, 1966)
	42	21N, 20W	West of Kingman; Q=Union Pass, 7.5	Pumicite; test for pozzolan marginal (U.S. Bureau Mines, 1969)
NAVAJO				
	43	S1,2,11,12,15,19, 25N, 21E	White Cone Peak; Q=White Cone, 15	Pumiceous tuff (Phillips, 1987); epiclastic
	44	S2,9,15,16, 24N, 21E	North of Indian Wells; Q= White Cone, 15	Pumicite (Kiersch and Hass, 1955); epiclastic
	45	S28, 26N, 21E	West of White Cone Peak; Q= White Cone, 15	Pumicite (Kiersch and Hass, 1955); epiclastic
	46	S32, 9N, 17E	Cibeque; Q=Spotted Mtn., 7.5	Pumicite (Williams, 1966); epiclastic

County	Map No.	Location	Area and Topographic Map	Reference and Description
SANTA CRUZ				
	47	S24, 23S, 12E	Northwest of Nogales; Q=	Pumicite (Phillips, 1987) Ruby, 15YAVAPAI
	48	S2&3, 14N, 9W	Bagdad; Q=Bagdad, 15 epiclastic	Epiclastic pumice (Phillips, 1987);
	49	S34&35, 15N, 9W	Prescott; Q=Bagdad, 15	Epiclastic pumice (Phillips, 1987); epiclastic
	50	S28&32, 13N, 4W	Prescott; Q=Kirkland, 7.5	Pumciite (Phillips, 1987); epiclastic
	51	S35, 11N, 2W	Prescott; Q=Walnut Grove, 7.5	Small white pumice (Phillips, 1987); epiclastic
YUMA				
	52	S1, 4N, 13W	East of Hope; Q=Harrisburg Valley, 7.5	Pumicite; test for pozzolan failed (U.S. Bureau Mines, 1969)

Table 11. Physical properties of selected Arizona pumices (R = range and A = average).

Location Map No.	Bill Williams Mtn., (S16, T21, R2) 2	Bill Williams Mtn., (S4, T21, R2) 2	Deadman Flat (S32, & 33, T25, R8) 16	Safford Area (S28, T5, R29) 3	White Vulcan Claim No. 2 (S19, T23, R8) 1
Surface Fines (%)	R = 0.6 - 0.9 A = 0.8	R = 0.3 - 0.9 A = 0.5	R = 0.1 - 0.7 A = 0.3	R = 0.2 - 0.4 A = 0.3	R = 0.5 - 1.5 A = 1.1
Apparent Density (g/cm^3)	R = 0.66 - 1.07 A = 0.92	R = 0.57 - 0.95 A = 0.73	R = 0.53 - 0.70 A = 0.62	R = 1.13 - 1.28 A = 1.21	R = 0.58 - 1.01 A = 0.74
Abrasion Loss (-%)	R = 1.9 - 3.3 A = 2.6	R = 1.2 - 2.5 A = 1.8	R = 1.2 - 4.2 A = 1.7	R = 4.5 - 17.1 A = 10.8	R = 0.9 - 2.6 A = 1.6
Absorption Capacity	R = 8 - 17 A = 12	R = 16 = 28 A = 21	R = 14 - 40 A = 24	R = 7 - 19 A = 13	R = 4 - 19 A = 11
Impregnation Rate (g./min.)	R = 1.6 - 3.5 A = 2.3	R = 3.3 - 5.7 A - 4.3	R = 2.8 - 8.0 A = 4.8	R = 1.4 - 3.8 A = 2.1	R = 0.8 - 3.7 A = 2.2
Coloration	light gray to brown, > 5% FeO	light gray to white	light tan to white	light gray to brown	light gray to white, some with FeO stain
Size (wt. % > 3/4 in)	< 5	30	21	2	25
Samples Tested	5	6	7	2	8

Physical property tests indicate a wide range of values for apparent density, absorption, abrasion loss, and impregnation rate. It appears that two distinct varieties of pumice occur in the deposit. One type has moderate apparent density (0.58-0.71 g/cm^3, 36.2-44.3 lbs/ft^3), moderate absorption (10 to 19%) and is moderately soft (abrasion loss = 1.9-2.6% mm) whereas the other has high apparent density (0.90-1.01 g/cm^3), very low absorption (4-7%), and is harder (abrasion loss = 0.9-1.6%).

The absorption capacity, during the standard five minutes of submergence in water, is only low to moderate. However, submergence of the pumice for longer periods of time, i.e. 20-25 days, results in liquid absorption of nearly 40% by weight. Therefore, to obtain the maximum uptake of liquid, the pumice should not be submerged or dipped but impregnated under a vacuum. The vacuum method will take only a few minutes and obtain the maximum liquid capacity of the pumice.

The White Vulcan pumice appears suitable for acid-washing, if it is impregnated under a vacuum, and a majority of the iron-stained lumps are eliminated. The origin of the two distinctly different pumice types may be due to more than one volcanic eruption. Dennis (1981) noted that the lower beds of White Vulcan pumice are rhyolitic and aphyric, whereas the upper horizons are dacitic and porphyritic.

Pumice of San Francisco Mountain (Deadman Flat)

The pumice deposit at Deadman Flat contains about 21% lumps with a diameter of plus 19 mm (3/4 in) by weight. The pumice is light tan to white, devoid of phenocrysts, and moderately vesicular. Physical property tests indicate that the pumice is medium high in impregnation rate, low on abrasion loss, and has medium density and absorption. Vacuum impregnation indicates the pumice can increase in weight up to 42% by the absorption of water.

The pumice at Deadman Flat appears to be a very desirable stone for acid-washing because of its high capacity to absorb liquid under a vacuum, and its low abrasion loss.

Bill Williams Mountain

Two ash-fall pumice deposits were sampled and tested at this area; the first deposit, in section 4, is located at the Moody pit and the second in section 16.

The Moody pit pumice has medium density, absorption, and impregnation rate, and low abrasion loss. It would be an excellent pumice for acid-washing except for the fact that when wet, it develops internal fractures that result in the pumice splitting apart during tumbling.

The pumice in section 16 is of poor quality. It has medium-high apparent density, medium-low absorption, abrasion loss and impregnation rate. In addition, it contains an occasional abundance of surface iron oxide.

Stafford Area

The ash-fall pumice located east of Stafford has a very high apparent density, low absorption, and impregnation rate, and a very high abrasion loss during tumbling. In the field it was observed that the pumice is altered to clay minerals and zeolites. These properties make this pumice unacceptable for either stone- or acid-washing.

ARIZONA PRODUCERS AND MARKETS

Producers and Current Markets

Presently, only one active mine produces pumice and pumicite in the state. Arizona Tufflite, Inc., which produces from the White Vulcan No. 2 claim in Coconino County, for both construction and laundry uses. Prior to late 1986, the pumiceous materials were marketed for light-weight structural concrete, aggregate and concrete masonry units. In January 1987, Tufflite was shipping three truck loads a day of lump pumice to El Paso,Texas for stonewashing. At the present time, the company markets over 50% of its pumice for laundry use in a number of states including Texas, Tennessee, and Kentucky (C.T. Morgan, pers. commun., August 14, 1991).

Mountain View Mining, Inc. is listed in 1990 as producing laundry use pumice from the Dead Eye mines (secs. 4, 16, T21N, R2E) at Bill Williams Mountain (Directory of Active Mines in Arizona, 1991). The deposit in section 4 is the Moody Pit, but no figures are available for 1990 production. When the Moody pit was visited in August 1991, no pumice was being mined.

The property in section 16 (T21N, R2E) has not produced any pumice for commercial uses. In July 1989, an operating plan for an open pit pumice operation was received by the Kaibab Forest; the claimant maintained the pumice was an uncommon variety. The Forest Service mineral examiner recommendation was that the material is common variety; the claimant appealed and a final decision has not been rendered.

Future Markets

Prior to the late 1980's, Arizona pumice was utilized in the construction industry. Today the laundry business consumes over one-half of the state's production. The largest current markets for laundry pumice are in Los Angeles, California and El Paso, Texas. In El Paso, over 2268 mt (2500 st) per month are consumed by laundries; the majority of the pumice is imported from Ecuador, Guatemala, and Mexico.

The major pumice deposits in Arizona are associated with the San Francisco volcanic field, in the Flagstaff-Williams area, which are located approximately 735 km (460 mi) and 686 km (430 mi) from El Paso and Los Angeles, respectively. Transportation costs to these two cities would be about \$0.015/lb compared to \$0.05-\$0.07/lb for imported pumice thereby allowing Arizona pumice to compete favorably with the imports.

Another market that needs to be developed is a commercial use for the pumice fines that are derived from mining lump pumice. Arizona Tufflite is presently rescreening the 0.95 cm (-3/8 in) materials into 0.8 cm (5/16 in), 0.3 cm (1/8 in), and 0.2 cm (3/32 in) fractions for use in horticulture, ballfield covers, and roofing tiles, respectively.

SUMMARY AND CONCLUSIONS

Pumice and pumicite resources are abundant in Arizona, which currently ranks within the top four states in U.S. production. The principal deposits are ash-fall in origin and are associated within the San Francisco volcanic field in the north-central part of the state.

Currently, only one active mine produces pumiceous materials from wihtin the state; the production is from the White Vulcan claim near Flagstaff (Arizona Tufflite, Inc.). Past production has been recorded from deposits located in Coconino (Bill Williams Mountain), Yavapi (Bagdad), Maricopa (northeast of Phoenix), Pinal (Florence), and Graham (Safford) Counties. Numerous occurrences of pumicite exist in Apache and Navajo Counties.

The principal uses of the state's pumice-pumicite are in the production of concrete aggregate, light-weight building block, and as an abrasive. The abrasive use of pumice has increased dramatically in the past few years because of the demand in the laundry industry to produce designer jeans.

The quality and potential use of Arizona pumices have been evaluated by the testing of their physical properties, such as apparent density, absorption, abrasion characteristics, surface properties, and impregnation rate. The results, based upon the analyses of 28 representative samples, indicate that Arizona pumices are of poor to good quality. Most of the pumices are suitable for construction uses, but only the White Vulcan and Deadman Flat deposits are recommended for laundry use.

ACKNOWLEDGEMENTS

The writer would like to thank Ken Phillips of the Arizona Department of Mines and Mineral Resources for supplying me with pumice and pumicite reports and maps from the Bureau files. C.T. Morgan, Arizona Tufflite, Inc., allowed access to the White Vulcan claims.

In addition, Robin ~~Straphy~~ Strathy and Tom Gillette, U.S. Forest Service, Arizona Zone, accompanied the author into the field to observe the pumice deposits at Bill Williams Mountain.

Thanks are also extended to Robin Straphy and Liz Mathews (U.S. Forest Service, Arizona and New Mexico Zone, Mineral Examiners, respectively) for discussions and guidance in unraveling the legal documents concerning "common versus uncommon" pumice.

APPENDIX I

LOCATABLE PUMICE ON FEDERAL LANDS

Introduction

A significant number of pumice deposits occur on public lands in the western United States and their locatability is, therefore, subject to the Federal Mining Law of 1872. This law was modified by Congress in 1955 and its interpretation, as applied to pumice, is continuing to evolve through the courts.

The Federal Mining Law was designed to encourage individual prospecting, exploration, and development on public lands. Under the law, prospectors may go out on public domain, not otherwise withdrawn, locate a mining claim, search out its mineral wealth and, if discovery of a mineral is made, can then obtain a patent. The patented property becomes the individual's to

X develop or sell according to his wishes ~~(U.S.A. v. Multiple Use, Inc., 1988)~~. ok.

Common versus Uncommon Pumice

Prior to 1955, pumice was determined to be a locatable mineral under the law and a patented claim could be obtained on such a mineral deposit. In 1955, Congress enacted legislation removing certain "common varieties" of previously locatable minerals from the mining law. Mineral deposits of "common variety" pumice and pumicite were among those minerals removed from the law. Congress recognized that certain of the above minerals are not "common varieties" and such materials valuable and locatable if the deposit has some property that gives it a distinct and special value such as "block pumice" having one dimension of at least 51 mm (2 in) or more.

Case law has defined standards for distinguishing between common and uncommon varieties. The material in question must have some unique property giving the deposit a distinct and special economic value. The value should be reflected by a higher market price for the mineral or by a substantial reduction in production cost or overhead.

economic value. The value should be reflected by a higher market price for the mineral or by a substantial reduction in production cost or overhead.

Subsequent regulations, issued by the Department of Interior, have elaborated on those properties that give the mineral distinct and special value (43CFR 3711.1 ca):

> "<u>Common varieties</u>" includes deposits which, although they may have value for use in trade, manufacture, the sciences, or in the mechanical or ornamental ares, <u>do not possess a distinct, special economic value for such use over and above the normal uses of the general run of such deposits</u>. Mineral materials which occur commonly shall <u>not</u> be deemed to be "common varieties" <u>if</u> a particular deposit has <u>distinct and special properties making it commercially valuable</u> for use in a manufacturing, industrial, or processing operation. In the determination of commercial value, such factors may be considered as quality and quantity of the deposit, geographical location, proximity to market or point of utilization, accessibility to transportation, requirements for reasonable reserves consistent with usual industry practices to serve existing or proposed manufacturing, industrial or processing facilities, and feasible methods for mining and removal of material.

White Vulcan Pumice Claims

In 1988, the courts handed down a ruling on the White Vulcan deposit in Sec. 9, T23N, R8E, Coconino County, Arizona. The decision declared that a portion of the deposit contained a common variety of pumice whereas the other portions were determined to have unique physical properties, such as absence of staining and uniform size. These properties gave the pumice a distinct value (premium price) for use in stone washing. The decision was appealed.

On July 15, 1991, the appeal was denied by the court, and the no discovery status was upheld on the White Vulcan No. 1 claim. Because a patent application is pending a portion of the White Vulcan deposit. The court was unable to predict the potential of future stone washing sales of the pumice and extended the appeal for further evidence at a future hearing.

Current and Future Status

It appears at the present time, based upon the recent court ruling that unique properties and a higher market price as stone washing pumice qualifies some of the White Vulcan pumice as uncommon and therefore possibly eligible for patent.

The author's experience in testing and classifying pumices worldwide for stone washing during the past 7 years indicates such properties as porosity, density, abrasion loss, hardness and surface coloration are useful in identifying laundry pumice. Perhaps one in five pumice possess suitable physical properties that can and have been used by various laundries in acid and stone washing.

Those pumices most desirable for laundry use, and therefore commanding the higher prices, do not necessarily possess unique values of porosity, density, hardness, etc., but they are unique in a more important aspect. Their uniqueness is due to consistency of the product and its performance. Most laundries can adapt their washing processes to many different kinds of pumice as long as the pumice is consistent from day to day. If the pumice varies greatly, for example in porosity, density, hardness, etc., it can change a particular look that the laundry is trying to produce and end up as a charge back to the laundry. For example, if the pumice hardness changes daily or weekly, the amount of abrasion will increase or decrease on the fabric.

The courts up to the present time have attempted to relate pumice uniqueness to such properties as shape, uniform size, and surface staining. They have not included, what this author considers through his work with laundry pumice, the property that makes some pumices unique -- consistency; my experience indicates that perhaps 1 in 25 pumices qualify as consistent.

REFERENCES

American Society for Testing and Materials, 1979, Concrete and mineral aggregates, Part 14, ASTM C 618-78, Standard specification for fly ash and raw or natural pozzolan for use as a mineral admixture in portland cement concrete, p. 362-365.

Anderson, C. A., Schloz, E. A., Strobell, J. D., 1955, Geology and ore deposits of the Bagdad area Yavapai County, Arizona, U.S. Geol. Surv. Prof. Paper 278, 99 p.

Bates, R. L., 1960, Geology and industrial rocks and minerals: Harper, 439 p.

Bolen, W. P., 1990, Mineral commodity summaries 1989, pumice and pumicite: U.S. Bur. of Mines, p. 130-131.

Bolen, W. P., 1991, Mineral commodity summaries (Annual Preliminary) 1990, pumice and pumicite: U.S. Bur. of Mines, 3 p.

Cas, R. A. F. and Wright, J. V., 1987, Volcanic successions modern and ancient: Allen and Unwin, Ltd., 528 p.

Cashman, K. V. and Fiske, R. S., 1991, Fallout of pyroclastic debris from submarine volcanic eruptions: Science, v. 253, no. 5017, p. 275-280.

Chesterman, C. W., 1956, Pumice, pumicite, and volcanic cinders in California: Calif. Dept. Natural Res., Div. of Mines, Bull. 174, 119 p.

Chesterman, C. W., 1966, Pumice, pumicite, perlite, and volcanic cinders: Calif. Div. of Mines and Geol., Mineral Resources of Calif. Bull. 191, p. 336-341.

Dennis, M. D., 1981, Stratigraphy and petrography of pumice deposits near Sugarloaf Mountain, northern Arizona: M.S. Thesis, Northern Arizona University, 79 p.

Drewes, H., Houser, B. B., Hedlund, D. C., Richter, D. H., Thorman, C. H., Finnell, T. L., 1985, Geologic map of the Silver city 1° x 2° quadrangle New Mexico and Arizona: U.S. Geol. Surv. Misc. Invest. Series, Map I-1310-C, scale, 1:250.00.

Federal Register, 1990, Disposal of mineral materials, v. 55, no. 242, p. 51705-51706.

Fisher, R. V., 1961, Proposed classification of volcaniclastic sediments and rocks: Geol. Soc. Amer. Bull. 72, p. 1409-1414.

Fisher, R. V., and Schmincke, H. U, 1984, Pyroclastic rocks: Springer-Verlag, 472 p.

Harben, P. W., and Bates, R. L., 1984, Geology of the nonmetallics: Metal Bulletin, Inc., 392 p.

Harben, P. W., and Bates, R. L., 1990, Pumice and scoria: Industrial minerals, geology and world deposits: Metal Bulletin, p. 217-219.

Hickson, C. J., and Barnes, W. C., 1986, The direct blast at Mount St. Helens, May 18, 1980: surge or flow?; in Mount St. Helens Five Years Later: Eastern Wash. Univ. Press, p. 34-43.

Hoffer, J. M., 1989, Physical property specifications for pumice used in acid- and stone-washing: Unpublished report, 35 p.

Hoffer, J. M., 1991, Pumice and pumicite in New Mexico: New Mexico Bur. Mines and Mineral Resources, Bull. 140, in press.

Holm, R. F., 1988, Geologic map of San Francisco Mountain, Elden Mountain, and Dry Lake Hills, Coconino County, Arizona: U.S. Geol. Surv., Misc. Invest. Series, Map I-1663, scale, 1:24,000.

Keith, S. D., 1969, Pumice and pumicite; in Mineral and Water Resources of Arizona: Arizona Bur. Mines, Bull. 180, p. 407-412.

King, C. R., 1961, Preliminary report on the McDaniel pumice deposit and claims near Bagdad, Yavapai County, Arizona: Arizona Dept. of Mines and Mineral Resources Data File, 4 p.

Kiersch, G. A., and Haff, J. C., 1955, Pozzolan; in Mineral Resources, Navajo-Hopi Indian Reservations, Arizona-Utah: College of Mines, Univ. of Arizona, V. II, Nonmetallic Minerals, p. 84-89.

McMichael, B., 1990, Pumice markets: Volcanic rise of stonewashing: Industrial Minerals, No. 272, p. 22-37.

Meisinger, A. C., 1983, Pumice and pumicite; in Minerals Yearbook, 1983: U.S. Bur. Mines, p. 709-712.

Meisinger, A. C., 1988, Pumice and pumicite; in Minerals Yearbook, 1988: U.S. Bur. Mines, p. 713-716.

Mielenz, R. C., Green, K. T., Schieltz, N. C., 1951, Natural pozzolan for concrete: Econ. Geol,, v. 46, p. 311-328.

Moore, R. B., and Wolfe, E. W., 1987, Geologic map of the east part of the San Francisco volcanic field, Arizona: U.S. Geol. Surv., Misc. Field Studies Map MF-1960, scale 1:50,000.

Newhall, C. G., Ulrich, G. E., and Wolfe, E. W., 1987, Geologic map of the southwest part of the San Francisco volcanic field, north-central Arizona: U.S. Geol. Surv., Misc. Field Studies Map MF-1958, scale 1:50,000.

Peterson, N. V., and Mason, R. S., 1974, Pumice, pumicite and volcanic cinders; in Leford, S.W. (editor), Industrial Minerals and Rocks: Soc. of Mining Engineers, New York, p. 991-994.

Phillips, K. A., 1987, Arizona industrial minerals, pumice and pumicite: Arizona Dept. of Mines and Mineral Resources, p. 23-26 and 138-154.

Reynolds, S. J., 1988, Geologic map of Arizona: Arizona Geol. Surv., scale 1:1,000,000.

Sheridan, M. F., and Updike, R. G., 1975, Sugarloaf Mountain tephra - A Pleistocene rhyolite deposit of base-surge origin in northern Arizona: Geol. Soc. of Am., Bull., v. 86, p. 571-581.

Smith, A.L. and Roobol, M.J., 1990, Mt. Pelee, Martinique: A study of an active island-arc volcano: Geol. Soc. America Mem. 175, 105 p.

Sparks, R. S. J. and Brazier, S., 1982, New evidence for degassing processes during explosive eruptions: Nature v. 295, p. 218-220.

Ulrich, G. E., Condit, C. D., Wenrich, K. J., Wolfe, E. W., Holm, R. F., Nealey, L. D., Conway, F. M., Aubele, J. C., and Crumpler, L. S., 1989, Miocene to Holocene volcanism and tectonics of the southern Colorado Plateau, Arizona, excursion 5A; in Field Excursions to Volcanic Terraines in the Western United States, Vol. 1, Southern Rocky Mountain Region (Chapin and Zidek, eds.): New Mexico Bur. Mines and Mineral Resources, Mem. 46, p. 1-41.

Ulrich, G. E., and Bailey, N. G., 1987, Geologic map of the SP Mountain part of he San Francisco volcanic field, Arizona: U. S. Geol. Surv., Misc. Field Studies Map MF-1956, scale 1:50,000.

United States of America versus Multiple Use, Inc., 1988, Arizona MC 28246-a, U.S. Dept. Interior, Office of Hearings and Appeals, Salt Lake City, Utah, p. 1-52.

U. S. Bureau of Mines, 1969, Pozzolanic raw material resources in central and western United States: Information Circ. 8421, 117 p.

Verhoogen, J., 1951, Mechanics of ash formation: Am. Jour. Sci., v. 249, p. 729-739.

Walker, G. W., 1951, Pumice deposits of the Klamath Indian Reservation, Klamath County, Oregon; U.S. Geol. Surv., Circ. 128, 6 p.

Whitham, A. G., and Sparks, R. S. J., 1986, Pumice: Bull. of Volcanology, v. 48, p. 209-233.

Williams, F. E., 1966, Potential pozzolan deposits in Arizona: M. S. Thesis, Univ. of Arizona, 93 p.

Williamson, D.R. and Burgin, L., 1960, Pumice and pumicite: Colorado School of Mines, Mineral Industries Bull., v. 3, 12 p.

Wolfe, E. W., Ulrich, G. E., Holm, R. F., Moore, R. B., and Newhall, C. G., 1987, Geologic map of the central part of the San Francisco volcanic field, Arizona: U. S. Geol. Surv., Misc. Field Studies Map MF-1959, scale 1:50,000.

Wright, J. V., Smith, A. L., and Self, S., 1980, A working terminology of pyroclastic deposits: Jour. Volcanol. and Geothermal Research, v. 8, p. 315-339.