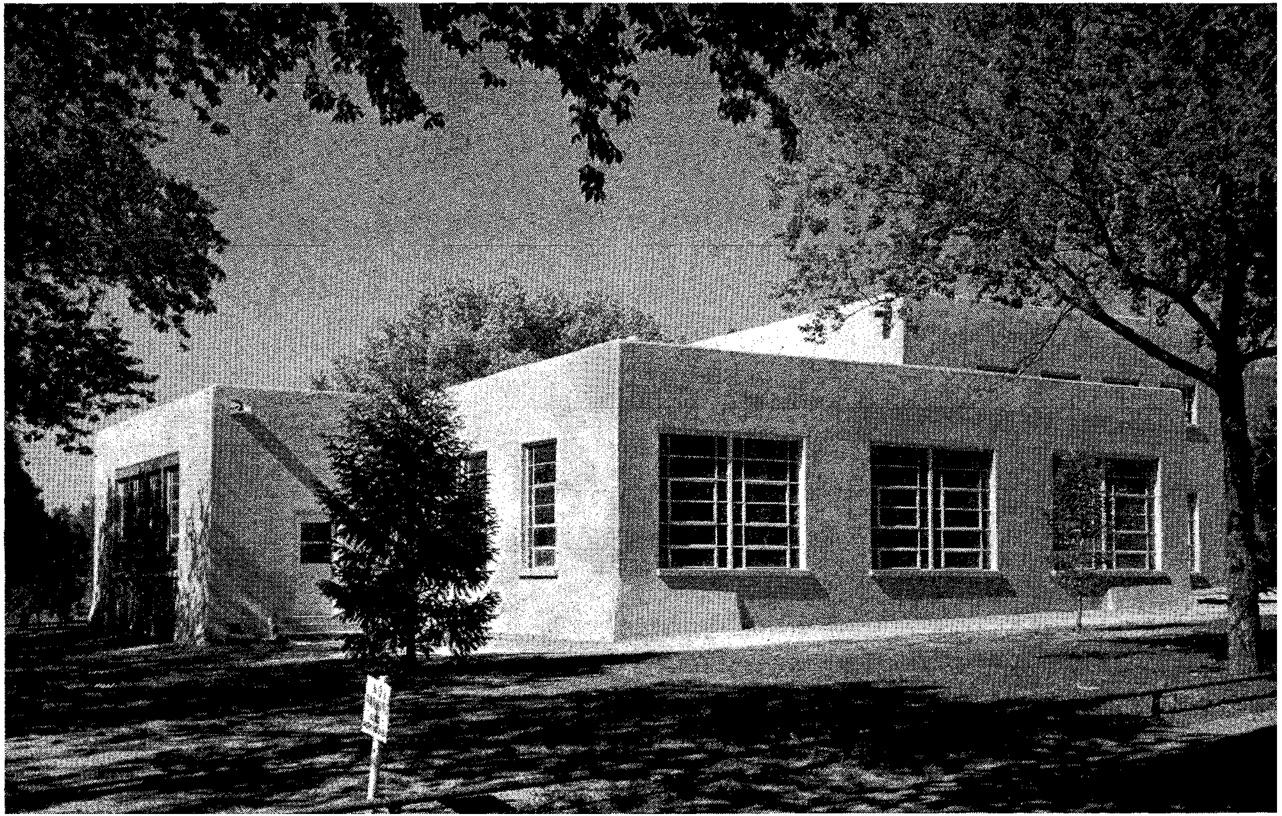


Chemical Engineering Building, University of New Mexico, Albuquerque. An example of pumice-concrete construction.

NEW MEXICO
BUREAU OF MINES AND MINERAL RESOURCES

A DEPARTMENT OF THE SCHOOL OF MINES

E. C. ANDERSON
Director

BULLETIN 28

Pumice Aggregate in New Mexico
Its Uses and Potentialities

By

DONN M. CLIPPINGER

and
WALTER E. GAY

SOCORRO

1947

CONTENTS

PLATES

FIGURES

THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

The New Mexico Bureau of Mines and Mineral Resources, designated as "a department of the New Mexico School of Mines and under the direction of its Board of Regents," was established by the New Mexico Legislature of 1927. Its chief functions are to compile and distribute information regarding mineral industries in the State, through field studies and collections, laboratory and library research, and the publication of the results of such investigations. A full list of the publications of the New Mexico Bureau of Mines and Mineral Resources is given on the last pages of this Bulletin.

Pumice Aggregate in New Mexico
Its Uses and Potentialities

By

DONN M. CLIPPINGER[1]

and

WALTER E. GAY[2]

INTRODUCTION

PURPOSE AND SCOPE OF THE REPORT

As a result of the acceptance of pumice as a highly desirable and advantageous natural lightweight concrete aggregate, a new industry is being rapidly developed. Recent activities in the field of construction show that this new resource is adding greatly to the wealth and welfare of New Mexico. The State has sufficient pumice to supply for decades to come the aggregate needs, at the present rate of building, of all plants producing concrete and concrete products in New Mexico, Texas; Colorado, Oklahoma, Kansas, Nebraska, Missouri, and Iowa. These states comprise the large region within which pumice can be shipped by rail and still remain well within competitive range.

The purpose of this bulletin is to describe and discuss the uses and favorable characteristics of pumice, especially in construction. Data have been compiled from reliable sources concerning the successful uses of pumice aggregate and the physical properties of pumice products. Experiments have also been conducted using generally accepted particle distribution and concrete-mix designs. Graphs and charts comparing the physical properties of pumice with those of other building materials are presented. Special emphasis is placed on the importance of proper control in mining and grading operations, to produce a satisfactory and marketable aggregate. The general application for building use is outlined, as well as agricultural applications and possibilities. Studies,, have been made of the economics of pumice concrete. The past and present production has been surveyed as an aid in predicting future demand.

[1] Field engineer, New Mexico Bureau of Mines and Mineral Resources.

[2] Consulting lightweight-concrete engineer.

This report supplements Bulletin 24 of this series, "Building Blocks from Natural Lightweight Materials of New Mexico," which is devoted to all natural lightweight building materials in general.

ACKNOWLEDGMENTS

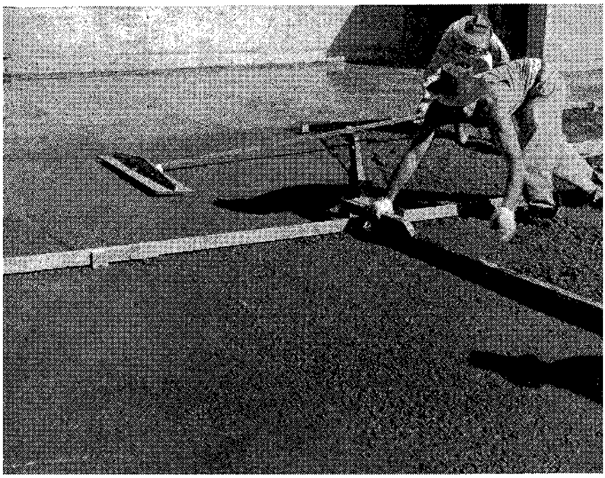
The authors gratefully acknowledge the cooperation of all those who have contributed to this bulletin. Paul R. Splane and E. P. Lockwood, of Paul R. Splane, Incorporated furnished test data and illustrations of many pumice-concrete structures of California. E. G. Cullum of Santa Fe supplied pumice samples for the concrete tests. Gene Sundt, president, Albuquerque Gravel Products Company, furnished cement and air-entraining admix for tests. S. L. Meyers, chief chemist, Southwestern Portland Cement Company, contributed test data and material. Richard Walters of Albuquerque contributed pictures and data of hydro-ponies. Walter Brauer, president, National Self-Shaded House Corporation, furnished illustrations and information on prefabricated construction. Information was contributed by William C. Wagner, head, Department of Civil Engineering, University of New Mexico; Walter K. Wagner, research engineer, New Mexico State Highway Department; Raymond E. Davis, professor Civil Engineering, University of California, and W. T. Neelands, construction engineer, Barker Dam, Boulder, Colorado.

Appreciation is also extended to T. D. Benjovsky, chief of the Mining Division, T. C. Crawford, spectrographer, and E. L. Murusky, office engineer, New Mexico Bureau of Mines and Mineral Resources, for valuable assistance in laboratory work.

HISTORY OF PUMICE AS CONCRETE AGGREGATE

Pumice was used in Rome over 2,000 years ago in the construction of the great dome of the Pantheon, the immense vaults of the public baths, and other notable structures. The matrix or cementitious material employed was composed basically of pumicite. Pumice as a concrete aggregate has been used in Germany since about 1850, and still holds a principal position in the building industry there. From New Zealand, Japan, and other countries where suitable pumice occurs in quantity, good reports have been received on its use for building purposes. However, little research work has been performed until recent years.

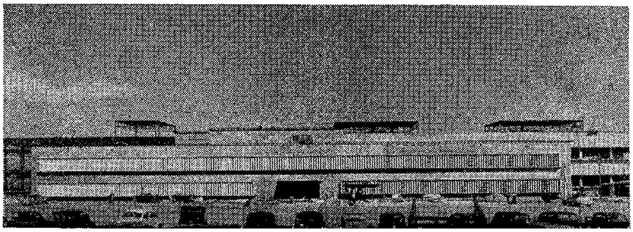
The information now available is conclusive enough to provide the architect and engineer with strength values in compression, flexure, tension, shear, bond, unit weight, thermal conductivity, coefficient of heat transmission, thermal coefficient of expansion, fire resistance, modulus of elasticity, sound absorption, and resistance to condensation. Paul R. Splane president, Paul R. Splane, Incorporated, Los Angeles, first collected a file



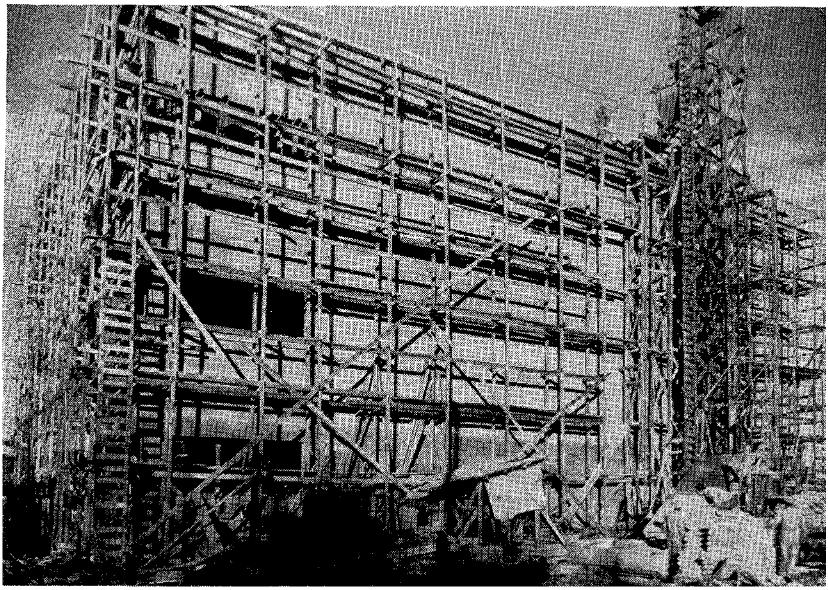
A. Rodding and bull-floating roof of the telephone building at Van Nuys, California.

B. Finishing roof of General Motors building at Van Nuys, California. Sheen is not due to wetness of mix, but to texture of pumice fines.

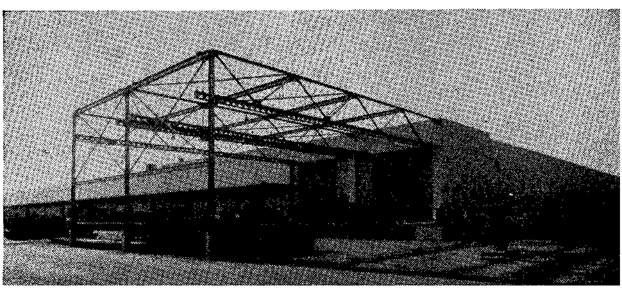
CONSTRUCTING ROOFS OF PUMICE CONCRETE



A. General Motors building at Van Nuys, California.

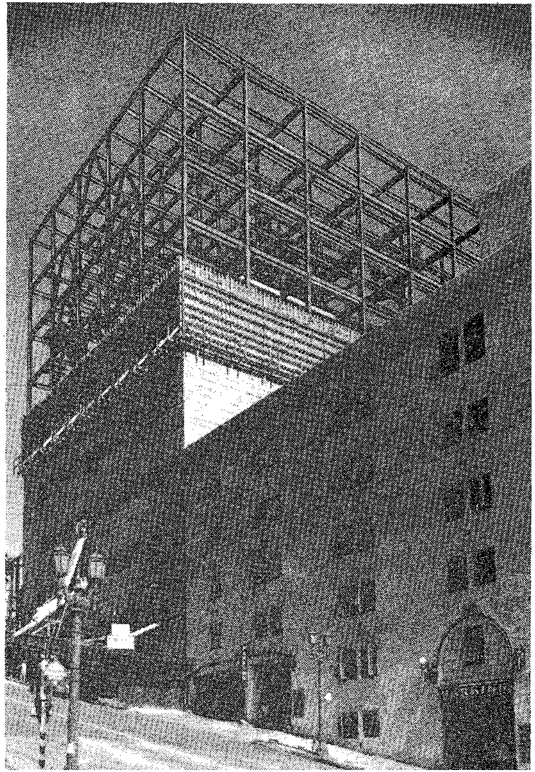


B. Telephone building at South Van Nuys, California.

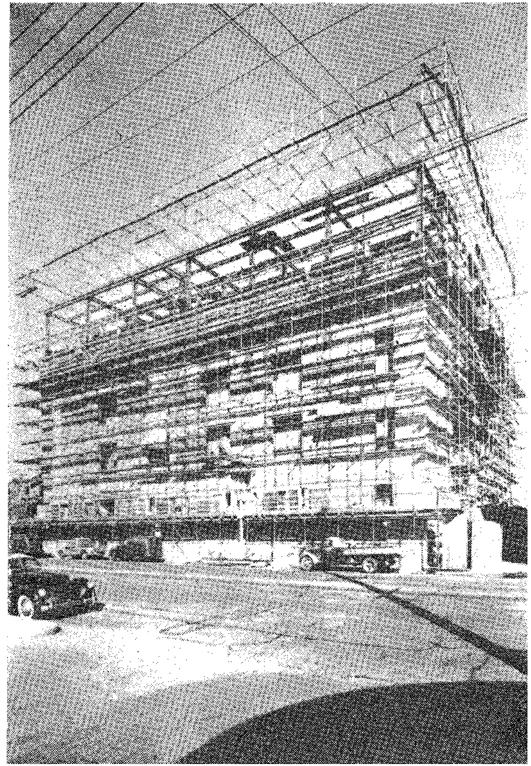


C. Clayton Manufacturing Company's air-conditioned factory at Rosemead, California.

MONOLITHIC STRUCTURES OF PUMICE CONCRETE

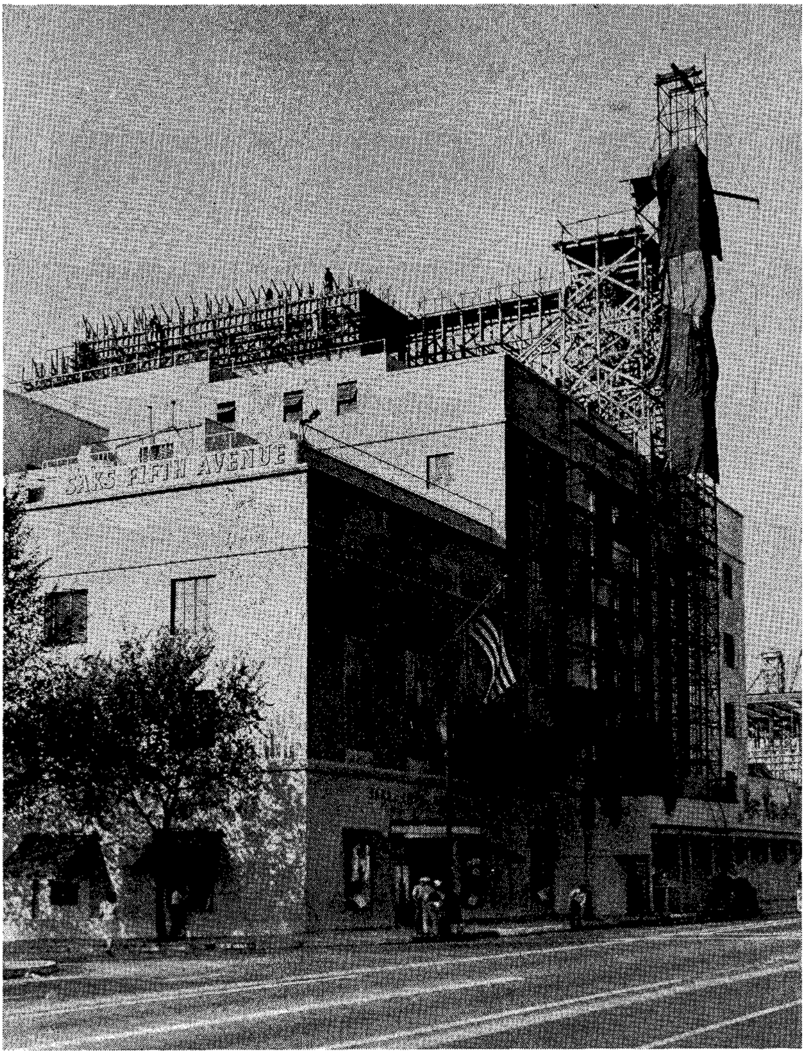


A. Telephone company's building at Fifth and Grand Avenue, built to maximum allowable height limit.



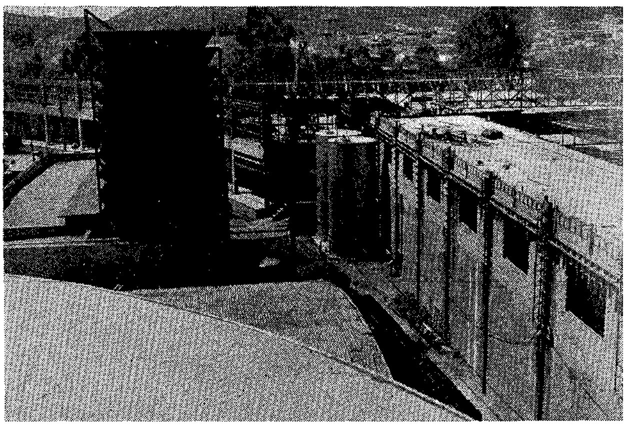
B. Telephone company's building at Wilshire and La Brea.

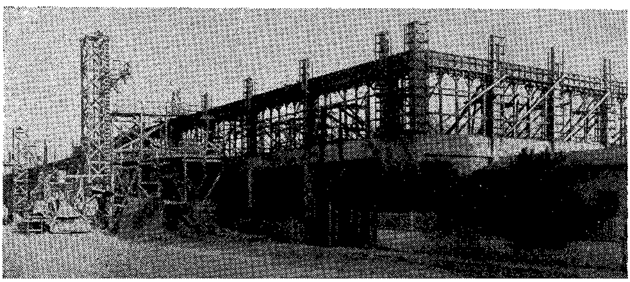
MONOLITHIC STRUCTURES OF PUMICE CONCRETE IN LOS ANGELES

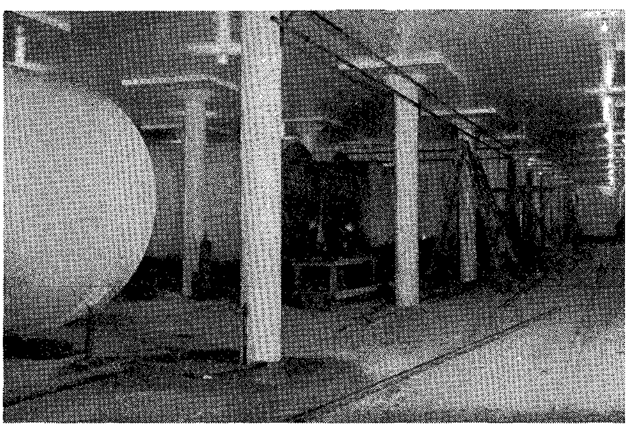


Store of Saks Fifth Avenue on Wilshire Boulevard, Los Angeles. A monolithic structure of pumice concrete. Photo shows store addition under construction. I. Magnin store in background.

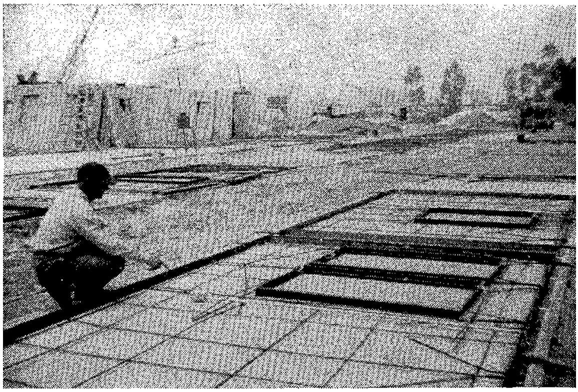
MONOLITHIC STRUCTURES OF PUMICE CONCRETE



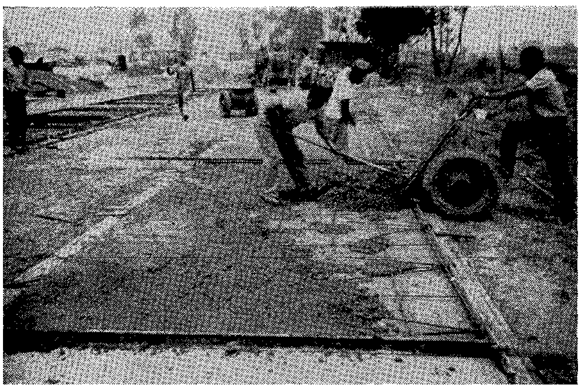




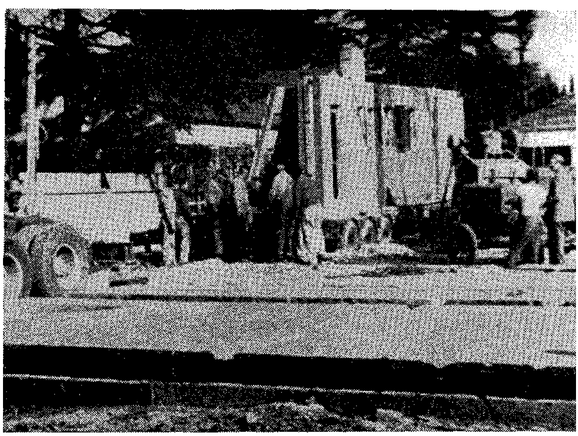
An example of pumice-concrete construction.
VIEWS OF THE TECATE BREWERY, TECATE,
MEXICO.



A. Wall forms laid on ground with steel reinforcements and electrical conduits in place.

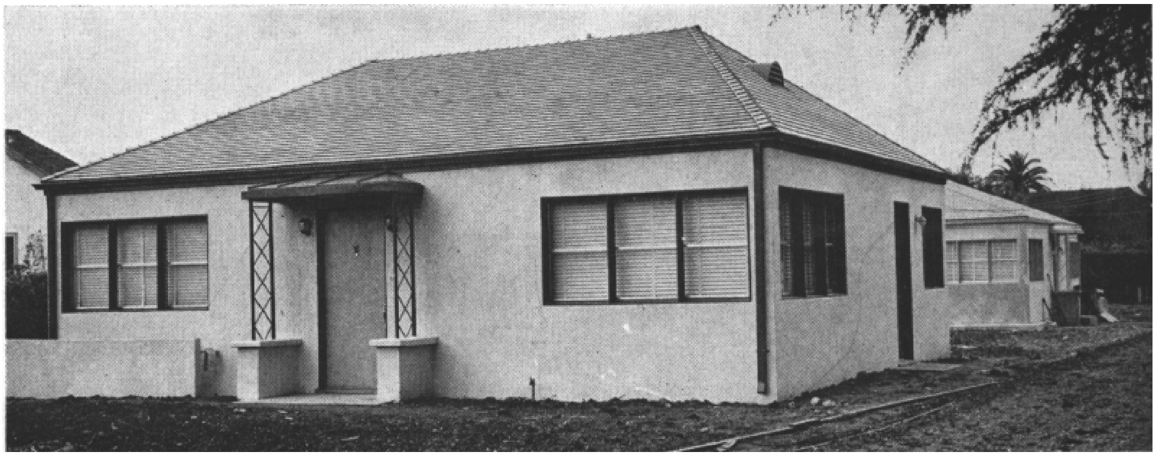


B. Pouring of wall forms.

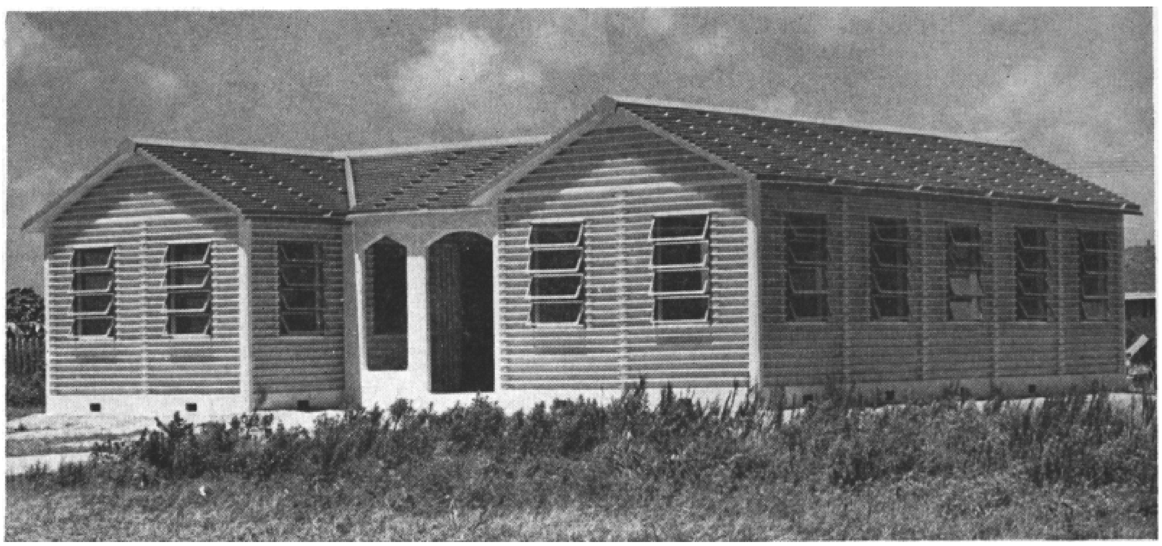


C. Erection of wall panels. Concrete foundation and floor in place (foreground).

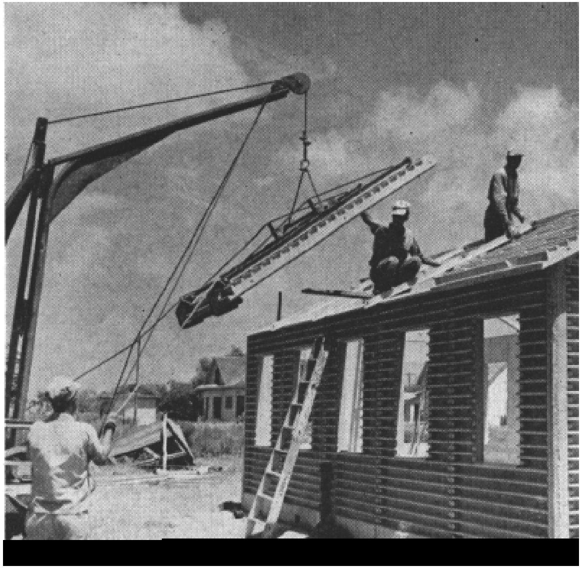
PREFABRICATED HOME CONSTRUCTION



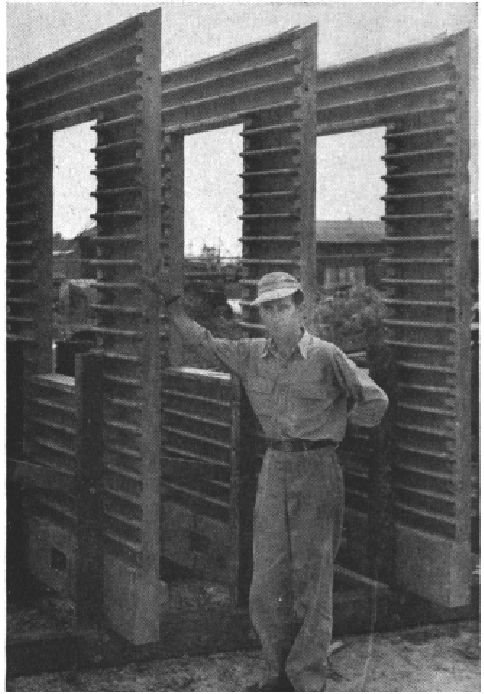
A. King Style home at Los Angeles.



B. Brauer self-shaded house at Rockport, Texas, built for test purposes. PREFABRICATED HOMES



A. Erection of test house at Rockport, Texas, showing roof panel being laid in place on steel roof truss.



B. Wall panels in curing racks.

CONSTRUCTION OF BRAUER SELF-SHADED
CONCRETE HOUSE

of research data on pumice as used in the building industry. As a result of his efforts, many large buildings of monolithic construction have been and are being erected in Los Angeles and vicinity, utilizing pumice as the total aggregate in the concrete. On the basis of Splane's data, the U. S. Navy accepted pumice for the construction of the $9,000,000 research laboratory and related structures at the Naval Ordnance Test Station, Inyokern, California.

The concrete products industry in California today provides a very large proportion of the building material used, and pumice aggregate is utilized extensively in concrete products. Although the use of pumice for building purposes in New Mexico is comparatively new, it is steadily increasing; and volume of shipment of pumice to other states has risen continually.

As with any building material that still re3ains the aspect of novelty, general acceptance is slow until the merits of the new material are conclusively proved. It is hoped that the information given here will help to establish the production of pumice as an industry that can well be one of the most important in New Mexico.

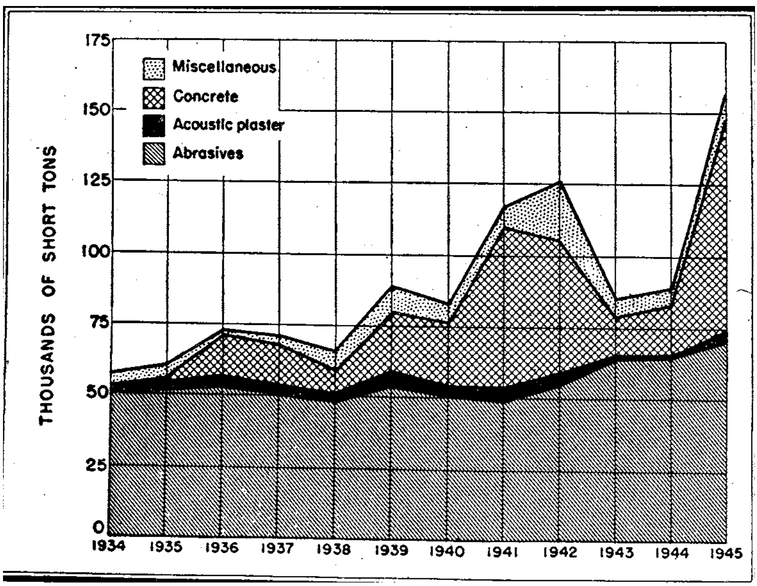


FIGURE 1.--Trends, by uses, of pumice and pumicite sold or used by producers in the United States, 1934-45. Concrete aggregate is included under Miscellaneous. (From Minerals Year Book 1945: U. S. Bur. Mines, p. 1368, 1947.)

PRESENT APPLICATIONS PUMICE AGGREGATE

MONOLITHIC PUMICE CONCRETE

The following data on the manufacture, transport, handling, and placing of pumice concrete are applicable to most types of lightweight concrete.

The coarse material should be presaturated. The minus No. 4 (sand size) absorbs water rapidly in the mixer and becomes sufficiently saturated without undue delay. One-half to two-thirds of the total water required should be charged before cement is introduced into the mixer. Usually an elapsed mixing time of one minute allows sufficient absorption of the water to eliminate excessive slump loss.

A 2-inch slump in pumice concrete is equivalent to one of 3½ to 4 inches in ordinary concrete. The appearance of wet pumice concrete of this consistency is misleading, as when a 2-inch slump is attained the aspect is that of an overly dry consistency, yet the placeability is comparable in speed and compaction to the higher slump in ordinary concrete. Over-wetting pumice concrete must be avoided because of the segregation that would take place. Shrinkage cracks may occur in pumice if it is placed in an excessively wet condition, but this is also true of plain concrete.

When a standard design of the minus No. 4 to pan (sand size) is used, it should be redesigned in reference to percentage of each size by volume rather than by weight. Common sand does not normally vary in bulk specific gravity more than 0.04 in the range from minus No. 4 to pan, inclusive. It is a characteristic of pumice sand that the bulk specific gravity becomes proportionately higher as the individual particle sizes diminish. If the recommended percentage by weight were accepted, a deficiency in the fines (Nos. 28, 48, and 100 size range) would result.

Plates 2, 3, and 4 show some of the monolithic structures that displayed a substantial net saving by allowing lighter foundation design, reduction of structural and reinforcing steel, greater span between form studs, and greater speed. in handling and placing, as well as automatically furnishing insulation against heat, cold, sound, and shock. The ready acceptance of pumice concrete is reflected by its application in the various buildings that have been completed over the past few years.

PREFABRICATED HOME CONSTRUCTION

The normal required thickness for prefabricated constructed is 4 inches. In pumice concrete the structural strength is easily attained and the high efficiency of insulation eliminates the necessity for a double wall and for furring and lath. The finish or texture of the panels makes plastering unnecessary if good care is exercised in finishing and handling.

As electrical conduits and receptacles are installed before the pouring is begun, a marked saving in labor costs is gained when the panels are installed. When the foundations are poured, a groove or key is made by using 2- by 4-inch lumber strips with the tops to grade of the foundation. Before installing the panel sections, the grooves are grouted with a recommended neat-cement grout mix or with an accepted mastic sealer.

Several large home-building projects are now under way in California. E. S. McKittrick Company is installing 110 pumice-concrete houses at the Naval Base in Inyokern, to be constructed by either the Normac or LeTourneau system. Thirty-seven houses have just been completed in Trona for the American Potash and Chemical Company, and 100 more units at Muroc are to be produced for the U. S. Army. J. E. Haddock, Ltd. is building 48 housing, units of approximately 1,200 square feet each at Pomona, employing the Kettell system of pouring a concrete floor slab, erecting collapsible plywood forms, and pouring the pumice-concrete wall monolithically. Conventional roofs will be used for the first units, but pumice-concrete roof slabs are being designed. An additional 200-unit project is to be constructed in the Pomona-Chino district within the immediate future. Plate 6 displays the manner and method used by the King Style Corporation. Precast pumice-concrete slabs are being fabricated in Puente, California, and transported to job sites within a radius of 250 miles.

A prefabricating method that produces the "Brauer self-shaded lightweight concrete house" shows promise of adaptability to the use of pumice concrete. This system of construction (Plate 8) involves the production and erection of portable precast reinforced lightweight concrete slabs or panels. These panels are poured at a central location in special sheet-metal forms. They are removed from the forms 18 to 22 hours after pouring and are placed in vertical curing racks for a 5- to 7-day curing period. All work is performed on a specially designed production system of different sizes to meet construction demand.

To produce the important "self-shaded" feature, all exterior panels have fins or ribs cast on their outer surfaces, which extend approximately 3½ inches from the wall and are 4 inches apart (Plate 8B). These fins shade the walls and roof of the house from the direct rays of the sun and, since they are thinner than the back wall, they tend to dissipate the heat received into the shaded space beneath each fin. Tests show that a 10- to 14-degree temperature difference from outside to inside wall is produced. For use in cooler climates the panels may be reversed, with the fins or ribs inside to be lathed and plastered. The units are adaptable to a variation of house designs.

CONCRETE PRODUCTS

MASONRY BLOCKS

The manufacture of masonry building blocks has increased rapidly in recent years. The greatest use for lightweight aggregate is in this field. Many large cities stipulate a specific maximum allowable weight of block per mason beyond this weight two masons are required to lay the units. Pumice masonry blocks have a weight far below the lowest maximum allowable and permit a fast, labor-saving laying schedule.

Many plants in Colorado, Texas, Oklahoma, Kansas, Nebraska, Missouri, and Iowa are receiving a steadily growing volume of pumice aggregate from New Mexico producers. The present needs, representing the normal production of the larger plants within this area, exceed 3,400 cubic yards per day. The aggregate requirements of the smaller producers in this same area equal this figure. The manufacturers in New Mexico are also using pumice extensively for masonry blocks.

In California pumice-concrete masonry blocks have been manufactured and used for the past 18 years. The world's largest building-block manufacturing plant is owned and operated by Wailes-Bageman, Incorporated, Los Angeles, with a present normal daily production of 45,000 pumice-concrete blocks, size 8 by 8 by 16 inches. Careful planning and design of the plant made this production possible. An illustrated description of this out-standing plant appeared recently.[3] The Pumice Manufacturing Company, Incorporated, Albuquerque, New Mexico, equipped with a fully automatic Noble batching plant and block-manufacturing equipment; is rapidly developing into one of the largest producers of pumice-concrete products in New Mexico.

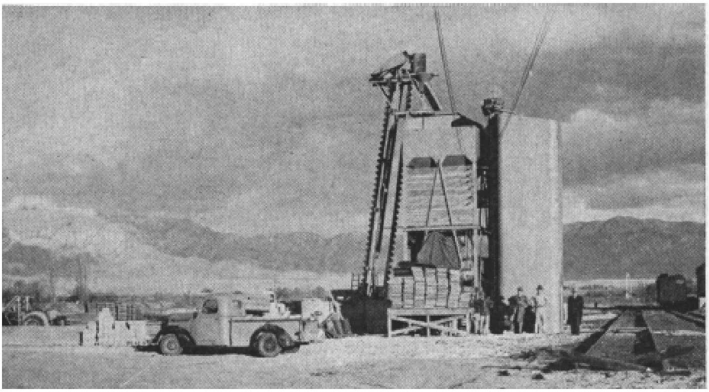
SHINGLES AND ROOF TILE

Although the use of pumice concrete for shingles and roof tile is comparatively new, the available supply of these products is far below the demand. This demand is expected to increase.

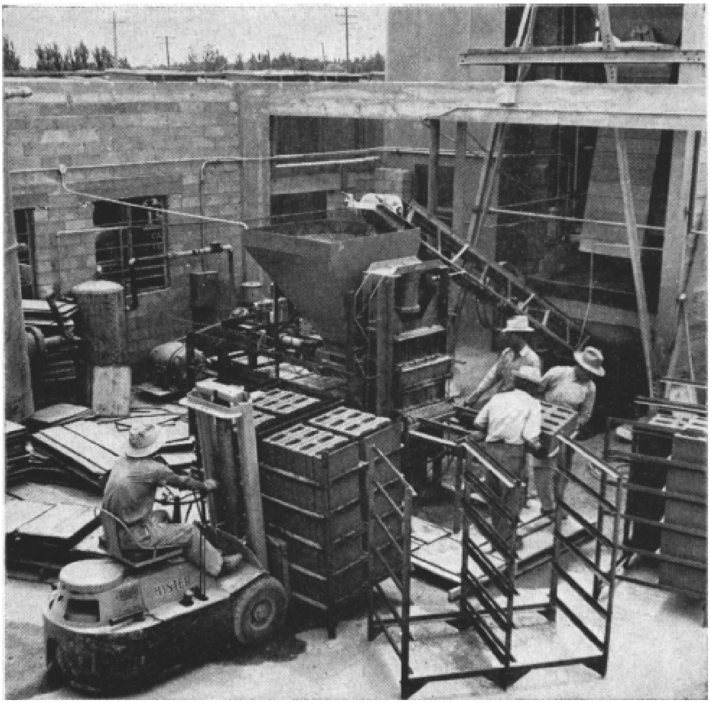
The Macatee Corporation, Dallas, Texas, which is one of the largest suppliers of roofing materials in that state, is installing large roof-tile manufacturing plants in Dallas and Houston. These plants are designed to supply all the needs for this field in Texas.

A new machine, designed to produce a precast panel, is soon to be on the market. The precast panel will aid in the speedy and economical erection of homes. It may be used to construct load-bearing and partition walls, ceilings and roofs in flat-roof

[3] Rock Products, vol. 50, no. 2, pp. 147-149. February 1947.



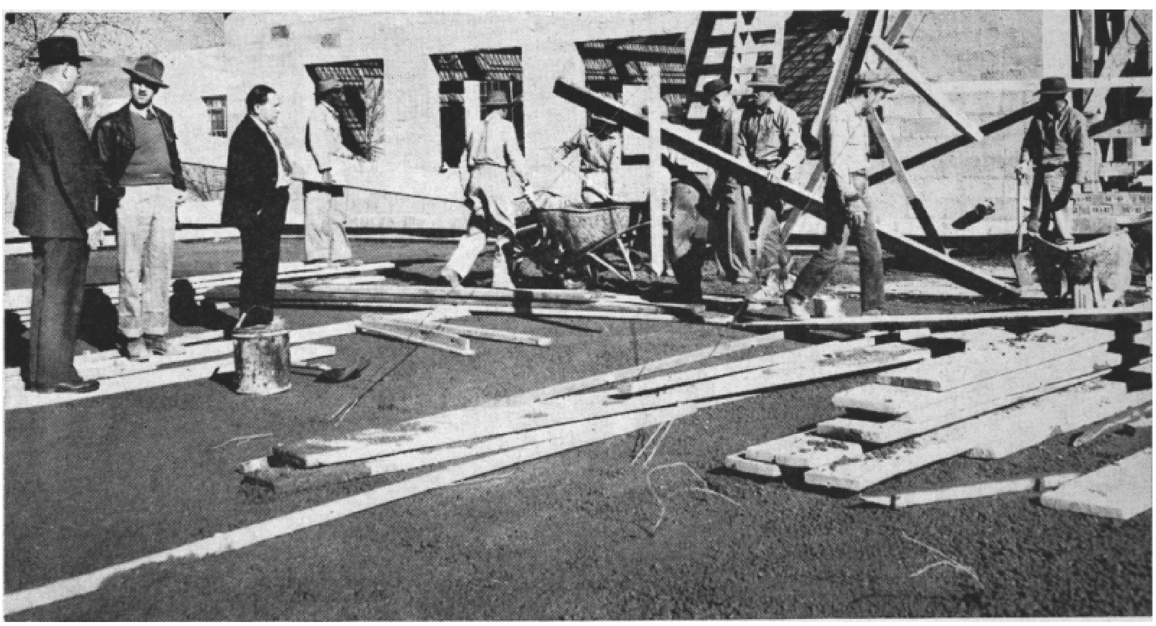
A. General view.



B. Manufacture of blocks.

PLANT OF PUMICE MANUFACTURING COMPANY,
ALBUQUERQUE, NEW MEXICO

A. Under construction.



B. Pouring pumice-concrete roof.

CHEMICAL ENGINEERING BUILDING, UNIVERSITY OF NEW MEXICO, ALBUQUERQUE construction, precast floors, and shingles, all in a combination of patterns or designs. The panel is of rib construction, 18 by 24 inches, with a modular of 9 inches vertically and 12 inches horizontally. The principal feature that makes this product possible is the extreme light weight of pumice concrete.

ACOUSTIC PANELS

By tests recently completed on the trowelled face of a pumice-concrete specimen, the average coefficient of sound absorption was found to be 66.1 percent, with sound frequency ranging from 116 to 2,400 cycles per second. The sound absorption efficiency is 83.9 percent for normal office noises. Consequently, a precast acoustic panel, composed of pumice aggregate graded at 40 percent minus No. 4 to No. 8, 35 percent minus No. 8 to No. 16, and 25 percent Minus No. 16 to No. 28, will provide a sound-absorption coefficient approaching 100 percent.

OTHER PRECAST CONCRETE PRODUCTS

The extreme light weight of pumice, and its insulating ability, are distinct advantages in roof construction. The flexibility of pumice concrete offers a factor for comfort in its application to floors.

To reduce the cost of handling and placing precast joists, sills, and lintels, light weight is of major importance. Flexural and tensile strengths of pumice concrete are sufficiently high to allow for most live-load requirements. For standard-size openings in home construction, one man can install with comparative ease a pumice-concrete sill or lintel of conventional design.

APPLIED FINISHES

ACOUSTIC PLASTER

At little additional cost, acoustic pumice plaster is being applied in studios, churches, theaters, and other buildings that require a high degree of sound absorption. The recommended grading is the same as that for acoustic panels.

STUCCO

Stucco plaster of pumice is beneficial to' increase the insulation value. Applied on existing frame buildings, it has the additional function of being an excellent protection against fire loss. The recommended grading is the same as indicated on page 19 (Figure 5C) for minus No. 4 aggregate.

INTERIOR PLASTER

Pumice plaster for interior finishes provides any desired texture, depending on the designed gradation. Pumice plaster is popularly used in California on all types of construction. The effect of using pumice concrete is discussed below.

MASON MORTAR

Pumice mortar is used in the same manner as ordinary sand mortar, proportioned according to A.S.T.M. Designation: C 161-44 T,[4] except that 2.75 parts pumice sand is recommended in order to meet strength requirements. The particle distribution should conform to A.S.T.M. Designation: C 144-44.[5] Pumice mortar provides the same insulation as the pumice masonry blocks; furthermore, the thermal coefficient of expansion of pumice mortar balances that of the masonry block, resulting in uniform expansion and contraction. The volume change in ordinary sand mortar tends to destroy the bond between mortar and block, causing unnecessary separation and resulting in a series of seams that admit water.

THE ECONOMICS OF PUMICE CONCRETE

LIGHT WEIGHT

With comparative costs considered, the lighter the concrete used to obtain the required strength, the greater the economy realized. In large structures, the higher initial cost of pumice concrete is more than overcome by the allowable reduction in steel reinforcing. For example, in the construction of the Southern California Telephone and Telegraph building in Los Angeles, by redesign to pumice concrete a saving of over 300 tons of reinforcing and structural steel was attained.

A saving may begin with a lighter foundation design, in which fewer and/or lighter pilings are required. Assume, for example, that a structure will total 30,000,000 pounds dead load using steel-frame and reinforced-concrete construction, 150 pounds per cubic foot being the normal weight of ordinary concrete. By comparison, pumice concrete meeting strength specifications for steel-frame construction weighs from 64 to 70 pounds per cubic foot, Because of the light weight of the pumice and the proportionate reduction in steel, the total dead load is reduced to less than 15,000,000 pounds.

Speed of handling and placing is indicated by a simple comparison. If one man can load and deliver to the point of placement half the cubic capacity of a two-wheel buggy of ordinary concrete, which is usually a load limit for one man, then a full load of pumice concrete can be handled with the same effort.

The weight comparison of pumice with other materials is shown in Figure 2.

[4] A.S.T.M. Standards, Am. Soc. for Testing Materials, pp. 1256-59, 1944.

[5] Idem, pp. 232-33.

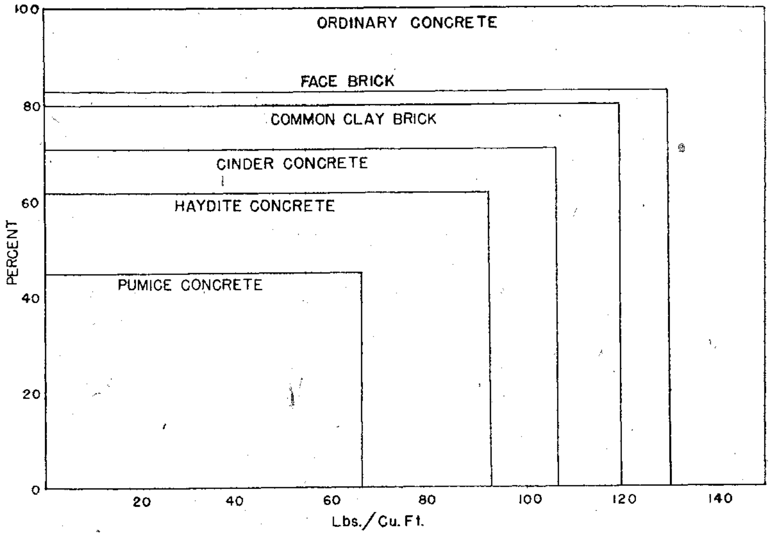


FIGURE 2.-Weight comparison of various materials, based on compressive strengths of 2,000 p.s.i.

INSULATION AGAINST HEAT AND COLD

As shown in Figure 3, pumice concrete provides by far the highest efficiency against loss of heat or cold. This means a substantial saving, as further insulation is unnecessary except for refrigeration or furnace insulation.

Pumice-concrete precooling units installed at Tolleson, Arizona, for precooling of cantaloupes proved to be entirely satisfactory, from the standpoints both of insulation and of low cost of construction. Although these coolers were operated in my under the Arizona sun at temperatures ranging from 120° to 127° F., the interior temperature was retained a approximately 20° F. The refrigeration losses compared favorably wit those of other types of insulation that had been used. The exterior showed no sweating.

Reinforced pumice concrete was used in the construction of a large refrigerated portion of the Tecate brewery, Tecate, Mexico (Plate 5). No applied insulation was necessary in spite of extremely high outside temperatures. Pumice concrete is now being specified for new construction.

The following table gives a comparison study of the heat insulation properties of various widely used .building materials (see also Figure 3).

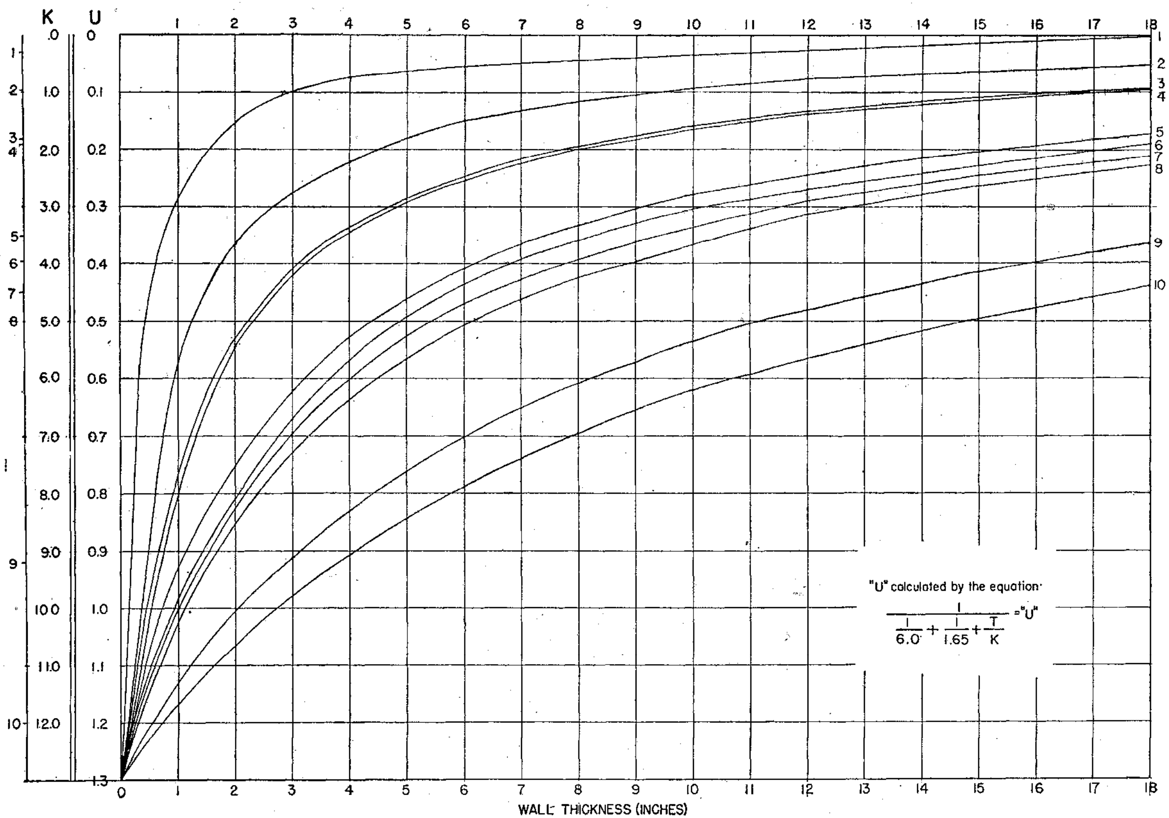


FIGURE 3.-Thermal insulation efficiency of pumice concrete as compared with that of various other materials (see Table 1). U factor or overall coefficient of heat transmission is expressed in B.t.u./hr./ sq. ft./degrees F. difference in temperature between the air on the two sides of the walls as per thickness indicated, based on an outside wall wind exposure of 15 miles/ hr. Refer to Table 1 for numbers.

K factor or thermal conductivity is expressed as B.t.u./hr./sq. ft./inch thickness/degrees F.

TABLE 1. HEAT CONDUCTIVITY OF BUILDING MATERIALS

	Substance	Density (Ms. per cu. ft.)	K factor [a]
1.	Corkboard - Celotex - Masonite	10 to 13	0.33
2.	**Pumice** insulating roof and floor fill	35	0.98
3.	Haydite insulating roof and floor fill	55 to 70	1.82
4.	**Pumice** structural concrete	61 to 74	1.86
5.	Adobe brick	100 to 120	3.57
6.	Haydite structural concrete	89 to 96	3.98
7.	Cinder concrete	100 to 114	4.50
8.	Common clay brick	120	5.00
9.	Face brick	125	9.20
10.	Ordinary concrete	145 to 150	12.00

[a] K factor of thermal conductivity is expressed as B.t.u./hr./sq. ft./inch thickness/ degree F.

SOUND ABSORPTION

The cost of materials that provide desirable sound absorption commonly represents an additional expenditure over and above ordinary construction. It is noteworthy, therefore, that pumice concrete usually meets most requirements without additional expense. The values given in Figure 4 show the sound absorption offered by pumice concrete as compared to other materials.

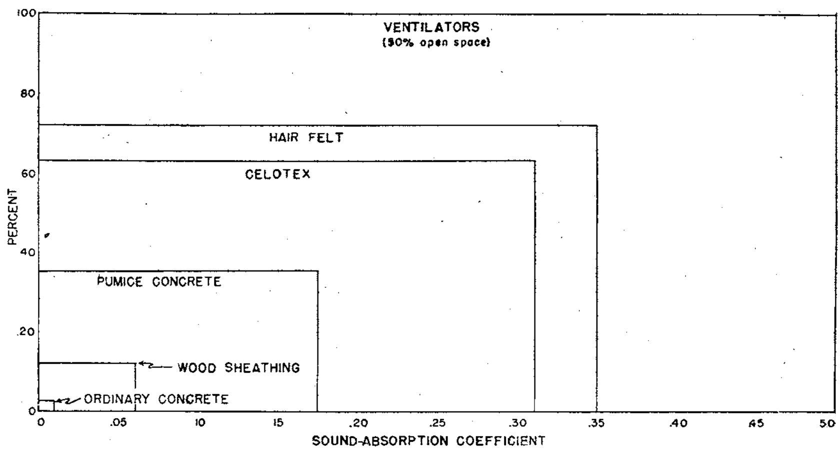


FIGURE 4.-Sound-absorption of pumice concrete compared with that of various other materials.

LACK OF CONDENSATION

Condensation is prevalent with heavy, dense material that presents a high thermal conductivity. Good insulation assures warm, dry inside walls, and leaves no opportunity for precipitation of moisture within the structure. Owing to the high insulating value of properly designed pumice concrete, condensation by ordinary variations in temperature, cannot occur.

FIRE RESISTANCE

The average fusion point of pumice is 2,450° F. If a fire occurs in a building constructed of pumice concrete, the loss is limited to interior finish and other inflammable materials. Because no volume change or expansion occurs in pumice until the temperature reaches 1,400° F (at which point the extreme outer fibers contract or shrink), no spalling or other damage takes place, inasmuch as the recorded peaks of heat generated in the average fire ranger from 900° to 1,200°F. After application of acetylene-torch heat to a pumice block (Plate 11A), no spalling occurred and it required 12 minutes of direct heating before the inside wall of the block showed a change in temperature.

Plate 11B is a photograph of a prefabricated pumice-concrete home during a fire test performed in Los Angeles. This test was supervised by the city engineering and inspection departments, and performed by the city fire department. Two 55-gallon drums of gasoline were poured on a layer of sand which was spread over the pumice-concrete floor. The gasoline was then ignited. When it became safe enough to do so, a like amount of gasoline was again distributed over the floor to repeat the operation. When the heat was estimated to be at the highest point, two firemen played fire hoses on the interior walls, with water pressure comparable to normal fire-fighting pressures. Inspection of this house on the, following day showed that the pumice walls had not been damaged to reduce their structural safety and permanency.

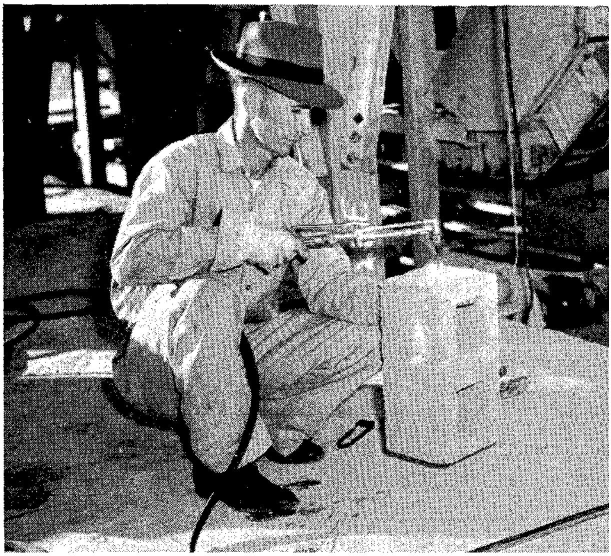
SHOCK RESISTANCE

The modulus of elasticity of ordinary concrete ranges from 3,000,000 to 7,000,000. In comparison, pumice concrete, with ultimate 28-day compressive strengths at 2,000 p.s.i., has a modulus of elasticity of 680,000 to 750,000, which is expressive of approximately six times the flexibility of ordinary concrete. Pumice concrete is thus much more resistant to earthquake shock, owing to its flexibility and to its lower inertia because of lighter weight.

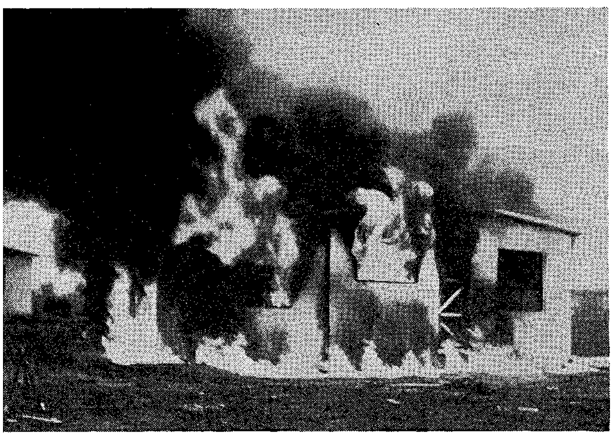
In the manufacturing of concrete products, the light weight and greater flexibility of pumice reduces to a minimum the breakage loss incurred in handling, thus allowing a further saving.

STRENGTH

Desirable strengths depend, first, on the quality and soundness of the pumice aggregate. Impurities, such as silt and organic and alkali matter will greatly impair the ultimate strength. Careful selection of stripping and excavating equipment will produce



A. Torch subjects pumice-concrete block to heat of approximately 1,600° F.



B. Fire test on pumice-concrete house. (See text description.)

RESISTANCE TO FIRE

pumice of high quality (see page 38) After clean, sound pumice is obtained, it must be properly graded and sized. As with all other concrete aggregate, careful. preparation produces the most economical and strongest concrete workability and placeability to attain the desired ease and efficiency of compaction reflect directly upon the particle distribution In the concrete.

TESTING PROCEDURE

SELECTION OF AGGREGATE

Representative samples were taken from the E. G. Cullum deposit, T. 20 N., R. 7 E., Santa Fe County, New Mexico. This deposit, which lies in the northeastern approaches to the Jemez Mountains, is representative of the more desirable pumice available. The pumice lacks bedding planes and has an angular scoriaceous surface. It shows no indication of having been transported by water, but appears to be an eruptive deposit. All the remaining discussions in this report refer to this New Mexico pumice.

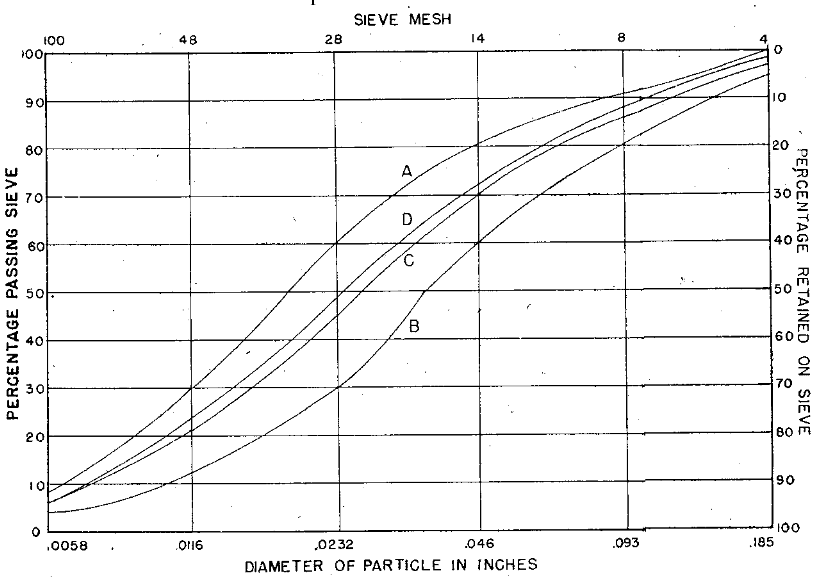


FIGURE 5.-Particle distribution of fine concrete aggregate.

A. Minimum grading limits.
B. Recommended maximum grading limits.
C. Recommended mean grading requirements.
   (As recommended by U. S. Bureau of Reclamation)
D. Mean recommended grading requirements as adapted to pumice aggregate.

PARTICLE DISTRIBUTION

Twelve to 15 percent of the pit-run material passed a No 8 screen, and contained about 35 percent combined quartz and feldspar crystal fragments. This portion was rejected, as it provided very little strength and increased the unit weight by about 150 pounds per cubic yard. Due to the progressively higher specific gravities of pumice sand, as the sizes diminish, the recommended[6] grading for ordinary aggregate required some adjustment. This adjustment was accomplished by use of bulk specific gravities of the individual size particles to obtain a volumetric sizing consistent with the recommended grading for ordinary aggregate. Figure 5 shows the adaptation of recommended sand size to pumice sand. If this peculiarity of pumice is overlooked, a deficiency of fines (minus No. 28 to pan) results.

DETERMINATIONS OF PHYSICAL PROPERTIES

The test procedure to determine specific gravities and absorption is given in Table 2. This, method was used because in the manufacture of pumice concrete excellent control is maintained by weigh-batching on the bone-dry basis and adding the weight in moisture determined by simple test.

TABLE 2. BULK SPECIFIC GRAVITIES AND ABSORPTION

		Coarse pumice	Fine pumice
(A)	Weight of bone-dry sample	312.00 grams	275.00 grams
(B)	Weight of saturated surface-dry sample	478.50 grams	400.00 grams
(P)	Weight of pycnometer[a] and water	1,508.00 grams	1,508.00 grams
(P_s)	Weight of pycnometer and sample	1,607.00 grams	1,642.50 grams
(G_b)	Bulk specific gravity[b]	0.82	1.04
(W)	Total percent absorption[c]	53.30	45.50
	Bone-dry unit weights of blended aggregate	28.72 lbs./ft.^{3}	40.51 lbs./ft.^{3}

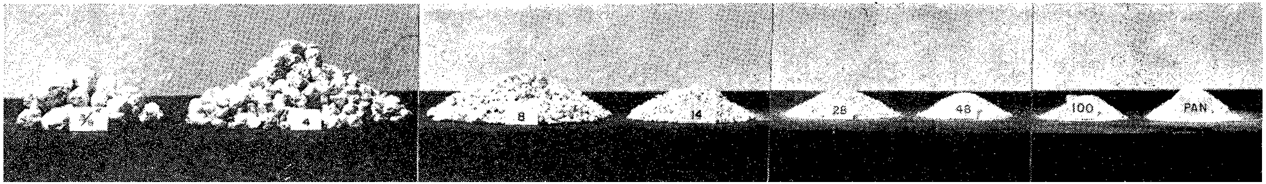
[a] Pycnometer as used by the American Association of State Highway Officials, Method T-15.

[b] Determined by the equation $G_b = \frac{A}{B + (P - P_s)}$

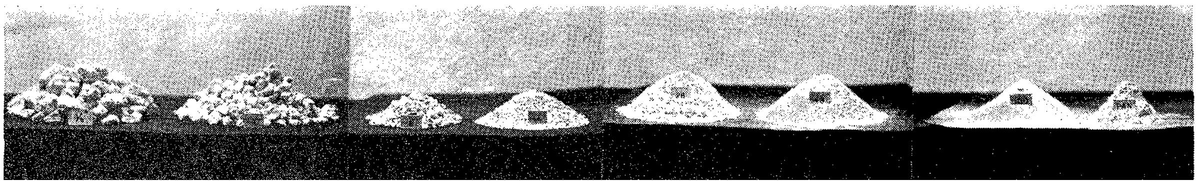
[c] Determined by the equation $W = \frac{B - A}{A}$

The samples were boiled one hour to accelerate complete absorption, then cooled to room temperature before surface drying. The unit weights taken were filled in a unit-weight container in three lifts and each jigged 50 times to simulate normal complete loose compaction, in accordance with A.S.T.M. Designation: C - 29 - 42, paragraph 6.

[6] U. S. Bureau of Reclamation, Concrete Manual, 4th edition, p. 67, 1942.



A. Distribution in pit-run pumice from near Espanola, New Mexico.



B. Recommended distribution, in a properly designed aggregate. Contrast amounts in sizes 8, 14, 28, and 48 with photo above.

PARTICLE DISTRIBUTION

The greatest accuracy in reaching a true saturated surface-dry condition on fine pumice was made by the use of a black steel spatula, which was passed through the sample at intervals until moisture or free water ceased to collect on the blade. This method was used successfully during the concrete ship-building program in which Haydite aggregate was used. The specific gravities fluctuated in this considerably, necessitating close control of mix designs the above method for accurate testing evolved from this necessity for control.

CEMENT

The cement used for the tests, produced by the Southwestern Portland Cement Company, was a Type I cement complying with Federal Specification SS - C - 192. Its analysis and properties are shown in Table 3.

TABLE 3. ANALYSIS AND PROPERTIES OF TYPE I CEMENT

Insoluble residue	0.13 percent
Silica (SiO_2)	21.38 percent
Alumina (Al_2O_3)	5.16 percent
Iron oxide (Fe_2O_3)	2.87 percent
Calcium oxide (CaO)	64.60 percent
Magnesia (MgO)	2.09 percent
Sulphur trioxide (SO_3)	2.03 percent
Loss on ignition	1.09 percent
Autoclave expansion	0.03 percent
Specific surface	1,940 cm/gm
Initial set	2:55
Final	6:10
Three-day compressive strengths	2,150 p.s i.
Seven-day compressive strengths	3,300 p.s.i.

CONCRETE MIX-DESIGN PROCEDURE

A range of batches was selected using various cement quantities per cubic yard. The concrete mix-design procedure was as follows.

1. The cement content in pounds was converted to cubic feet by absolute volume.

Example: 5.5 sacks = 517 lbs. ÷ 196.65 lbs./cubic foot (sp. gr. = 3.15) = 2.632 cubic feet.

2. The water-cement ratio was selected, as a constant for all batches at 0.40.

Example: 517 lbs. x 0.40 = 206.8 lbs. water;
206.8 lbs. ÷ 62.4 lbs./cubic foot = 3.322 cubic feet.

3. The sum of cement 2.632 + water 3.322 = 5.954 cubic feet.

4. 27.00 - 5.954 = 21.046 cubic feet.
5. (48 percent fine aggregate x 21.046 cubic, feet) ÷ 100 = 10.11 cubic feet. 21.046 - 10.11 = 10.936 cubic feet or 52 percent coarse aggregate.

The relation between actual scale weights and actual unit-weight results, in the steps or operations outlined in Tables 4 to 8 provide desirable accurate information on the true net water-cement ratio, cement content, and actual yield. This formula is applicable and practical for use o lightweight concrete, and was used successfully in the construction of concrete ships in World War II by the U. S. Maritime Commission.

Tables 9 to 13, showing final mix design, corrected to even cement quantity and one-cubic-yard yield, include the correct quantities of all ingredients required for one cubic yard of plastic, workable pumice concrete. Also incorporated in these tables are the proportioning and particle distribution, and the individual and combined Fineness Moduli. (See also Figure 6.)

MIXING PROCEDURE

It was found that adding two-thirds of the total water required to the aggregate before the cement was introduced allowed for rapid absorption. The elapsed time of about 1½ minutes eliminated the excessive slump loss, which otherwise would result. The remainder of the water was introduced with the cement. Of equal importance is the elimination of loss of the cement matrix by absorption, into the minute pores of the aggregate if cement is added before sufficient absorption takes place. The resultant reduction in the amount of cement paste would render a harsh mix which would be difficult to handle and place, as well as causing appreciable reduction in ultimate strength. The mixing time for all batches was 4 minutes. The slump or consistency was controlled as a constant for all batches. The proportioning of minus No. 4 to pan, to ¾-inch to No. 4, was selected in order to balance uniformly the plasticity and workability. From observation and handling, all batches were relatively uniform, with the exception of Mix No. 4 PAE, in which air entrainment was included. This mix displayed a decided increase in workability and ease of placement, although the minus No. 48 was entirely removed and the water-cement ratio was lower.

CURING PROCEDURE

The. specimens were stripped 24 hours after casting, and were stored in water-soaked excelsior-padded boxes to retain a constant moist condition until actual test. To gain best results, pumice concrete should be water-cured for at
(Continued on page 34)

TABLE 4. COMPUTATIONS FOR WATER-CEMENT RATIO AND CEMENT CONTENT

			Admix	Coarse	Fine	Cement	Water	TOTAL
a.	Mix No. 1PN*	Batched weights	None	574.90	658.60	517.00	620.00	2,370.50
b.	As tested	Gross percent moisture		2.30	1.80			
c.	$b\left(\frac{a}{100+b}\right)$	Gross pounds moisture		12.90	11.60			
d.	$a-c$	Bone-dry weights		562.00	647.00	517.00	620.00	
e.	As tested **	Bulk specific gravity		0.82	1.04	3.15	1.00	
f.	62.38*e*	Factor		51.15	64.87	196.65	62.38	
g.	$\frac{d}{f}$	Cubic feet		10.99	9.97	2.63	9.96	33.55
h.	As tested	Percent absorption complete		53.30	45.50			
i.	*dh*	Pounds absorption		299.55	294.39			593.94
j.	Total of *g*	Yield if no absorption took place						33.55
k.	$\frac{\text{Total of } a}{j}$	Unit weight if no absorption took place						70.66
l.	$d-i$	Net pounds water with complete absorption						26.06
m.	$\frac{l}{62.38}$	Cubic feet water with complete absorption						0.42
n.	$j-(g\dagger-m)$	Cubic feet concrete with complete absorption						24.01
o.	$\frac{\text{Total of } a}{n}$	Unit weight concrete with complete absorption						98.73
p.	As tested	Actual unit weight concrete						78.60
q.	1.04*p*	Unit weight solid volume (assuming 4 percent air voids)						81.74
r.	$\frac{q-k}{o-k}$	Percent actual complete absorption in batch						39.47
s.	*ri*	Pounds water absorbed in batch						234.44
t.	$\frac{s}{62.38}$	Cubic feet water absorbed in batch						3.76
u.	$d-s$	Pounds net water in batch						385.56
v.	$\frac{u}{\text{cement}}$	Net water-cement ratio, W/c						0.73
w.	$j-t$	Cubic feet yield by specific gravity						29.79
y.	$\frac{\text{Total of } a}{p}$	Cubic feet yield by unit weight						30.16
z.	$\frac{\text{(Designed sacks per cubic yard) } 27}{y}$	Cement content						4.92

* See final mix design, Table 9.
** See procedure on page 20.
†Cubic feet water,

TABLE 5. COMPUTATIONS FOR WATER-CEMENT RATIO AND CEMENT CONTENT

			Admix	Coarse	Fine	Cement	Water	TOTAL
a.	Mix No. 2PN*	Batched weights	None	567.77	606.73	611.00	636.50	2,422.00
b.	As tested	Gross percent moisture		2.30	1.80			
c.	$b\left(\frac{a}{100+b}\right)$	Gross pounds moisture		12.77	10.73			
d.	$a-c$	Bone-dry weights		555.00	596.00	611.00	636.50	
e.	As tested **	Bulk specific gravity		0.82	1.04	3.15	1.00	
f.	$62.38e$	Factor		51.15	64.87	196.65	62.38	
g.	$\frac{d}{f}$	Cubic feet		10.85	9.19	3.11	9.94	33.09
h.	As tested	Percent absorption complete		53.30	45.50			
i.	dh	Pounds absorption		295.14	271.18			566.32
j.	Total of g	Yield if no absorption took place						33.09
k.	$\frac{\text{Total of } a}{j}$	Unit weight if no absorption took place						73.19
l.	$d-i$	Net pounds water with complete absorption						70.18
m.	$\frac{l}{62.38}$	Cubic feet water with complete absorption						1.13
n.	$j-(g\dagger-m)$	Cubic feet concrete with complete absorption						24.28
o.	$\frac{\text{Total of } a}{n}$	Unit weight concrete with complete absorption						99.75
p.	As tested	Actual unit weight concrete						82.20
q.	$1.04p$	Unit weight solid volume (assuming 4 percent air voids)						85.49
r.	$\frac{q-k}{o-k}$	Percent actual complete absorption in batch						46.31
s.	ri	Pounds water absorbed in batch						262.26
t.	$\frac{s}{62.38}$	Cubic feet water absorbed in batch						4.20
u.	$d-s$	Pounds net water in batch						374.24
v.	$\frac{u}{\text{cement}}$	Net water-cement ratio, W/c						0.61
w.	$j-t$	Cubic feet yield by specific gravity						28.89
y.	$\frac{\text{Total of } a}{p}$	Cubic feet yield by unit weight						29.46
z.	$\frac{\text{(Designed sacks per cubic yard) } 27}{y}$	Cement content						5.96

* See final mix design, Table 10.

** See procedure on page 20.

†Cubic feet water.

TABLE 6. COMPUTATIONS FOR WATER-CEMENT RATIO AND CEMENT CONTENT

			Admix	Coarse	Fine	Cement	Water	TOTAL
a.	Mix No. 3PN*	Batched weights	None	553.44	546.67	705.00	599.00	2,404.11
b.	As tested	Gross percent moisture		2.30	1.80			
c.	$b\left(\frac{a}{100+b}\right)$	Gross pounds moisture		12.44	9.67			
d.	$a-c$	Bone-dry weights		541.00	537.00	705.00	599.00	2,382.00
e.	As tested **	Bulk specific gravity		0.82	1.04	3.15	1.00	
f.	62.38e	Factor		51.15	64.87	196.65	62.38	
g.	$\frac{d}{f}$	Cubic feet		10.58	8.28	3.59	9.60	32.05
h.	As tested	Percent absorption complete		53.30	45.50			
i.	dh	Pounds absorption		288.35	244.34			532.69
j.	Total of g	Yield if no absorption took place						32.05
k.	$\frac{\text{Total of } a}{j}$	Unit weight if no absorption took place						75.01
l.	$d-i$	Net pounds water with complete absorption						66.31
m.	$\frac{l}{62.38}$	Cubic feet water with complete absorption						1.06
n.	$j-(g\dagger-m)$	Cubic feet concrete with complete absorption						23.51
o.	$\frac{\text{Total of } a}{n}$	Unit weight concrete with complete absorption						100.43
p.	As tested	Actual unit weight concrete						84.60
q.	1.04p	Unit weight solid volume (assuming 4 percent air voids)						87.98
r.	$\frac{q-k}{o-k}$	Percent actual complete absorption in batch						51.02
s.	ri	Pounds water absorbed in batch						271.79
t.	$\frac{s}{62.38}$	Cubic feet water absorbed in batch						4.36
u.	$d-s$	Pounds net water in batch						327.10
v.	$\frac{u}{\text{cement}}$	Net water-cement ratio, W/c						0.46
w.	$j-t$	Cubic feet yield by specific gravity						27.69
y.	$\frac{\text{Total of } a}{p}$	Cubic feet yield by unit weight						28.43
z.	$\frac{\text{(Designed sacks per cubic yard) } 27}{y}$	Cement content						7.13

*See final mix design, Table 11.

** See procedure on page 20.

† Cubic feet water.

TABLE 7. COMPUTATIONS FOR WATER-CEMENT RATIO AND CEMENT CONTENT

			Admix	Coarse	Fine	Cement	Water	TOTAL
a.	Mix No. 4PAE*	Batched weights	5.85	530.94	582.30	611.00	589.00	2,319.09
b.	As tested	Gross percent moisture		2.30	1.80			
c.	$b\left(\frac{a}{100+b}\right)$	Gross pounds moisture		11.94	10.30			
d.	$a-c$	Bone-dry weights	5.85	519.00	572.00	611.00	589.00	
e.	As tested **	Bulk specific gravity		0.82	1.04	3.15	1.00	
f.	62.38*e*	Factor		51.15	64.87	196.65	62.38	
g.	$\frac{d}{f}$	Cubic feet	††	10.15	8.82	3.11	9.44	31.52
h.	As tested	Percent absorption complete		53.30	45.50			
i.	*dh*	Pounds absorption		276.63	259.66			536.29
j.	Total of *g*	Yield if no absorption took place						31.52
k.	$\frac{\text{Total of } a}{j}$	Unit weight if no absorption took place						73.58
l.	$d-i$	Net pounds water with complete absorption						52.71
m.	$\frac{l}{62.38}$	Cubic feet water with complete absorption						0.85
n.	$j-(g\dagger-m)$	Cubic feet concrete with complete absorption						22.93
o.	$\frac{\text{Total of } a}{n}$	Unit weight concrete with complete absorption						101.14
p.	As tested	Actual unit weight concrete						80.60
q.	1.06*p*	Unit weight solid volume (assuming 6 percent air voids)						85.44
r.	$\frac{q-k}{o-k}$	Percent actual complete absorption in batch						44.04
s.	*ri*	Pounds water absorbed in batch						230.79
t.	$\frac{s}{62.38}$	Cubic feet water absorbed in batch						3.70
u.	$d-s$	Pounds net water in batch						358.21
v.	$\frac{u}{\text{cement}}$	Net water-cement ratio, W/c						0.58
w.	$j-t$	Cubic feet yield by specific gravity						27.82
y.	$\frac{\text{Total of } a}{p}$	Cubic feet yield by unit weight						28.77
z.	$\frac{(\text{Designed sacks per cubic yard})\ 27}{y}$	Cement content						6.10

* See final mix design, Table 1.2.
** See procedure on page 20.
† Cubic feet water.
†† Air-entraining agent dissolved in mixing water. Volume, therefore, included in water.

TABLE 8. COMPUTATIONS FOR WATER-CEMENT RATIO AND CEMENT CONTENT

			Admix	Coarse	Fine	Cement	Water	TOTAL
a.	Mix No. 5PP*	Batched weights	81.50	530.94	652.03	428.00	684.00	2,376.47
b.	As tested	Gross percent moisture		2.30	1.80			
c.	$b\left(\frac{a}{100+b}\right)$	Gross pounds moisture		11.94	11.53			
d.	$a-c$	Bone-dry weights	81.50	519.00	640.50	428.00	684.00	
e.	As tested **	Bulk specific gravity	1.40	0.82	1.04	3.15	1.00	
f.	62.38e	Factor	87.33	51.15	64.87	196.65	62.38	
g.	$\frac{d}{f}$	Cubic feet	0.93	10.15	9.87	2.18	10.97	34.10
h.	As tested	Percent absorption complete	33.70	53.30	45.50			
i.	dh	Pounds absorption	27.47	276.63	291.43			595.53
j.	Total of g	Yield if no absorption took place						34.10
k.	$\frac{\text{Total of } a}{j}$	Unit weight if no absorption took place						69.69
l.	$d-i$	Net pounds water with complete absorption						88.47
m.	$\frac{l}{62.38}$	Cubic feet water with complete absorption						1.42
n.	$j-(g\dagger-m)$	Cubic feet concrete with complete absorption						24.55
o.	$\frac{\text{Total of } a}{n}$	Unit weight concrete with complete absorption						96.80
p.	As tested	Actual unit weight concrete						79.90
q.	1.04p	Unit weight solid volume (assuming 4 percent air voids)						83.10
r.	$\frac{q-k}{o-k}$	Percent actual complete absorption in batch						51.36
s.	ri	Pounds water absorbed in batch						305.86
t.	$\frac{s}{62.38}$	Cubic feet water absorbed in batch						4.90
u.	$d-s$	Pounds net water in batch						378.14
v.	$\frac{u}{\text{cement}}$	Net water-cement ratio, W/c						0.88
w.	$j-t$	Cubic feet yield by specific gravity						29.20
y.	$\frac{\text{Total of } a}{p}$	Cubic feet yield by unit weight						29.74
z.	$\frac{\text{(Designed sacks per cubic yard) } 27}{y}$	Cement content						4.14

* See final mix design, Table 13.

** See procedure on page 20.

† Cubic feet water.

TABLE 9. FINAL MIX DESIGN REPORT FOR NO. 1 PN

Concrete materials	*Source*
¾-inch to- No. 4: Pumice.	E. G. Cullum deposit. T. 20 N., R. 7 E.,
No. 4 to pan: Pumice.	Santa Fe County.

Cement: Southwestern Portland Cement Company, Type I. Federal specification SS C 192.

COMPUTATION OF INITIAL BATCH QUANTITIES

Sacks per, cubic yard=5.00. Cement per cubic yard=470.00 lbs. W/c=0.78. Water=343.10 lbs.

Cubic feet solid volume per cubic yard Cement=2.39. Water=5.50. Aggregate=18.03. Admix= None.

Naturally entrained air=1.08.

	Cement	Water	No. 4 to pan	¾-inch to No. 4	Entrained air	TOTAL
Percent aggregate proportions by solid volume			48.00	52.00		
Cubic feet solid volume for 1 cubic yard concrete	2.39	5.50	8.65	9.38	1.08.	27.00
Bulk specific gravity	3.15	1.00	1.04	0.82		
Pounds bone-dry wt.	470.00	343.10	561.21	479.79		
Percent gross moisture (39.47% of total absorption)		201.83				
Scale setting	470.00	544.93	561.21	479.79		2,055.93

SCREEN ANALYSIS

Screen Size	Mix combination		Fine pumice		Coarse pumice	
	Percent		Percent		Percent	
	Cumulative passing	Individual retained	Cumulative passing	Individual retained	Cumulative passing	Individual retained
¾"	100.0	0.0	0.0	0.0	100.0	0.0
3/8”	68.7	31.3	0.0	0.0	40.0	60.0
4	47.2	21.5	98.5	1.5	0.0	40.0
8	42.2	5.0	88.0	10.5	0.0	0.0
14	34.8	7.4	72.5	15.5	0.0	0.0
28	23.3	11.5	48.5	24.0	0.0	0.0
48	11.5	11.8	24.0	24.5	0.0	0.0
100	2.9	8.6	6.0	18.0	0.0	0.0
Pan	0.0	2.9	0.0	6.0	0.0	0.0
Fineness Modulus	4.69		2.62		6.60	
Percent absorption			45.50		53.30	
Weight per cubic foot (lbs.)			40.50		28.70	

TABLE 10. FINAL MIX DESIGN REPORT FOR NO. 2 PN

Concrete materials	*Source*
¾-inch to No. 4: Pumice.	E. G. Cullum deposit. T. 20 N., R. 7 E.,
No. 4 to pan: Pumice.	Santa Fe County

Cement: Southwestern Portland Cement Company, Type I. Federal specification SS C - 192.

COMPUTATION OF INITIAL BATCH QUANTITIES

Sacks per cubic yard=6.00. Cement per cubic yard=564.00 Ibs. W/c=0.61. Water=344.04 lbs.
Cubic feet solid volume per cubic yard: Cement=2.87. Water =5.52. Aggregate=17.53. Admix=None.
Naturally entrained air=1.08.

	Cement	Water	No. 4 to pan	¾-inch to No. 4	Entrained air	TOTAL
Percent aggregate proportions by solid volume			46.00	54.00		
Cubic feet solid volume for 1 cubic yard concrete	2.87	5.52	8.06	9.47	1.08	27.00
Bulk specific gravity	3.15	1.00	1.04	0.82		
Pounds bone-dry weight	564.00	344.04	522.93	484.39		
Percent gross moisture (46.31% of total absorption)		229.74				
Scale setting	564.00	573.78	522.93	484.39		2,145.10

SCREEN ANALYSIS

Screen Size	Mix combination Percent		Fine pumice Percent		Coarse pumice Percent	
	Cumulative passing	Individual retained	Cumulative passing	Individual retained	Cumulative passing	Individual retained
¾"	100.0	0.0	0.0	0.0	100.0	0.0
3/8”	67.6	32.4	0.0	0.0	40.0	60.0
4	45 3	22.3	98.5	1.5	0.0	40.0
8	40.5	4.8	88.0	10.5	0.0	0 0
14	33.4	7.1	72.5	15.5	0.0	0.0
28	22.4	11.0	48.5	24.0	0.0	0.0
48	11.1	11.3	24.0	24.5	0.0	0.0
100	2.8	8.3	6.0	18.0	0.0	0.0
Pan	0.0	2.8	0.0	6.0	0.0	0.0
Fineness Modulus	4.77		2.62		6.60	
Percent absorption			45.50		53.30	
Weight per cubic foot (Ibs.)			40.50		28.70	

TABLE 11. FINAL MIX DESIGN REPORT FOR NO. 3 PN

Concrete materials	*Source*
¾-inch to No. 4: Pumice.	E. G. Cullum deposit. T. 20 N., R. 7 E.,
No. 4 to pan: Pumice.	Santa Fe County.

Cement: Southwestern Portland Cement Company, Type I. Federal specification SS - C - 192.

COMPUTATION OF INITIAL BATCH QUANTITIES

Sacks per cubic yard=7.00. Cement per cubic yard=658.00 lbs. W/c=0.46. Water=302.68 lbs.
Cubic feet solid volume per cubic yard: Cement=3.35. Water=4.85. Aggregate=17.72. Admix=None.
Naturally entrained air=1.08.

	Cement	Water	No. 4 to pan	¾-inch to No. 4	Entrained air	TOTAL
Percent aggregate proportions by solid volume			44.00	56.00		
Cubic feet solid volume for 1 cubic yard concrete	3.35	4.85	7.80	9.92	1.08	27.00
Bulk specific gravity	3.15	1.00	1.04	0.82		
Pounds bone-dry weight	658.00	302.68	506.06	507.41		
Percent gross moisture (47.85% of total absorption)		255.40				
Scale setting	658.00	558.08	506.06	507.41		2,229.55

SCREEN ANALYSIS

Scree Size	Mix combination Percent		Fine pumice Percent		Coarse pumice Percent	
	Cumulative passing	Individual retained	Cumulative passing	Individual retained	Cumulative passing	Individual retained
¾"	100.0	0.0	0.0	0.0	100.0	0.0
3/8"	66.4	33.6	0.0	0.0	40.0	60.0
4	43.2	23.2	98.5	1.5	0.0	40.0
8	38.6	4.6	88.0	10.5	0.0	0.0
14	31.8	6.8	72.5	15.5	0.0	0.0
28	21.3	10.5	48.5	24.0	0.0	0.0
48	10.5	10.8	24.0	24.5	0.0	0.0
100	2.6	7.9	6.0	18.0	0.0	0.0
Pan	0.0	2.6	0.0	6.0	0.0	0.0

	Mix	Fine pumice	Coarse pumice
Fineness Modulus	4.86	2.62	6.60
Percent absorption		45.50	53.30
Weight per cubic foot (lbs.)		40.50	28.70

TABLE 12. FINAL MIX DESIGN REPORT FOR NO. 4 PAE

Concrete materials	*Source*
¾-inch to No. 4: Pumice.	E. G. Cullum deposit. T. 20 N., R. 7 E.,
No. 4 to pan: Pumice.	Santa Fe County.

Cement : Southwestern Portland Cement Company, Type I. Federal specification SS - C - 192.

COMPUTATION OF INITIAL BATCH QUANTITIES

Sacks per cubic yard=6.00. Cement per cubic yard-564.00 lbs. W/c=0.58.
Water= 327.12 lbs. Admix= 5.40 lbs.
Cubic feet solid volume per cubic yard Cement= 2.87. Water= 5.24. Aggregate=17.27. Admix=1.62.
Entrained air=1.62.

	Cement	Water	No. 4 to pan	¾-inch to No. 4	Entrained air	TOTAL
Present aggregate proportions by solid volume			46.50	53.50		
Cubic feet solid volume for 1 cubic yard concrete	2.87	5.24	8.03	9.24	1.62	27.00
Bulk specific gravity	3.15	1.00	1.04	0.82		
Pounds bone-dry weight	564.00	327.12	520.99	472.63		
Percent gross moisture (44.04% of total absorption)		215.34				
Scale setting	564.00	542.46	520.99	472.63		2,100.08

SCREEN ANALYSIS

Scre Siz	Mix combination Percent		Fine pumice Percent		Coarse pumice Percent	
	Cumulative passing	Individual retained	Cumulative passing	Individual retained	Cumulative passing	Individual retained
¾"	100.0	0.0	100.0	0.0	100.0	0.0
3/8"	67.9	32.1	100.0	0.0	40.0	60.0
4	45.6	22.3	98.0	2.0	0.0	40.0
8	39.2	6.4	84.2	13.8	0.0	0.0
14	29.7	9.5	63.8	20.4	0.0	0.0
28	15.0	14.7	32.2	31.6	0.0	0.0
48	0.0	15.0	0.0	32.2	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0
Pan	0.0	0.0	0.0	0.0	0.0	0.0
Fineness Modulus	5.03		3.22		6.60	
Percent absorption			45.50		53.30	
Weight per cubic foot			40.50		28.70	

TABLE 13. FINAL MIX DESIGN REPORT FOR NO. 5 PP

Concrete materials	*Source*
3/4-inch to No. 4: Pumice.	E. G. Cullum deposit. T. 20 N., R. 7 E.,
No. 4 to pan: Pumice.	Santa Fe County.

Cement: Southwestern Portland Cement Company, Type I. Federal specification SS - C - 192.

COMPUTATION OF INITIAL BATCH QUANTITIES

Sacks per cubic yard=4.00. Cement per cubic yard=376.00 lbs. W/c= 0.88. Water, 330.88 lbs. Minus 100 pumice admix =71.61 lbs.*

Cubic feet solid volume per cubic yard: Cement=1.91. Water =5.30. Aggregate =17.89. Admix= 0.82.

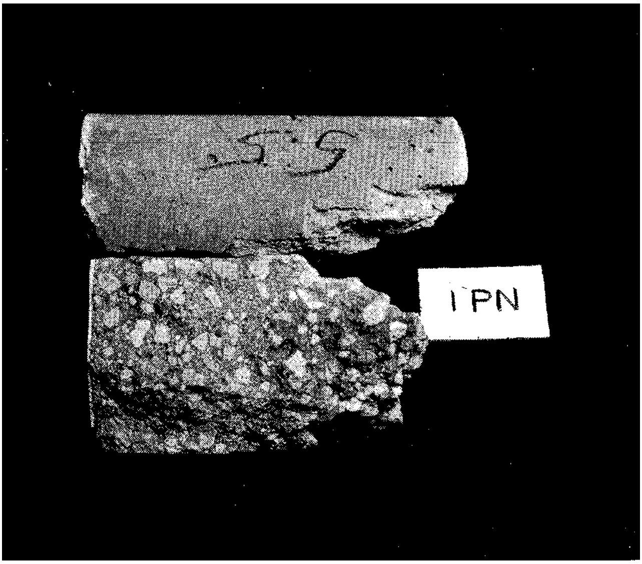
Naturally entrained air=1.08.

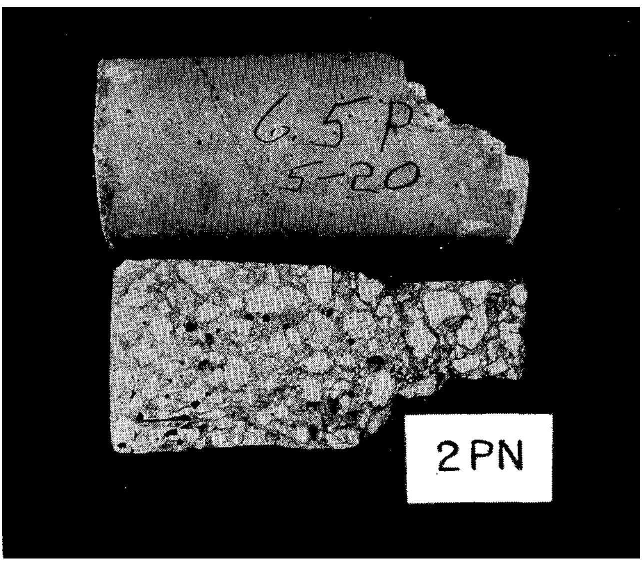
	Cement	. Water	No. 4 pan	¾-inch to No.	En- trained	Minus 100	TOTAL
Percent aggregate proportions by solid volume			46.00	54.00			
Cubic feet solid volume for 1 cubic yard concrete	1.9.1	5.30	8.23	9.66	1.08	0.82	27.00
Bulk specific gravity	3.15	1.00	1.04	0.82		0.82-	
Pounds bone-dry weight	376.00	330.88	533.88	494.11		71.61	
Percent gross moisture (51.36% of total absorption)		272.42					
Scale setting	376.00	603.30	538.88	494.11		71.61	2.078.90

SCREEN ANALYSIS

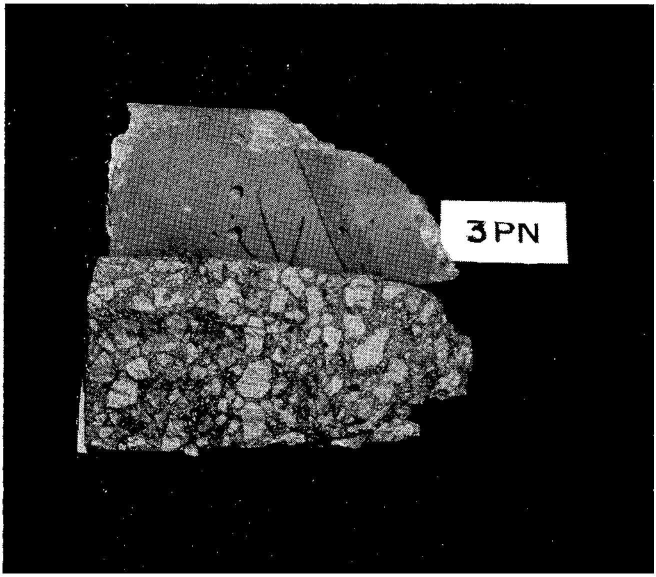
Scree Size	Mix combination		Fine pumice		Coarse pumice	
	Percent		Percent		Percent	
	Cumulative passing	Individual retained	Cumulative passing	Individual retained	Cumulative passing	Individual retained
¾"	100.0	0.0	0.0	0.0	100.0	0.0
3/8"	67.6	32.4	0.0	0.0	40.0	60.0
4	45.3	22.3	98.5	1.5	0.0	40.0
8	40.5	4.8	88.0	10.5	0.0	0.0
14	33.4	7.1	72.5	15.5	0.0	0.0
28	22.4	11.0	48.5	24.0	0.0	0.0
48	11.1	11.3	24.0	24.5	0.0	0.0
100	2 8	8.3	6.0	18.0	0.0	0.0
Pan	0.0	2.8	0.0	6.0	0.0	0.0
Fineness Modulus	4.77		2.62		6.60	
Percent absorption			45.50		53.30	
Weight per cubic foot			40.50		28.70	

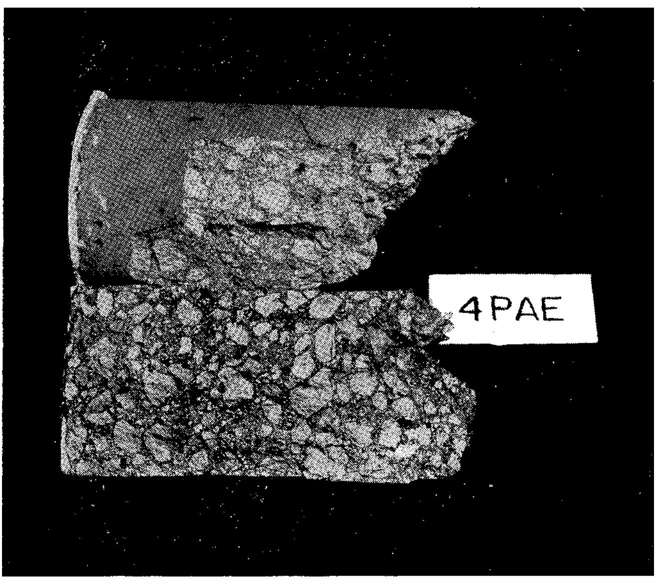
* 30 percent by volume of total cementitious material.





PUMICE-CONCRETE TEST CYLINDERS WITH PROPER DESIGN





PUMICE-CONCRETE TEST CYLINDERS WITH PROPER DESIGN

TABLE 14. COMPARISON STUDY OF PUMICE CONCRETES DESIGNED AND TESTED

Batch No.	Cement content (sacks per cubic yard)	Water-cement ratio	Fineness Modulus of aggregate	Unit weight bone-dry (lbs.)	Compressive strengths (p.s.i.) 7-day	28-day
1 PN	4.92	0.73	4.69	63.0	1,190	1,790
2 PN	5.96	0.61	4.77	65.4	1,510	1,960
3 PN	7.13	0.49	4.86	67.4	1,995	2,190
4 PAE	6.10	0.58	5.03	64.3	1,950	2,310
5 PP	4.14	0.88	4.77	59.4	970	1,655

least 7 days, at the end of which time the outer fibers will have become strong and dense enough to protect against evaporation and resultant too-rapid drying.

In commercial practice, steam curing of pumice-concrete products requires 8 hours at 180° F. and a relative humidity of plus 60 percent. A pattern of steam coils for heat generation and a desired number of open steam jets to provide desirable humidity are found to be most successful. When the elapsed 8 hours' curing period is reached, the steam jets are closed. By opening the doors and continuing the heat treatment, the absorbed water is driven off in 2 to 3 hours. This treatment reduces the time required for normal shrinkage, so that almost total shrinkage, is obtained. Total absorption is also reduced to below 40 percent, which will allow delivery of the product directly from curing shed to job site, if necessary.

TEST RESULTS

The selection of cement content was based on normal requirements for this class of lightweight concrete, from which are derived the best possible values in unit weights and moduli of elasticity. In the original design representing each batch no account was made to adjust for natural air entrainment this was estimated to be about 4 percent, with little variation in all batches except No. 4 PAE. In this batch it was intended that 4 percent additional air entrainment be introduced.

Inasmuch as all batches were treated alike in reference to consistency rather than by controlling a constant water-cement ratio and basing the proportioning of fines to coarse according to cement content, the workability and placeability was very uniform.

Mix No. 4 PAE, although the minus No. 48 was removed, displayed greater workability and ease of placement, plus the highest strengths. The unit weight was somewhat lower than No. 2 PN. The total air entrainment was finally computed at 6 percent.

Mix No. 5 PP was made, using minus 100-mesh pumice as an admix. This was used in a mix that was designed for 6.5 sacks per cubic yard, but 30 percent by volume of the cement was removed and replaced by the pumice fines (minus 100-mesh) by actual volume. By replacing the cement with pumice fines the cement content was reduced to 4.14 sacks per cubic yard. This mix showed a marked increase in plasticity. Seven-day strengths were 970 p.s.i. and 28-day strengths were 1,655 p.s.i. There would probably be an increase in -strength after 28 days with such a Pozzolana mix but not sufficient cylinders were made for tests to verify this.

Pozzolana cements were first made by the Romans, who use

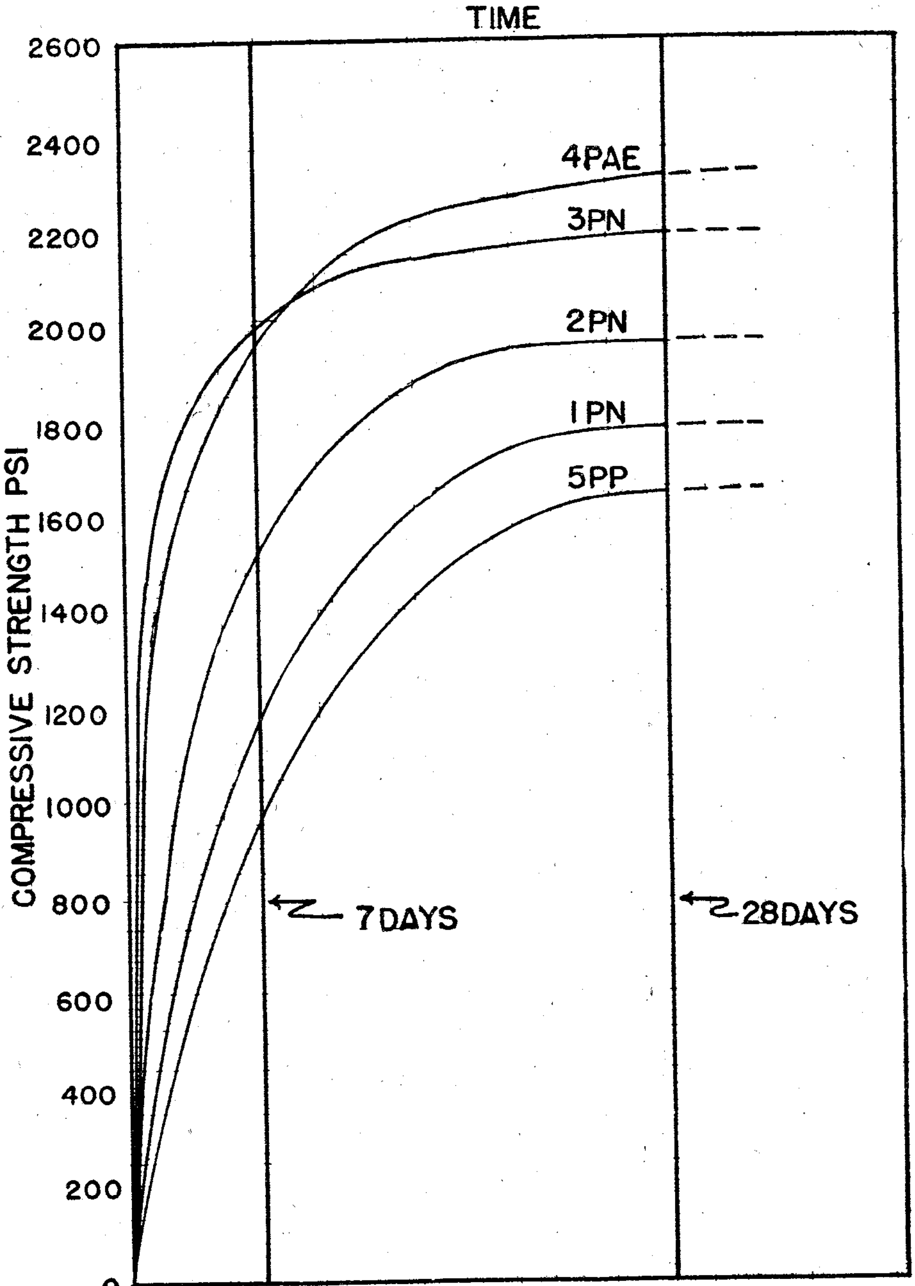
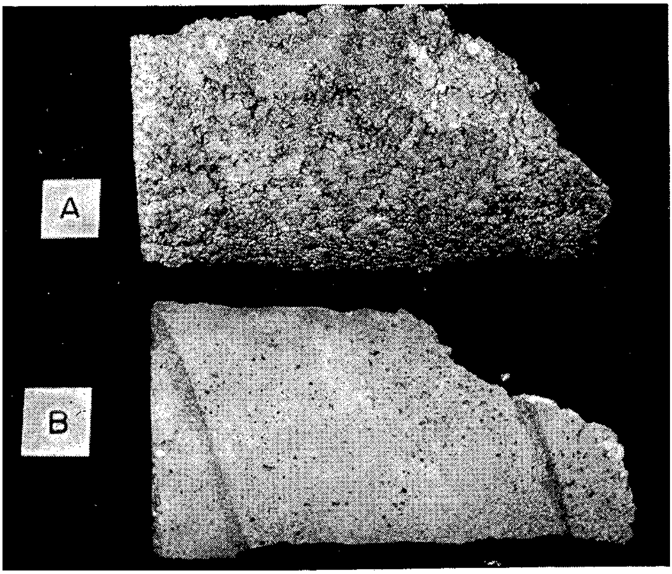
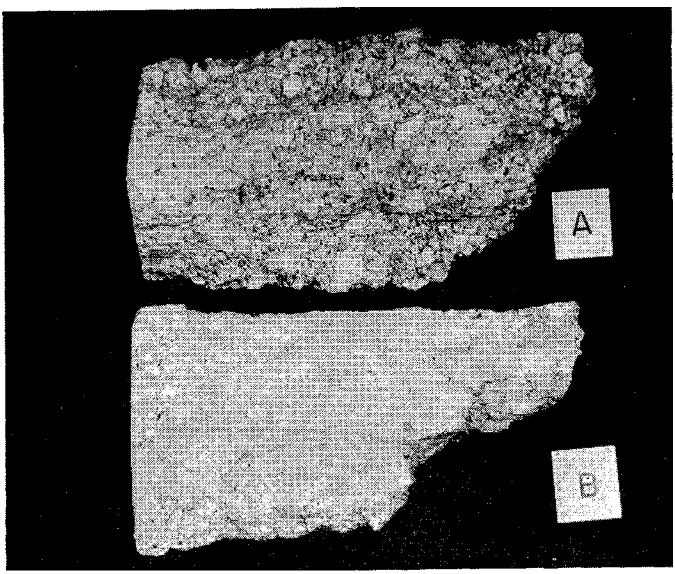


FIGURE 6.-Compressive strengths of the five concrete mixes tested.

a volcanic tuff consisting of fragments of pumice, obsidian, feldspars, pyroxenes, quartz, etc., with lime to produce a cement of excellent qualities. Many of the buildings and structures made from this cement are still in good condition after 2,000 years. Pozzolana cements with the addition of air entrainment for ultra light pumice concretes are worthy of investigation, for although the test cylinders mentioned above passed the required 1,600 p.s.i., the unit weight of this concrete was only 59.4 pounds per cubic foot. Such a concrete can be produced economically by pulverizing the standard run of graded material. by the individual plant operator.

Table 14 shows the relationship of the five mixes in regard to cement content, water-cement ratio; Fineness Modulus of aggregate, unit weights, and strengths. The strengths of the No. 4 PAE are highest coupled with a lower unit weight. This is caused b y. the better dispersion of the cement and air entrainment created by the admix. Nos. 4 PAE and 3 PN surpass safely the compressive-strength requirements of 2,000 p.s.i. for Class B concrete as prescribed by A. S. T. M. and the Uniform Building Code of the Pacific.





Same size-grading of aggregate used in all tests. Cylinders marked A were made with ordinary cement; those marked B were made with air-entraining cement. Note how aerated cement matrix filled voids in cylinders marked B.

TEST CYLINDERS MADE WITH POORLY DESIGNED AGGREGATE

PUMICE DEPOSIT IN SANTA FE COUNTY,
NEW MEXICO, 9 MILES SOUTHWEST
OF ESPANOLA

CONCLUSIONS

IMPORTANCE OF QUALITY IN PUMICE AGGREGATE

GRADING

Plate 15 as compared to Plates 13 and 14 shows graphic proof of the detrimental 'effect of poor gradation. Low strengths reflect on the poor particle' distribution present, as shown on Plate 15. Effort must be initially applied to proper sizing and blending.

DELETERIOUS SUBSTANCES

Most pumice deposits, in the Jemez Mountains district occur under a comparatively thin layer of overburden. This is normally composed of soil, decayed vegetation, trees, roots, and other sparse vegetation. The trees, mostly cedar, pine, and piñon, seldom exceed 20 to 25 feet in height, and should be carefully and thoroughly removed. The overburden can usually be removed without the need of rooters, or scarifiers, it is necessary to remove it without disturbing the clean pumice underneath, to avoid the danger of percolation and contamination. The thickness of pumice in a well-selected deposit of suitable quality ranges normally from 8 to 20 feet, although in places it may be 70 feet or more. Beneath the pumice lies impure material having the same undesirable properties as are found in the overburden. Care is exercised to remove only the clean pumice.

CHEMICAL INERTNESS

Analyses of two New Mexico pumice deposits follow.

TABLE 15. CHEMICAL ANALYSES OF SANTA CLARA AND COCHITI PUMICE

	Santa Clara [a] Percent	Cochiti [b] Percent
Silica (SiO_2)	71.67	70.28
Alumina (Al_2O_3)	12.64	13.54
Ferric oxide (Fe_2O_3)	2.30	2.06
Lime (CaO)	0.60	1.96
Magnesia (MgO)	0.70	0.88
Soda (Na_2O) / Potash (K_2O)	8.00	7.47
Titania (TiO_2)	Trace	0.26
Manganese oxide (Mn_3O_4)	Trace	0.30
Loss on ignition	4.46	3.73
Total	100.37	100.48
Water-soluble salts	0.16	0.068

[a] T. C. Crawford, New Mexico Bureau of Mines and Mineral Resources, analyst.
[b] Pittsburg Testing Laboratory, analyst.

Tests have shown that most of the deposits in the Jemez Mountain district contain practically no· deleterious organic material to cause tannic-acid reactions in concrete. If improper pit operations are used, there is danger of pollution of the pumice by overburden containing roots and other organic matter.

It has been noted by the U. S. Bureau of Reclamation that many highly, siliceous volcanic rocks and glasses (including pumice) are reacted upon by high-alkali cements. This reaction causes a breakdown of the aggregate and a serious loss in strength and durability. To overcome this condition, it is recommended that a low-alkali cement be used. Ameliorants are being sought at the present time. Until they have been discovered, cement containing less than 0.60 percent combined alkali should be used to eliminate an^y cement-aggregate reaction.

S. L. Meyers, (chief chemist for the Southwestern Portland Cement Company, states that he believes danger of an alkali-aggregate reaction unlikely in pumice concrete for the following reasons:[7]

> Porous aggregates can accommodate themselves to reasonable amounts of expansion. Further, the alkali-silicate gel might form to some extent within void spaces.
>
> Tests on mixes containing more than 25 percent of reactive aggregate show low expansions.
>
> The humidity and hygral condition of the concrete must be just right to develop expansion. In this climate, buildings above ground would not be subjected to it.
>
> Finely divided reactive aggregate, added to a mix containing other reactive aggregates, reduces expansion.

RECOMMENDED PIT OPERATIONS

The most successful procedure in the removal of overburden has been as follows. For the removal of trees, a chain or cable is attached to the base of the tree and passed over the end of a 3-foot timber brace set near the tree; the brace has a fulcrum effect that allows the bulldozer to lift the tree out rather than to push it over. This procedure will enable -the operator to pull out most of the roots that are embedded in the pumice under the over burden.

If the overburden occurs in a thin layer, a carry-all suitable for stripping may be used, The operator should take a deep cut for clean separation on the last pass, so that the load is carried over the undisturbed overburden remaining ahead. The rig on the return pass can then travel over the cleanly-exposed pumice without danger of contamination. Where the overburden occurs in depths of 2 feet or more, a bulldozer is used to remove the upper or major portion. The carry-all then can complete a good job of clean stripping.

[7] Personal communication, July 5, 1947.

Removal of the pumice from a given area provides an excavation into which the overburden from the next area to' be worked can be dumped.

RECOMMENDED SCREENING AND GRADING OPERATIONS

It is desirable to remove the minus No. 8 size of the pit-run pumice, as it is within this size range that undesirable material occurs. Tests show that 12 to 15 percent by volume of the pit-run material will pass the No. 8 screen. Of this amount, 35 percent is quartz and orthoclase of suitable quality for sandblast sand; it can be reclaimed economically and sold to a ready market.) The return for this product will enable the producer to reduce greatly the overall cost of mining, and reduction in weight of the pumice lowers considerably the cost of shipment.

The following equipment and procedure are recommended for producing 3,000 cubic yards of properly-graded pumice ice aggregate daily.

1. Pit-run open stockpile, to be drawn by tunnel belt to bucket elevator, then to scalping grizzly.

2. Scalping grizzly, 4 by 10 feet, equipped with 1½-inch square-opening screen deck, for removal of roots and undesirable oversize; elongated screen deck, with 1/8- by 5/8-inch openings, for rejecting minus No. 8 of pit-run.

3. Two-roller crusher, 30-inch span by 36-inch diameter, adjusted at 5/8-inch opening; one driver roller only at 380 r.p.m.

4. Three-deck vibrating screen. Speed of 1,850 r.p.m. on 1/3-inch travel, with eccentric bearings, provides clean separation and eliminates "floating" that occurs when slower speed and greater travel are used.

   (a) First deck: 7/8-inch square-opening screen, to assure control of undesirable oversize, occurring when overload increases openings of primary crusher. Oversize is returned to crusher.

   (b) Second deck: 7/16-inch square-opening screen.

   (c) Third deck: 3/16- by 1½-inch elongated-opening screen.

5. Adjustable diverting chute, to split and divert desired portion of 3/8-inch to No. 4 to secondary crusher.

6. Secondary crusher: 2-roller, 18-inch span by 36-inch diameter, to produce the size range from Minus No. 16 to No. 100.

7. Return chain drag or equivalent, to return the product of the secondary crusher to screen for proper blending.

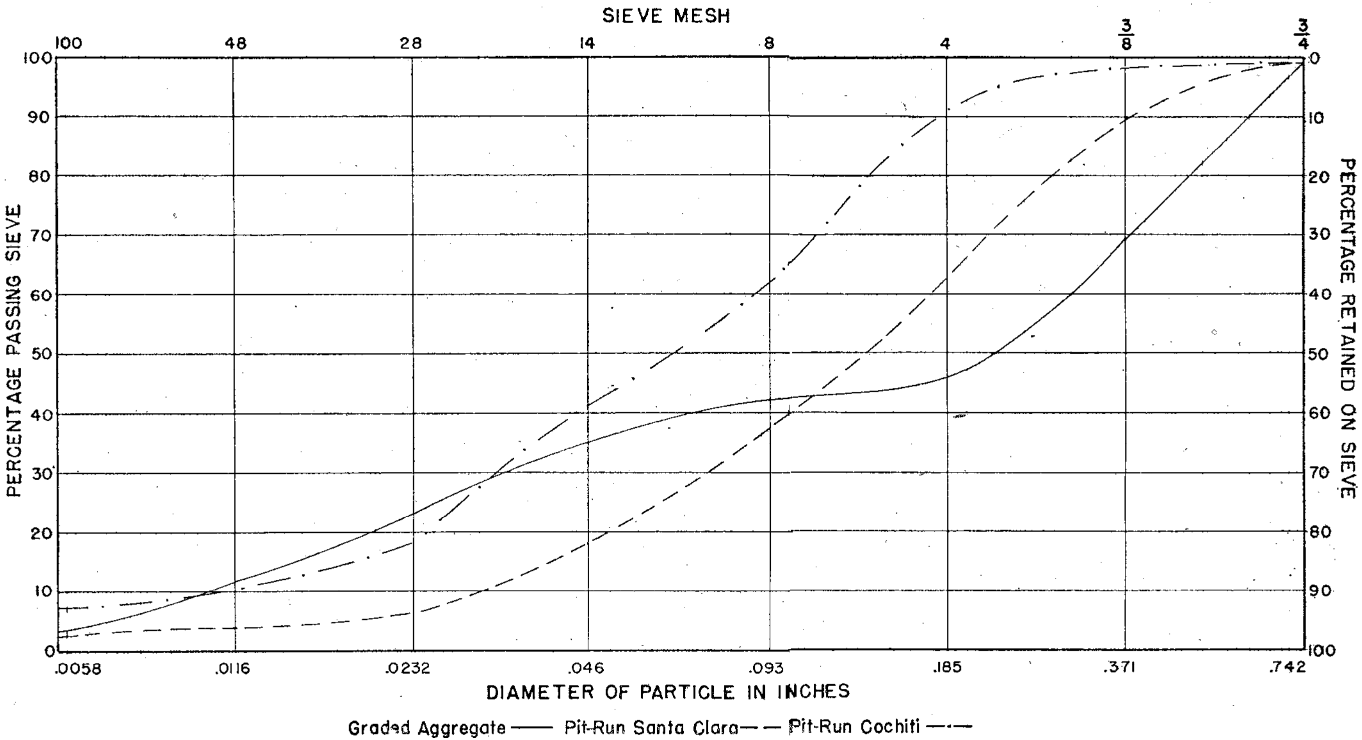


FIGURE 7.--Size distribution of correctly graded aggregate compared with that of two typical pit-run aggregates.

8. Transfer chutes, for segregation of individual sizes into bins.

9. Individual bins: 20 feet wide by 20 feet long by 30 feet high = 444.4 cubic yards each.

10. Tunnel conveyor belt, for drawing individual sizes or selected blend for relay to loading belt.

11. Loading belt.

12. Diverting swivel chute.

Remarks: The secondary crusher is necessary to reduce the normally excessive Nos. 4, 8, and 16 size range and increase the deficient range of Nos. 28, 48, and 100.

EFFECT OF CONCRETE DESIGN

PIT-RUN MATERIALS

Frequently the question has arisen as to whether or not de-posits of pumice are available within the State which may be used as concrete aggregate in a pit-run condition, or be made acceptable by simple screening operations without crushing. To our knowledge, no such deposits are to be found. Pumice does not naturally grade down from coarse to fine in a uniform manner like many alluvial deposits of ordinary gravel. Sieve analyses of two typical pit-run pumice aggregates are as follows.

TABLE 16. SIEVE ANALYSES OF PIT-RUN PUMICE

Screen Size	Santa Clara Indian Reservation Santa Fe County	Cochiti District Sandoval County
	Percent passing	Percent passing
¾"	98	100
3/8"	90	98
4	66	91
8	37	71
14	18	41
28	6	18
48	4	10
100	2	7
F. M.	4.79	3.64

Graphic representation of the above materials, compared with a well-balanced aggregate, shows the deficiency in certain important sizes in the pit-run materials. Plate 12 further emphasizes this deficiency.

It should be noted that the Fineness Moduli of these different gradings are misleading, and that the Fineness Modulus should normally be used as a criterion for plant control only after proper distribution of screen sizes has been established.

An attempt was made to attain a suitable aggregate from naturally occurring material by screening alone, but this attempt was unsuccessful. Pit-run pumice from the Santa Clara Indian Reservation, Santa Fe County, was passed over a 1/4-inch mesh screen placed at an angle of approximately 45 degrees. By this means, a coarse and a fine aggregate was produced. By improper unrestricted use of the Fineness Moduli, a mix was designed in the proportions of 1:4:2 to give a combined Fineness Modulus of 4.65. Sieve analysis of these products are as follows.

TABLE 17. SIEVE ANALYSES OF SCREENED PIT-RUN PUMICE FROM SANTA CLARA INDIAN RESERVATION

Screen Size	Coarse Aggregate	Fine Aggregate	1 :4:2 Mix	
	Percent passing	Percent passing	Percent passing	Individual Retained
3/4"	96	0	99	1
3/8"	78	0	93	6
4	23	99	74	19
8	3	61	41	33
14	2	28	19	22
28	1	9	6	13
48	1	5	2	4
100	1	3	1	1
Pan	0	0	0	1
F. M.	5.95	3.95	4.65	

In comparing this aggregate with that of No. 1 PN (Figure 6 and Plate 13), the difference is readily noted in the excessive amount of 3/8-inch, No. 8, and No. 14, and the insufficient sand sizes from 28-mesh to pan. Although the Fineness Modulus was in fact slightly lower than that of No. 1 PN (F. M. 4.69), the mix resulted in a harsh, porous, and honeycombed concrete. This mix displayed the low compressive strengths of only 235 p.s.i. at 28 days, as compared with No. 1 PN which had a similar cement content and water-cement ratio but showed compressive strengths at 28 days of 1,790 p.s.i.

AIR ENTRAINMENT IN PUMICE CONCRETE

Air entrainment in concrete, although a relatively recent development, is rapidly coming into use in the manufacture of lightweight concrete products. The principle of air entrainment is as follows. Certain agents when added to concrete in small quantities cause the inclusion in the mix of a larger amount of air than is found in ordinary concrete. This added air is in the form of minute disconnected bubbles or spheroids, which become well distributed throughout the cement matrix. These tiny bubbles have several beneficial functions. (1) They act as minute roller bearings to make the mix more plastic than ordinary concrete. (2) They improve the dispersion of the cement throughout the mix. (3) They help, to retain the cement on the glassy surface of the pumice fragments. (4) They decrease segregation when the concrete is handled and placed. (5) They reduce bleeding and water gain after placing.. (6) They replace some of the fine sand (minus 48 mesh), which results in a lighter unit weight of the concrete. (7) They markedly improve resistance to freezing and thawing.

For ordinary heavy aggregate it is recommended that a total content of 4 to 5 percent of entrained air by volume will give an improvement in durability without an appreciable loss of strength. This, however, is for solid aggregate which will attain strengths of 4,000 to 5,000 p.s.i. and greater. In pumice concrete, the matrix has a relatively greater strength compared to the aggregate it-self, so that it is possible to add entrained air in larger percentages to lessen the unit weight without comparative appreciable strength losses. Such may be the case where lightness of weight and maximum thermal insulation are desired, as for poured concrete roofs or in the fabrication of sheathing for heat and sound insulation.

In some instances where poorly graded aggregate is used, much greater strength. can be obtained by the use of air entraining than by ordinary cement. In tests using poorly graded aggregate it was found that ordinary concrete produced a porous honeycombed cylinder with 28-day compressive strengths of only 996 p.s.i., and that air-entraining cement produced a denser concrete having 28-day compressive strengths of 1,630 p.s.i. (see Plate 15). It is not suggested that air entrainment be employed as a cure-all for poorly designed aggregate mixture, but rather that by control in grading and air entrainment,. maximum desired strengths and minimum unit weights may be obtained for concretes for specific purposes. No figures are available pertaining to thermal insulating properties of such a matrix in conjunction with pumice, but a lower factor would undoubtedly result.

Air-entraining cement is being employed with favorable results in the manufacture of concrete blocks. The advantages are discussed and summarized by G. Farmer [8] as follows.

1. No additional expenses or unusual changes in manufacturing procedure have been found necessary by manufacturers who have changed from regular portland cement to air-entraining portland cement.

2. Breakage of block throughout the various stages of manufacture is very much. reduced particularly where block are made with aggregates defi-

8 Farmer, H. G., Air-entraining portland cement in concrete block: Rock Products, vol. 48, no. 1, pp. 209-217, January 1945.

cient in fine material or where harsh aggregates are used. The effect of this on rate of production and on costs is apparent.

3. Block are usually improved in appearance regardless of aggregates or block machine used. Richer looking block are obtained with sharper corners and edges and truer dimensions.

4. The greatest improvement in quality and appearance generally occurs with harsh aggregates where increased plasticity of this cement is advantageous in securing greater compaction of block.

5. Compressive strengths are generally increased. The amount of mixing water can be increased when using air-entraining cement to produce block of a strength more nearly approaching the maximum possible for the mixture and machine used.

6. Block have lower absorption and exhibit greater resistance to the passage of water. This has been established in the laboratory, and in the field. . . .

7. Concrete-block mixes containing air-entraining cement can be handled satisfactorily and efficiently by any of the commercial block machines.

A great many studies have been made on air entrainment in concrete within the past few years. Detailed information on the subject is obtainable from the American Concrete Institute, and the Highway Research Board, manufacturers of air-entraining cements and reagents, and various other sources.

Air entrainment can be accomplished by either of two methods. Air-entraining agents, manufactured for this purpose, may be introduced into the batch as an admix at the time of mixing; or cements may be used into which an air-entraining, agent has been interground at the time of manufacture. In the latter case the cement is used as usual with slight adjustment of the aggregate and mixing water to obtain the desired results.

AGRICULTURAL APPLICATIONS

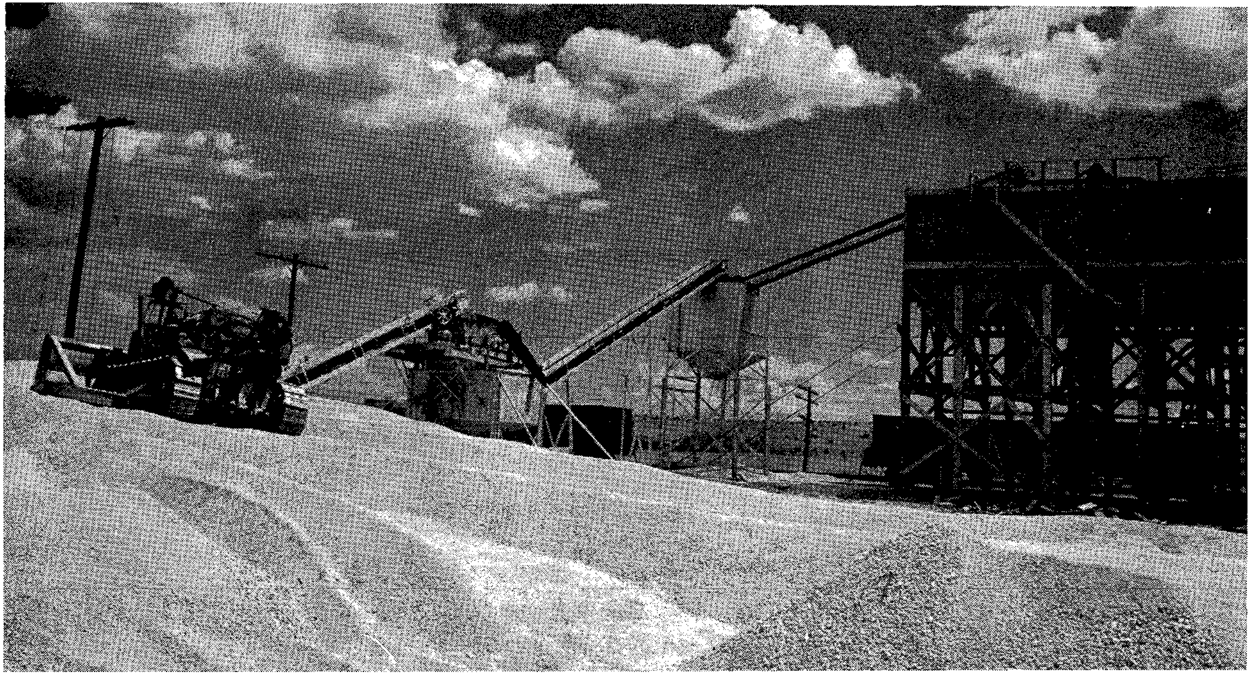
SOIL CONDITIONING

Pumice is being used at the present time as a soil conditioner for adobe soils, to render them porous and thereby promote plant growth. When. mixed with heavy soils each particle of pumice acts like a tiny sponge, absorbing moisture and air and holding them in the soil. Surface and subsoil are thereby kept damp. In alkaline soils the breakdown and erosion of the pumice probably frees potash, a beneficial fertilizer, although as yet no studies have been made on that reaction. Pumice aggregate has proved satisfactory as a mulch for lawns and fruit trees. It finds other application in the rooting of cuttings and in the growing of bulbs. In the seedbed, losses by damping-off and other diseases due to fungus and mildew are greatly reduced.

A, tomato plants; pumice bed in fore-ground.

B. Corn ready for picking by June 1 of growing season.

PUMICE CULTURE



CRUSHING AND SIZING PLANT OF THE PUMICE AGGREGATE SALES CORPORATION AT DOMINGO, NEW MEXICO

Experiments in the field of hydroponics have been made by Richard Walters of Albuquerque. By a method that he terms "Pumice Culture," lush growth and high yields of vegetables and flowers were obtained through the use of common chemicals applied in very dilute solution to a bed of pumice aggregate. Photographs of corn and tomatoes are shown on Plate 17. Both the tomatoes and corn were planted March 20; the photographs were taken on June 1. The tomatoes bore until the first killing frost on November 20. The vines reached an ultimate height of 13 feet. One hundred vines were planted 6 inches apart in two rows 25 feet long. The average yield was 40 tomatoes per vine. About four thousand tomatoes were grown in a bed with an area of only 37.5 square feet. The yield of hybrid golden-bantam corn was equally 'astonishing. In an 18-inch by 35-foot tank, seed was planted 6 inches apart each way and yielded 143 ears of corn. The "first ears were ready for the table on June 1.

To test the pH reaction of the neutral aggregate, various vegetables and flowers were planted side by side in a pumice culture tank. They all grew with good results. Among the plants tested were beans, lettuce, peppers, turnips, calendula, gaillardia, zinnia, and larkspur. These were representative of plants requiring a pH range from 5 to 7.5.

The simplicity of pumice culture is as amazing as are the results. Walters,' method employs the following inexpensive chemicals in a commercial-grade dry state: potassium chloride, 8 oz.; ammonium nitrate, 8 oz.; treble super phosphate, 4 oz.; and magnesium sulfate, 2 oz. The above reagents were dissolved in 50 gallons of water and the mixture added to the bed once a week until growth became heavy. After that time solution was added twice a week. Any solution not absorbed by the pumice was allowed to drain off. A light watering of clear water each morning was required to replace the moisture lost by evaporation and from absorption by the plants. The pumice aggregate for the bed was placed in wooden tanks 9 inches deep, 4 feet wide, and 25 feet long. After the growing season had ended, the pumice was inspected and it was found that little breakdown had taken place. The pumice remained practically inert, acting as a medium through which the roots grow and extract the chemicals require

The minute porosity of very finely-ground pumice makes it "useful as the carrying agent for insecticides for crop dusting. For this purpose very fine pumice dust (minus 325-mesh) is used. The insect- and bacteria-combatting chemical is absorbed into the cells of the pumice. When dusted upon the crop, the pumice clings to the leaves and gradually releases the chemical over a longer period of time than other carrying agents.

A similar field that shows promise is the utilization of pumice as a carrying agent for fertilizer. It has been established that one of the most important functions of humus or compost is its ability to absorb plant nutrients, and upon application to the soil to release the plant food as required through disintegration and the leaching action of water. The humus, however, breaks down in a relatively short time and must be replaced. It is possible that pumice could be thoroughly impregnated with fertilizer and a 3 to 4 years' requirement applied at once. The fertilizer might be released gradually by the leaching action of water upon the pumice, so that the nutrients would not be over-supplied. The pumice would of course have the advantage over the humus of lasting for several years. Coupled with the soil-conditioning a vantage mentioned above, a highly desirable and beneficial agricultural product might be developed. This is a conjecture based on the use of pumice as an insecticide-carrying agent; to our knowledge, no experimental work has been done on pumice as a fertilizer-carrying agent.

PRESENT AND POTENTIAL MARKET

Because the cost of mining, processing, and shipping of pumice aggregate is within easy reach of the concrete manufacturer and the concrete-products producer in several states surrounding New Mexico, the acceptance of this natural light-weight material has shown a steady increase since January 1946. The total shipment of pumice aggregate during 1946 is in the neighborhood of 75,000 cubic yards, of which two-thirds was shipped by rail and one-third by truck.

T. Jack Foster, president, Pumice Aggregate Sales Corporation, Albuquerque, states that in 1946 his concern shipped 40,713 cubic yards of pumice by rail and 18,785 cubic yards by truck. Shipment during the first 5 months of 1947 was 19,803 cubic yards by rail and 5,910 cubic yards by truck. Foster continues:[9]

> The experience that our customers have had over the past year and a half in the use of pumice has convinced us beyond any reasonable doubt that maximum strengths can only be obtained through proper gradation; therefore, we are erecting a grading plant at a cost of $35,000, with separate bins for the various grades so that we can ship to the plant, that so desires it, a coarse material in one car and the fine material in the other or to those who desire a blended grade, we will control this with the use of Syntron Gates under the bins.

The groundwork has been laid for this phase of the mining industry, and New Mexico is prepared, by the extent of her pumice resources, to supply the building needs of a large area in the south and middle western United States for decades to come.

[9] Personal communication, June 23, 1947.

SELECTED BIBLIOGRAPHY

ALLISON, IRA S., Pumice beds at Summer Lake, Oregon: Geol Soc. America Bull., vol. 56, no. 8, pp. 789-807, Aug. 1945.

AMERICAN CONCRETE INSTITUTE, Symposium on air entrainment in concrete: Detroit, Mich., June 1944.

ANONYMOUS, Largest products plant on west coast: Rock Products, vol. 50, no. 2, pp. 147-149, Feb. 1947.

BOGUE, ROBERT HERMAN, The chemistry of portland cement: Reinhold Publishing Corp., New York City, 1947.

BRADLEY, WALTER W., Pumice and volcanic ash: Mineral abstracts of the State of California, Dept. Min. Res., Div. of Mines, Sept. 1939.

CARITHERS, WARD, Pumice and pumice occurrences of Washington: Wash. Dept. Conservation and Development, Div. of Mines and Geology, Rept. of Inv., no. 15, 1946.

CLEARY, J. B., Haydite manual: American Aggregate Co., Kansas City, Mo., 1940.

CLIPPINGER, DONN M., Building blocks from natural lightweight aggregates of New Mexico : N. Mex. Bur. Mines and Min. Res. Bull. 24, 1946.

COPELAND, R. E., and CARLSON, C. C., Tests of the resistance to rain penetration of walls built of masonry and concrete (reprint) Jour. Am. Concrete Inst. Proc., vol. 36, Nov. 1939.

FARMER, H.G., Air-entraining portland cement in concrete block: Rock Products, vol. 48, no. 1, pp. 209-217, Jan. 1945.

HANSON, E. B., and NEELANDS, W. T., The effect of curing conditions on compressive, tensile and flexural strength of concrete containing Haydite aggregate: Jour. Am. Concrete Inst., vol. 16, no. 2, pp. 105-114, Nov. 1944.

HIGHWAY RESEARCH BOARD, Use of air-entraining concrete in pavements and bridges: Current ,Road Problems, no. 13, Washington, D. C., May 1946.

LADOO, RAYMOND B., Nonmetallic minerals : McGraw Hill Book Co., Inc., New York City, pp. 455-464, 1925.

LENHART, W. B., Building third modern block plant: Rock Products, vol. 50; no. 4, pp. 163-165, April 1947.

MASON, RALPH S., Building-block boom: The Ore.-Bin, Dept. Geology and Min. Industries, vol. 9, no. 2, pp. 11-18, Feb. 1947.

MOYER, FORREST T., Lightweight aggregates for concrete: U. S. Bur. Mines Info. Circ. 7195, Jan. 1942.

RANDAL, F. A., Economics of lightweight concrete in buildings: Jour. Am. Concrete Inst., vol. 271, pp. 925-956, Mar. 1931.

TUTHILL, LEWIS H., Concrete operations in the concrete ship program: Jour. Am. Concrete Inst., vol. 16, no. 3, pp. 136-177, Jan. 1945.

WASHA, GEORGE W., and WENDT, KURT F., The properties of lightweight structural concrete made with Waylite aggregate: Jour. Am. Concrete Inst., vol. 13, no. 6, pp. 505-517, June 1942.

WENDT, KURT F., and WOODWORTH, PAUL M., Tests on concrete masonry units using tamping and vibration molding methods (reprint): Jour. Am. Concrete Inst. Proc., vol. 36, Nov. 1939.

WILK, BENJAMIN, Influence of grading on strength of concrete: Rock Products, vol. 50, no. 2, pp. 169-170, Feb. 1947.

INDEX

Figures in *italic* indicate main references.

PUBLICATIONS

PUBLICATIONS OF THE MINERAL RESOURCES SURVEY

No.	*Title and Author*	*Date*	*Price*
1	The Mineral Resources of New Mexico, Fayette A. Jones-	1915	Out of print
2	Manganese in New Mexico; E. H. Wells ----------------------	1918	Out of print
3	Oil and Gas Possibilities of the Puertecito District, Socorro and Valencia Counties, New Mexico; E. H. Wells ----------	1919	Out of print

PUBLICATIONS OF THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

BULLETINS

No.	*Title and Author*	*Date*	*Price*
4	Fluorspar in New Mexico; W. D. Johnston, Jr. (Superseded by Bulletin 21) --	1928	Out of print
5	Geologic Literature of New Mexico; T. P. Wootton (Superseded by Bulletin 22) ------------------------------------	1930	Out of print
6	Mining and Mineral Laws of New Mexico; Charles H. Fowler (Superseded by Bulletin 16) ----------------------------	1930	Out of Print
7	The Metal Resources of New Mexico and their Economic Features; S. G. Lasky and T. P. Wootton ----------------------	1933	.50
8	The Ore Deposits of Socorro County, New Mexico; S. G. Lasky ---	1932	.60
9	The Oil and Gas Resources of New Mexico; Dean E. Winchester (First edition; superseded by Bulletin 18) -------	1933	Out of print
10	The Geology and Ore Deposits of Sierra County, New Mexico; G. Townsend Harley ----------------------------------	1934	.60
11	The Geology of the Organ Mountains, with an Account of the Geology and Mineral Re-sources of Dona Ana County, New Mexico; Kingsley Charles Dunham---------------------	1935	1.00
12	The Non-Metallic Mineral Resources of New Mexico and their Economic Features (Exclusive of Fuels); S. B. Talmage and T. P. Wootton ------------------------------------	1936	.50
13	Geology and Economic Features of the Pegmatites of Taos and Rio Arriba Counties, New Mexico; Evan Just ----------	1937	.50
14	Some New Mexico Fusulinidae; C. E. Needham ------------	1937	.50
15	The Geology and Ore Deposits of Northeastern New Mexico (Exclusive of Colfax County); G. Townsend Harley --	1940	.60

16	Mining, Oil, and Mineral Laws of New Mexico; C. H. Fowler and S. B. Talmage (Supersedes Bulletin 6) ------------	1941	.75
17	Pennsylvanian System in New Mexico; M. L. Thompson ---	1942	.50
18	The Oil and Gas Resources of New Mexico; compiled by Robert L. Bates (Second edition; supersedes Bulletin 9) ------	1942	2.50
19	Manganiferous Iron-ore Deposits near silver City, New Mexico; Lawson P. Entwistle-------------------------------------	1944	.50
20	Stratigraphy of the Colorado Group, Upper Cretaceous, in Northern New Mexico ; Charles H. Rankin ---------------------	1944	Out of print
21	Fluorspar Resources of New Mexico; H. E. Rothrock, C. H. Johnson, and A. D. Hahn. (Supersedes Bulletin 4) -------------	1946	2.50
22	Geologic Literature of New Mexico Through 1944; Robert L. Bates and Marian R. Burks (Supersedes Bulletin 5) ------------	1945	.30
23	Stratigraphy and Oil-producing Zones of the Pre-San Andres Formations of Southeastern New Mexico—A Preliminary Report; Robert E. King --	1945	.50
24	Building Blocks from Natural Lightweight Materials of New Mexico; Donn M. Clippinger -------------------------------------	1946	.50
25	Mica Deposits of the Petaca District, Rio Arriba County, New Mexico, with Brief . Descriptions of the Ojo Caliente District, Rio Arriba County, and the Elk Mountain District, San Miguel County; Richard H. Jahns ---------------------------	1946	2.00
26	Geology of the Gran Quivira Quadrangle, New Mexico; Robert L. Bates, Ralph H. Wilpolt, Archie J. MacAlpin, and Georges Vorbe --	1947	.60
27	Contributions of New Mexico's Mineral Industry to World War II; compiled by T. D. Benjovsky ----------------------------	1947	.50
28	Pumice Aggregate in New Mexico — Its Uses and Potentialities ; Donn M. Clippinger and Walter E. Gay --------	1947	1.00

CIRCULARS

1	An Outline of the Mineral Resources of New Mexico E. H. Wells --	1930	Out of print
2	Geology and Ore Deposits, of the Ground Hog Mine, Central District, Grant County, New Mexico; S. G. Lasky. -------------	1930	Out of print
3	First, Second, and Third Annual Reports of the Director, and Preliminary Report for the Fourth Year; E. H. Wells ----------	1931	Out of print

4	The Hobbs Field and Other Oil and Gas Areas, Lea County, New Mexico; Dean E. Winchester --------------------------------	1931	Out of print
5	Gold Mining and Gold Deposits in New Mexico; E. H. Wells and T. P. Wootton, 1932; revised by T. P. Wootton ------------	1940	No charge
6	Carbon Dioxide in New Mexico; E. H. Wells and A. Andreas (Superseded by Circular 9) --	1938	Out of print
7	Outlook for Further Ore Discoveries in the Little Hatchet Mountains, New Mexico; S. G. Lasky ---------------------------	1940	Out of print
8	Selected Bibliography on Coal in New Mexico; Robert L. Bates ---	1943	No charge
9	Carbon Dioxide in New Mexico; Sterling B. Talmage and A. Andreas (Reprinted from Bulletin 18) ---------------------------	1942	No charge
10	Natural Light-weight Building-block Materials of New Mexico; T. D. Benjovsky and D. M. Clippinger ----------------	1945	No charge
11	Reconnaissance Survey of the Headstone Mining District, Rio Arriba County, New Mexico; T. D. Benjovsky ------------	1945	No charge
12	Future Oil Possibilities of New Mexico; Robert L. Bates -----	1946	No charge
13	Compilation of State Tax Law Relating to Mineral Properties in New Mexico; E. P. Ripley -------------------------------------	1946	No charge
14	Oil and Gas Production Data, Eddy County, New Mexico, 1943-1945; compiled by N. Raymond Lamb and W. B. Macey ---	1947	No charge
15	Tables of Fluorescent and Radioactive Minerals compiled by Robert L. Hershey ---	1947	No charge
16	New Mexico Oil and Gas Production Data for 1946 (Exclusive of Lea County); compiled by N. Raymond Lamb and W. B. Macey ---	1947	No charge

ANNUAL REPORT

1	For the Fiscal Year July 1, 1945 - June 30, 1946; E. C. Anderson ---	1946	No charge
2	For the Fiscal Year July 1, 1946-June 30, 1947 (includes Annual Report of State Inspector of Mines); E. C. Anderson--	1947	No charge

OIL AND GAS MAP

Oil and Gas Map of New Mexico; Dean E. Winchester, 1931; revised by Robert L. Bates to July, 1942. Scale about 16 miles to 1 inch. (This map is included in Bulletin 18.)	1942	$ .75

WELL LOGS

Over 5,000 typed drillers' logs of wells drilled in New Mexico -- ----------- Prices on request

PUBLICATIONS OF THE U. S. GEOLOGICAL SURVEY, FOR SALE BY THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

BULLETINS

No.	*Title and Author*	*Date*	*Price*
752	Coal Resources of the Raton Coal Field, Colfax County, New Mexico; W. T. Lee --	1924	.50
859	Geology of the Santa Rita Mining Area, New Mexico; A. C. Spencer and Sidney Paige --	1935	.40
860-A	The Coal Field from Gallup Eastward toward Mount Taylor; Julian Sears --	1934	.35
860-B	The Mount Taylor Coal Field; Charles B. Hunt ----------------	1936	1.00
860-C	The La Ventana-Chacra Mesa Coal Field; Carle H. Dane -----	1936	.40
*870	Geology and Ore Deposits of the Bayard Area, Central Mining District, New Mexico; Samuel G. Lasky --------------	1936	.80
*885	Geology and Ore Deposits of the Lordsburg Mining District, Hidalgo County, New Mexico; Samuel G. Lasky -------------	1938	1.25
922-C	Manganese Deposits in the Little Florida' Mountains, Luna County, New Mexico—A Preliminary Report; S. G. Lasky --	1940	.25
922-M	Tin Deposits of the Black Range, Catron and Sierra Counties, New Mexico; Carl Fries, Jr. ---------------------------------------	1940	.50
945-C	Beryllium and Tungsten Deposits of the Iron Mountain District, Sierra and Socorro Counties, New Mexico; R. H. Jahns ---	1944	1.25

PROFESSIONAL PAPER

*200	Geology and Ore Deposits of the Magdalena Mining District, New Mexico; G. F. Loughlin and A. H. Koschmann --	1942	2.00

MAPS AND CHARTS

Topographic map of New Mexico Scale about 8 miles to 1 inch; contour interval 100 meters --	1925	.75
Geologic Map of New Mexico; N. H. Darton. Scale about 8 miles to 1 inch; contour interval 100 meters ---------------------------	1928	1.50
A Reconnaissance and Elevation Map of Southeastern New Mexico; Walter B. Lang. Scale 4 miles to 1 inch --------------	1943	1.50
Maps Showing Thickness and General Character of the Cretaceous Deposits in the Western Interior of the United States; J. B. Reeside, Jr. Scale 225 miles to 1 inch. **Preliminary Map 10.** Oil and Gas Investigations --	1944	.25

* Prepared in cooperation with the New Mexico Bureau of Mines and Mineral Resources.

Geologic Map and Stratigraphic Sections of Permian and Pennsylvanian Rocks of Parts of San Miguel, Santa Fe, Sandoval, Bernalillo, Torrance, and Valencia Counties; North Central New Mexico; C. B. Read and others. Scale 3 miles to 1 inch. **Preliminary Map 21**, Oil and Gas Investigations -----	1944	.60
Stratigraphic Distribution of the Pennsylvanian Fusulinidae in a Part of the Sierra Nacimiento of Sandoval and Rio Arriba Counties, New Mexico; Lloyd G. Henbest and others. **Preliminary Chart 2**, Oil and Gas Investigations -------------	1944	.25
Correlation of Basal Permian and Older Rocks in Southwestern Colorado, Northwestern New Mexico Northeastern Arizona, and Southeastern Utah; N. W. Bass. **Preliminary Chart 7**, Oil and Gas Investigations ---	1944	.40
Map of Eddy and Lea Counties, Showing Oil and Gas Fields by Colors. Scale about 5½ miles to 1 inch --------------------------	1945	No charge
Geology and Asphalt Deposits of North-central Guadalupe County, New Mexico; Joseph M. Gorman and Raymond C. Robeck. Scale 1 mile to 1 inch. **Preliminary Map 44**, Oil and Gas Investigations --	1946	.60
Lucero Uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico; V. C. Kelley and G. H. Wood. Scale 3 miles to 1 inch. **Preliminary Map 47**, Oil and Gas Investigations -------	1946	.60
Stratigraphic Relations of Eocene, Paleocene, and Latest Cretaceous Formations of Eastern Side of San Juan Basin, New Mexico; C. H. Dane. **Preliminary Chart 24**, Oil and Gas Investigations --	1946	.35
Geologic Maps of a Part of the Las Vegas Basin and of the Foothills of the Sangre de Cristo Mountains, San Miguel and Mora Counties, New Mexico; S. A. Northrop, H. H. Sullwold, Jr., A. J. MacAlpin, and C. P. Rogers, Jr. Scales, 2/3 mile to 1 inch and 4 miles to inch. **Preliminary Map 54**, Oil and Gas Investigations ---	1946	.60
Geology of Nacimiento Mountains, San Pedro Mountain, and Adjacent Plateaus in Parts of Sandoval and Rio Arriba Counties, New Mexico; S. A. Northrop and G. H. Wood. Scale 11/2 miles to 1 inch. **Preliminary Map 57**, Oil and Gas Investigations --	1946	.60

*Geologic Map and Stratigraphic Sections of Paleozoic Rocks of Joyita Hills, Los Pins Mountains, and Northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico; R. H. Wilpolt, A. J. MacAlpin, R. L. Bates, and Georges Vorbe. Scale 1 mile to 1 inch. **Preliminary Map 61**, Oil and Gas Investigations --	1946	.65
*Geology of Northwestern Quay County, New Mexico; Ernest Dobrovolny, C. H. Summerson, and Robert L. Bates. **Preliminary Map 62**, Oil and Gas Investigations --------------	1946	.75
Geology and Mineral Deposits of the Gallinas District, Lincoln County, *New* Mexico; V. C. Kelley, H. E. Rothrock, and R. G. Smalley. Scale 2 miles to 1 inch. **Preliminary Map 3-211**, Strategic Minerals Investigations ---------------------------------	1946	.30
Topographic maps of approximately 80 quadrangles in New Mexico and adjacent parts of Arizona and Texas. Scales range from 1,000 feet to 1 inch, to 4 miles to 1 inch -----------		.20 each

PUBLICATION OF THE U. S. GENERAL LAND OFFICE, FOR SALE BY THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

State of New Mexico. Geographic map, scale 12 miles to 1 inch -------	1936	.35

PUBLICATIONS OF THE UNIVERSITY OF NEW MEXICO, FOR SALE BY THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

BULLETIN

Title and Author	*Date*	*Price*
Minerals of New Mexico; Stuart A. Northrop ------------------------------	1942	3.00

MAP

Mining Districts of New Mexico; Stuart A. Northrop. Scale 20 miles to 1 inch. (This map is included in the above bulletin.) ----------------	1942	.75

PUBLICATION OF THE STATE INSPECTOR OF MINES, FOR SALE BY THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

Title	*Date*	*Price*
Mining Laws of New Mexico --	1946	.25

*Prepared in cooperation with the New Mexico Bureau of Mines and Mineral Resources.