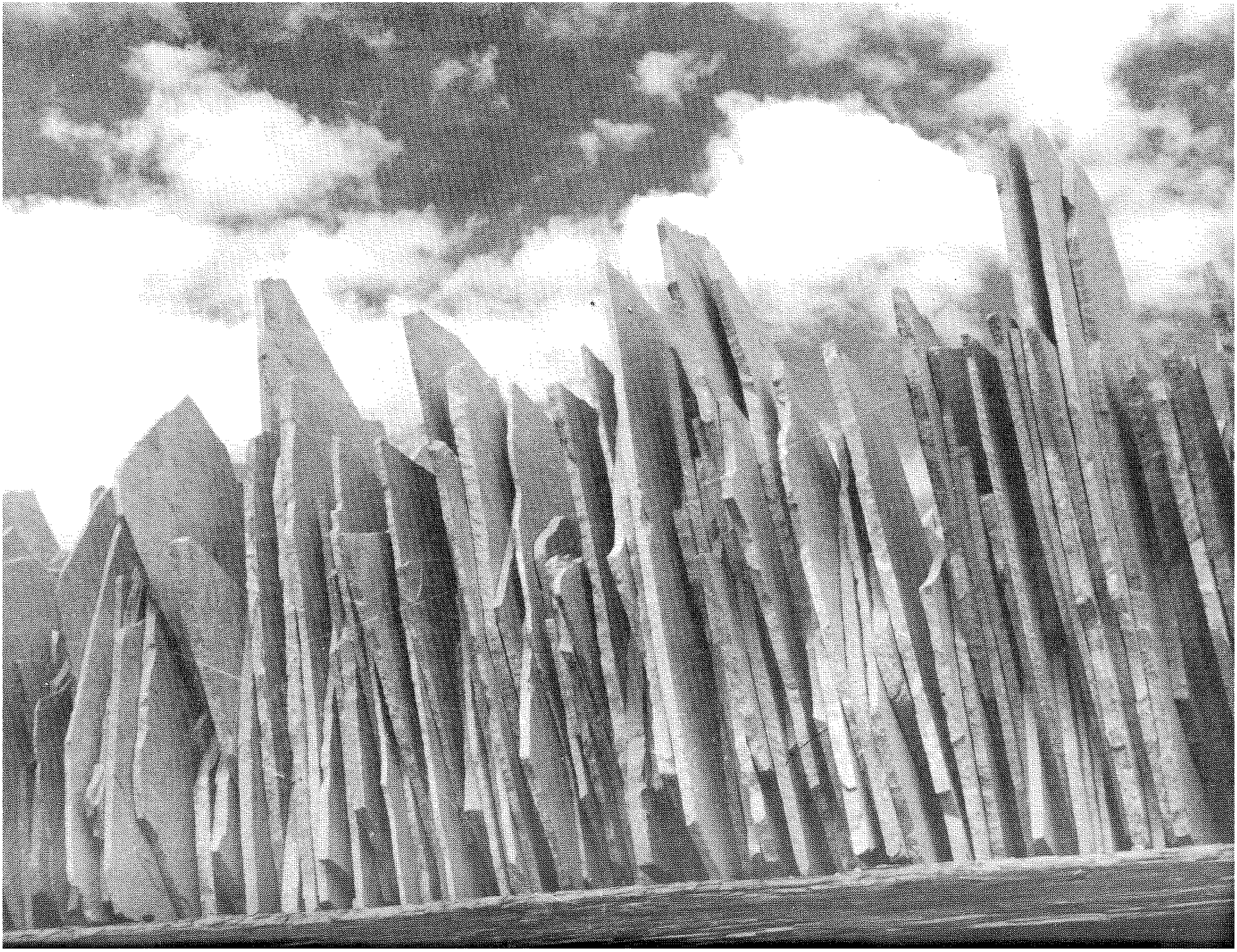
STONE IN ARIZONA



STONE IN ARIZONA

An Economic Study

prepared for

ARIZONA DEVELOPMENT BOARD

by

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I. ACKNOWLEDGMENTS

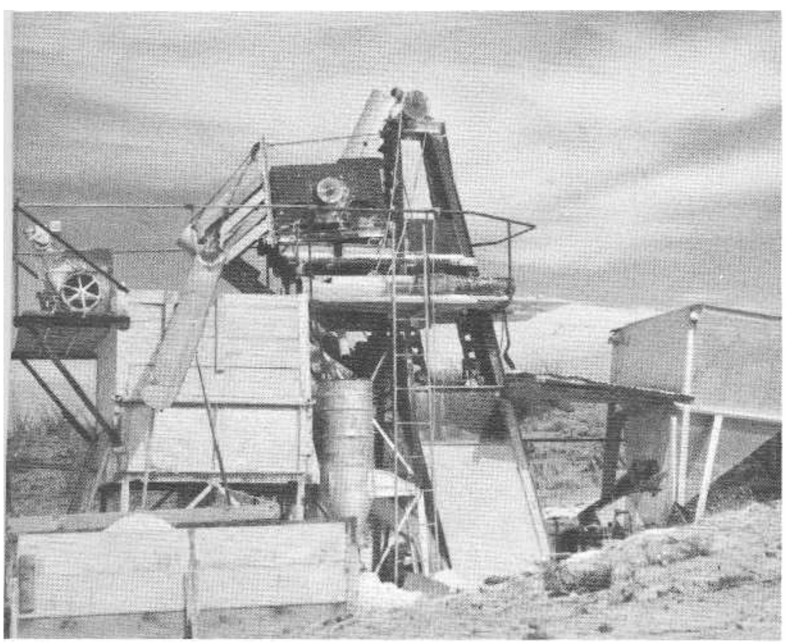
In preparing this report, many quarry operators and stone producers were contacted. Not a single one refused aid or data; each has contributed information about his experience in the stone industry, making the report possible. Use of specific data is noted in the report. In addition, several state and federal agencies made avail-able both time and information. Mr. Louis Smith and others on the staff of the Arizona Department of Mineral Resources provided valuable data on quarry locations and production. Mr. H. Wesley Peirce of the Arizona Bureau of Mines gave many valuable suggestions. Mr. Frederick C. Ryan of the Arizona State Land Department provided helpful data. Mr. Dee E. Reese and Miss Wilma Richard of the Arizona State Employment Service gave helpful data on the labor market. Also, in-formation on transportation was given freely by Mr. Hans M. Kruesl, Watson Bros. Transportation Co., Inc., Mr. Donald B. Malcolm, The Atchison, Topeka & Santa Fe Ry. Co., and Mr. C. F. Head, Southern Pacific Company.

II INTRODUCTION

The natural beauty of rock formations in Arizona is famed the world around. No wonder, then, that with the tremendous population growth in the west, stone producers and users are looking to Arizona for sources to supply the ever-increasing market. All of the principle types of building stone, and many unique varieties are available within this one state.

The purpose of this report is to draw together known data on occurrences of stone, present production techniques and problems, types and varieties of available stone, markets, labor and land conditions, and the general potential of the stone industry in Arizona. Thus, the report is primarily an economic study. Data on building stone, landscaping stone, and crushed rock used in building for its decorative purpose are included; aggregate, ballast, rip rap, etc. are not included. Compilation of complete data on as widespread and varied an industry as this would probably be impractical at this time. Therefore, an annotated bibliography has been included; reference numbers in the text indicate items in the bibliography. Reference is also made to the state and federal agencies that can provide additional data. It is hoped that this report is sufficiently detailed to show basic trends, economics, and potential to both the present producers and those considering participation in this industry.

Data have been gathered from many sources. A map is included showing by symbol the general location of many active and inactive quarries, as well as unworked prospects known to have a good potential. Over the years some stone deposits have been worked intermittently by various persons; an absolute count and check of reported locations has been unfeasable for this report. In some places several quarries are located within an area that must be represented by only a single symbol. Under such circumstances, omissions or errors in location are both unintentional and unavoidable.



III GENERAL

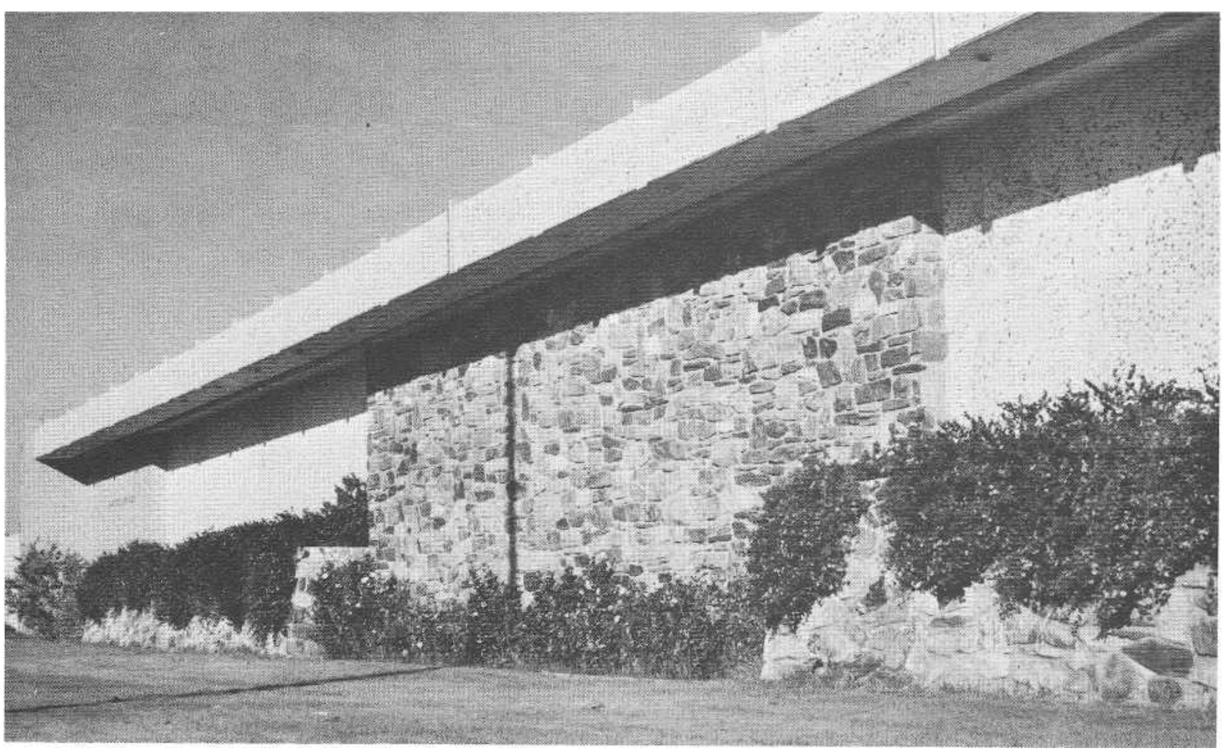
HISTORY

Stone is doubtless the world's earliest and oldest building material, prized through the ages for its strength and durability, for its adaptability to both simple and sophisticated construction needs, and for its decorative qualities. Trends in use have been determined by accessibility and local needs, transportation, changing construction and stone production methods, and by current fashions. Arizona stone has been used since the earliest settlement of the state. Until 1946, commercial production was intermittent, with local projects and use being dominant. Quarries were opened for temporary markets or individual jobs, then virtually abandoned.

After World War II, several new factors contributed simultaneously to the development of the Arizona stone industry. First, a building boom necessarily followed the war. Second, population in west coast areas and in Arizona increased beyond comprehension, compounding building needs. Third, new equipment became available, from power machines in quarries to guillotine cutters in stone yards, to high speed, economical trucks on new highways. At the same time, cross-country freight rates climbed, hampering shipping to the west from traditional stone sources in the east. While these factors may diminish somewhat, their continuing effect at a steady rate will tend to stabilize the stone industry.

Immediateley after the war, building needs were simple, and were met with available materials. As the construction gap began to close, new building techniques, materials and styles made stone popular. Aluminum and glass enjoyed novel uses, and steel in concrete changed structural requirements. By themselves they are efficient, but they tend to give a hard, cold appearance. Natural stone was found to give texture and warmth to structures. So the age-old concept of stone used

Section of field stone in a wall of cast slabs with exposed aggregate.



primarily structurally, changed to use of stone as a facing or curtain wall, and use in places where its decorative qualities are paramount but durability, strength, and low maintenance are also desired.

In addition, use of uncut and of crushed stone increased. New building methods now allow for low pitched roofs with crushed stone coatings, and highly decorative and efficient uses of terrazo have become popular. Style changes have introduced exposed aggregate, again combining the structural factors with decorative qualities. Fashions in landscaping have sent prospectors to the hills for sources of flagstone, rubble, and crushed rock for walks, driveways, and gardens. Fines from crushing operations are being used in cast products.

One of the most important style trends has been to design almost any uncut stone into large wall areas. Even otherwise nondescript stones, that might as individual pieces lack attractiveness, such as field stone, talus, or slabby boulders, may be used with attractive results. The only requirement seems to be a common color or texture, such that the whole effect is that of a large mass. This mass effect, combined with modern materials such as aluminum and glass gives an appearance of both dignity and stability found only in older buildings made wholly of stone. Few new business buildings in the Phoenix area lack a mass effect stone wall. Another trend opening new design possibilities has been to different mortar joints; some are recessed, others abnormally wide. Some stones are cast into poured walls, giving the stone an appearance of floating. In all, keeping abreast of design trends has become an important phase of the stone industry.

PRESENT USES

Today the uses of Arizona stone are many and varied,[15] but they can be grouped as follows:

1. *Buildings* — structural and decorative dimension and uncut
2. *Roofing* -- granular, crushed rock, insulation
3. *Terrazo* — granules, aggregate
4. *Inside flooring* — sheets of stone
5. *Retaining and yardwall* — cut and uncut
6. *Patios and walks* — flagstone and crushed rocks
7. *Furniture* -- table tops, benches
8. *Monuments*
9. *Fireplaces and fireboxes*
10. *Landscaping* — ground cover, uncut and crushed
11. *Landscaping* — planters, edging
12. *Fines* — aggregate, swimming pool copings and plaster

INDUSTRY ECONOMIC STATUS

Basically, growth of the stone industry is dependent on the construction industry, and in turn, on population growth. The full potential of the state's resources, and the most fficient production are realized when a stable m rket of a size able to warrant substantial capita investment is attained. Although new uses of stone, wider range of products, and vigorous sales promotion can in-crease demand, long-term stability requires a large population within the optimum marketing area.

Obviously, before the end of World War II, Arizona alone could not suppoit a large stone industry similar to those in the eastern United States. Even west coast markets were nbt easily developed. Today, however, factors mentioned above appear to provide a basis for a strong stone industry. Heretofore, producers might be said to have "felt their way" in expanding their part of the production. Today, market demands sometimes exceed supply, and stone materials usually available in Arizona are even imported. Today, producers are looking to mechanization and otherwise increasing production, and to assuming processing functions now being done elsewhere.

EXPLORATION

After being prospected for, more than a century, Arizona would seem to have no geologic secrets. Indeed, most of its surface has been trod by explorers, prospectors, miners, and geologists. Also, inasmuch as nearly all rock formations can yield some material to meet basic construction requirements, the need for exploration for stone quarries would seem small. However, the character of rock formations may vary greatly froth place to place,[2] and quality and style specifications require increasingly greater selectivity of quarry sites. In order for a producer to compete for markets, he must consider such things as accessibility, transportation, labor supply, and housing conditions in the choice of a quarry site. Moreover, the success of a quarry may depend on geologic changes or variations in the stone not apparent except by close examination; a marble quarry may run into a fault or shear zone, or a good "dune set" of beds in sandstone may be truncated by a younger set. Many abandoned quarries are testimony to the need for careful selection of sites.

In a recent publication, L. W. Currier [7] has given detailed procedure for the broad, geologic exploration for quarry sites, and also describes the industrial factors in evaluation of deposits, with particular reference to traditional producing areas in the eastern United States. He points out that the lower production from the far western states is not a measure of availability of suitable deposits, but is due to factors of population, economic conditions, and industrial development. These factors, plus the facts that western deposits are more complex in distribution,[8] and market demands are for new construction forms and new colors and textures, make exploration requirements somewhat different in Arizona.

It should also be noted that for stone production in Arizona, the character of most rock formations at any significant depth is not known. That is, no quarries have been developed to depths far be-low the weathered zone, or into `fresh' rock that is not affected by surface considerations of topography, chemical alteration, fracturing, etc. Some formations may be seen at depth in mines, drill hole cores, and large open pits, but generally these are not cut in rock types that might be considered for large-scale stone production.

Below is a brief outline of important considerations in exploring and prospecting for stone deposits in Arizona:

Type of Stone — sandstone, schist, marble, etc.
geologic formation; distribution

Economic factors — markets land status*
access
transportation
labor supply

Physical characteristics [1] — color and texture strength;
compressive, tensile, shear, hardness, toughness
porosity and absorption
insulation, reflection

Workability — topography
overburden
fractures
cleavage and partings
weathering
trends at depth
cutability
reserves

* ***See*** *land status considerations page 38*

PRODUCTION AND VALUES

By far the bulk of Arizona's stone production has been carried on since World War II. Gross production figures have beer compiled from time to time,[23] [26] but only since 1953 have they begun to show consistent trends, as below :

STONE PRODUCTION IN ARIZONA
(From Area Reports, Mineral Industry Surveys, U. S. Bur. Mines)

YEAR	TONS	VALUE
1954	1,205,452	$1,914,315
1955	1,600,939	2,328,566
1956	1,623,000	2,475,000
1957	2,101,000	2,982,000
1958	1,528,000	2,731,000
1959	2,468,000	3,998,000

The above figures are reportedly from mine shipments, sales, or marketable production, including consumption by producers. The average price per ton of approximately $1.60 indicates that the figures probably represent mostly production of limestone for cement, and of :rushed rock for aggregate. Even the lowest values (quarry prices of unprocessed rock) of stone used for granules and for dimension stone are in the magnitude of $4 and $10 per ton respectively. Because of the newness of the stone industry, and its wide range of size and distribution of operations, accurate data on total production and values are not available.

However, a compilation f estimates by producers of dimension stone an flagstone, crushed stone as used in this report, nd decorative rock used in construction and landscaping, indicates the following general estimate:

YEAR	TONS	VALUE (wholesale-processed)
1959	75,000	$1,575,000

A more detailed account of values may be seen from a consideration of average quarry and processed prices for representative materials. For example, in the case of marble crushed for roofing materials, some rock is sold F.O.B. quarries; having passed an 8-12 inch grizzly and been roughly screened of fines less than to $3/_4$ inches. Here, prices average about $4.00 per ton. After processing, the wholesale market price varies from $13 to $20 per ton, depending on bulk or bagged, transportation allowed, etc. In the case of sandstone, quarry products consist mostly of large sheets in a variety of thicknesses as needed to supply the market. Here, average value at the quarry is about $7. 50 per ton, in a range from $5.00 to $11.00 per ton, depending on quality. Because of the many different products made in processing, wholesale prices here vary widely; small pieces of poor grade flagstone may sell for little more than $10.00 per ton, while special cuts will run more than $30.00 per ton.

Thus, it may be seen that in 1960, at least 85, 000 tons of stone were produced at an average wholesale value of $21-$22 per ton. Coupled with the retail business in Arizona, the State's stone industry may be said to be well over $2,000,000 gross.

IV RESOURCES

SANDSTONE

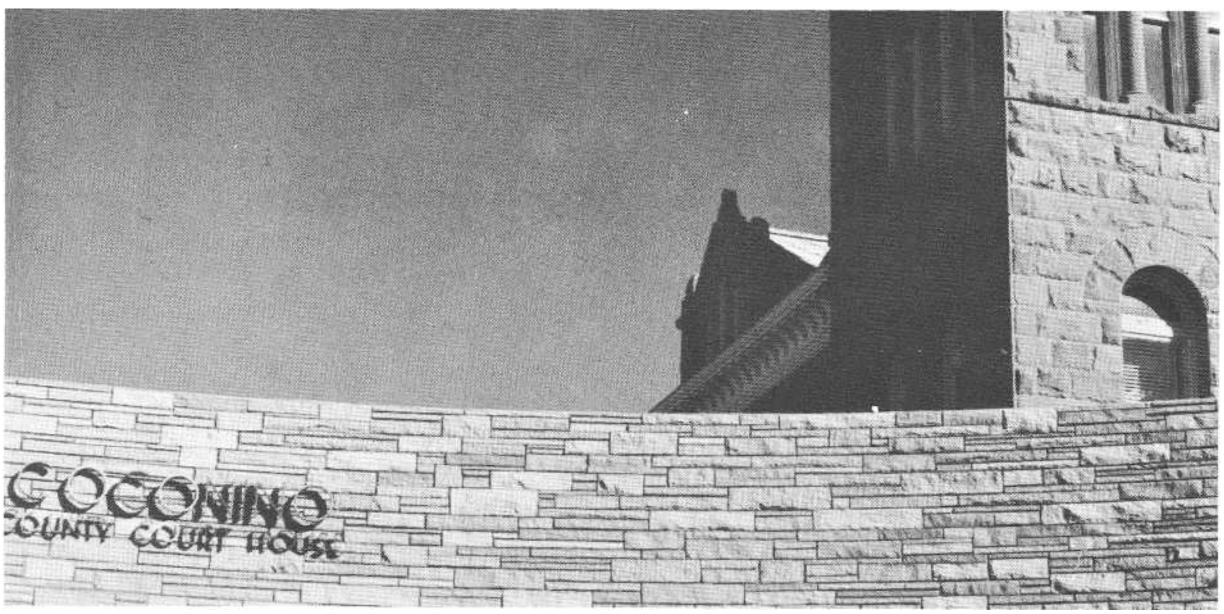
At the present time, production from the popular Coconino sandstone dominates the stone industry in Arizona. It probably accounts for 75 per cent of both tonnage produced and dollar volume of sales. Although flagstone and dimension stone are quarried from as far east as Holbrook, and as far west as Seligman, the town of Ashfork is known as the center of production. Railroad cars and trucks leave Ashfork daily with loads consigned to all parts of the United States.

Geology and areal extent

The Coconino sandstone is a uniformly medium-grained, well-cemented, generally pink, red, or white, eolian sandstone of Permian Age. As part of the Permian-Pennsylvanian Aubrey Group, this formation underlies the Kaibab limestone, and overlies the Hermit shale and Supai formation. Stratigraphically, its thickness is from 40 feet to more than 400 feet. Thus, it underlies the entire Coconino plateau in northern and northeastern Arizona.

Extensive outcrops of Coconino sandstone

Old and new—Tower of Moenkopi sandstone, and new wall of Coconino sandstone.



are found in Mohave, Coconino, Yavapai, Navajo, Apache, and Gila Counties.[11] However, due to its position under a hard, relatively resistant limestone, and over softer shales and sandstones, its out-crops do not generally cover the very broad areas of northern Arizona as do the Kaibab limestone and other formations. Although not practical as producing areas, the most extensive outcrops are in the rim of the Colorado River and its tributaries, crossing Coconino and into Mohave Counties. The beds are well exposed at the Grand Canyon.

Some of the more important areas of present and potential production of Coconino sandstone are as follows: In Coconino County north of Seligman, the sandstone forms the slopes of Aubrey Cliffs under a capping of Kaibab limestone. Approximately 10 miles northwest, north, and northeast of Ashfork, Coconino sandstone is exposed or under slight soil cover over more than 75 square miles. From east of Drake to the Oak Creek Canyon area, it crops out along the Coconino and Yavapai Counties border, where it forms the southern edge of the Colorado Plateau. In Yavapai County about 15 miles west of Ashfork it is exposed over a few square miles near Picacho Mountain. In Navajo County, the Coconino sandstone covers many square miles in scattered areas south, southwest, and west of Holbrook; exposures in valleys tributary to the Little Colorado River are abundant. Less accessible are outcrops along the Mogollon Rim in northern Gila County, and wide areas southeast of Show Low in southern Navajo and northeastern Gila Counties. The widest single area of Coconino sandstone is in northern Apache County on the Navajo Indian Reservation. Here, the Coconino sandstone and DeChelly sandstone are undiffrentiated.

Structure

In general, and as a formation, the Coconino sandstone beds are nearly flat-lying. In places, folding and faulting have created structural dips up to more than 45 degrees, but beds dipping steeply enough to create problems in quarrying are rare. However, this formation is noted for its intense cross-bedding. Stratigraphic beds are from thin seams to more than 20 feet thick, but within these beds the arcuate cross-bedding is dominant. Thus, in quarrying, thin sheets are split along these arcuate lines. A single zone of cross-bedding is some-times only 20-30 feet in length, but more often the best quarries are in zones up to more than 100 feet long.

Fractures across the bedding are not closely spaced. Parting is generally fair to excellent, but some massive zones 1-3 feet thick are present. Most parting surfaces are smooth and nearly flat; surfaces with ripple marks are sometimes found.

Composition and physical character

The Coconino sandstone consists essentially of rounded grains of quartz which are cemented by silica. As a formation, other materials are present, mostly as thin seams of clay minerals, mica, and secondary silica, calcite, and gypsum. Inasmuch as these thin seams are usually culled in quarrying, the rock produced is an even-textured, quartz sandstone. Of this rock, the silica content is generally more than 90% and sometimes more than 97%. Minor amounts of feldspar, mica, and iron oxide are the most notable accessories; heavy minerals are present in academic quantity only.

Color variations are due largely to the quantity of iron oxide present. Gradations from white through pink to red are dominant; such variations are broad in scale, both vertically and laterally. Thus, any single quarry usually produces only one color with small variation. In some quarries, the white tends to gray or to pink, and the red tends to tan, buff or to pink. Rarely, yellowish, purple, lavendar, and even banded colors are found, but not in large quantities.

Porosity varies from approximately *7%* to as much as 19%. Moisture content varies from quarry to finished stone; rock in place is usually damp, but tends to dry quickly on exposure. One sample of finished stone tested 0.3% moisture.* Compressive or crushing strength is generally high, but may vary according to cementing and weathering. Samples from the Navajo Indian Reservation tested is from 2,225 pounds per square inch to 12,975 psi, with an average of 5,382 psi. However, three samples of quality dimension stone* tested 14,795,

** Dunbar Stone Co., Ashfork, Arizona*

013,450, and 13,993 psi.

Weathered rock, that is rock buried in soil or within a few feet of the surface, tends to be gray, if white at depth, and maroon, if red or pink at depth. It also is more porous, may be friable (crumbly), and is weaker or lower in compressive strength.

Production

To the uninitiated, production of flagstone and dimension stone from sandstone beds may seem fairly simple. Most pieces of "float" seen on mile after mile of 'surface may be attractive for a stepping stone or two in a garden or patio, but production of specified sizes, consistent colors, and uniform strength, all in large quantities for demanding markets requires careful exploration, skilled quarrying, and efficient handling. Present practice is as follows:

1. Prospecting for likely quarry sites. Considerations are accessibility, terrain, and transporta tion terminals, as well as quality of rock. Exploration usually consists of finding an exposed bed of proper angles of cross-bedding in a wash or valley, or of bull-dozing the surface in timbered or soil-covered areas.

2. Overburden or weathered rock is removed by bulldozing or simple quarrying; sometimes blasting is done to develop a back seam to work toward.

3. Approximately 4-inch thick sheets are wedged and barred from in place. Massive beds unsuitable for splitting are left as islands, or cut around and bull-dozed to waste pits.

4. Sheets are split by wedging, and broken to size for handling, and graded and stacked on edge. Handling in quarries is aided by roller conveyers and by rubber-tired, 2-wheel carts than can handle up to 500 pounds.

5. Graded rock is loaded on flat bed trucks and hauled from quarries to cutting yards. Grad-

Arcuate bedding in Coconino sandstone____beds rise to right and left of truck in bottom of "trough".

ing in quarries is by size, color, firmness, smoothness, lack of scale, etc. Some operators market their products at this point, hauling to dealer's sales yards or to consumers in cities, or selling by contract to cutters who further process the stone; sales are by weight.

6. At cutter's yards, the stone is again sorted, graded, sized and cut to dimension. Cutters are the "guillotine" type, hydraulically operated. Flat sheets of stone up to 12 inches thick, and as much as 5 feet in longest dimension, move under the cutter blade on rollers. The cutter consists of a row of "teeth", each powered separately, which are lowered in unison to the surface of the stone. The individual teeth fit any irregularities in the surface. Power is applied, and the teeth snap the stone, creating a "split face." Eleven of these cutters of different capacities are now in use in Arizona.

7. Finished stone is again graded by cut dimensions and stacked on pallets, bound with steel tape, and in some cases covered with paper or plastic. Palleted stone is stored in yards, then loaded on trucks or railroad cars for shipment to dealers, or direct to jobs.

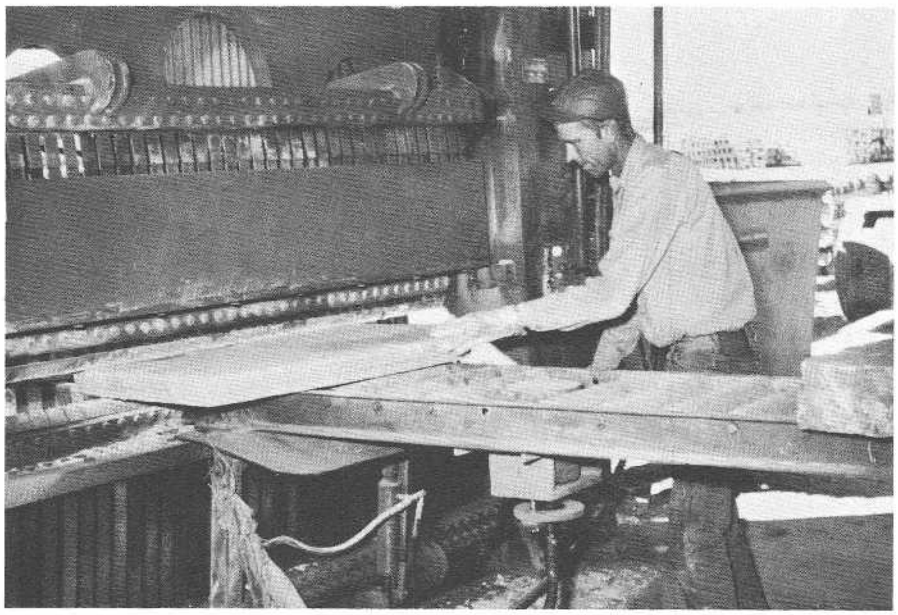
8. Flagstone is often transferred from quarry trucks to docks, and then loaded direct to cross-country trucks or railroad cars for shipment.

9. Recently one operator installed a wire saw. Massive pieces unsuitable for splitting, are rolled

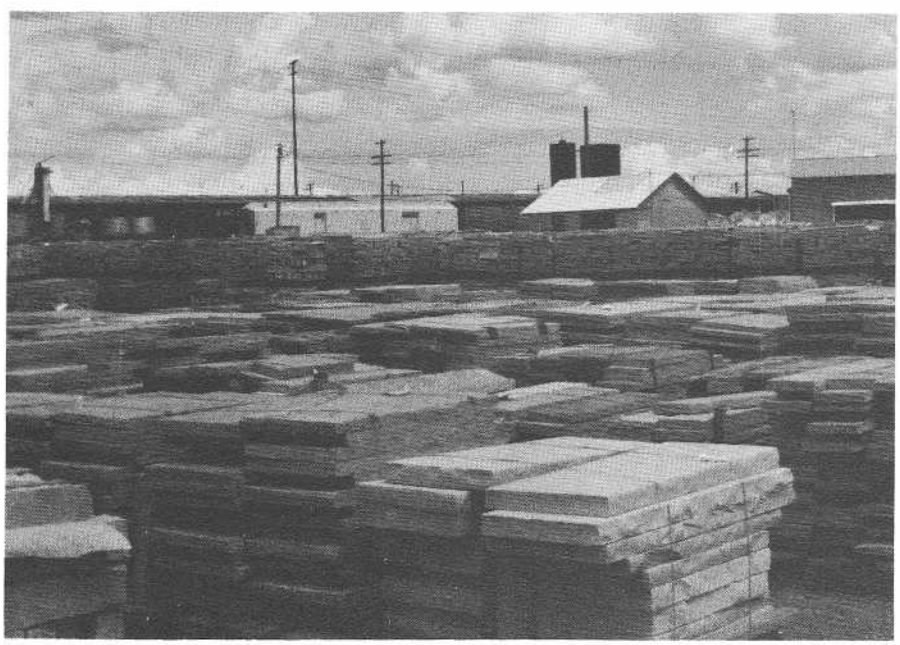
Quarry in Coconino sandstone, showing wedging, waste, and stone stacked for shipment.

Guillotine stone cutter in quarry of Coconino sandstone.

Conveyor from stone cutting house.



Close view of guillotine cutting Coconino sandstone.



Palleted Coconino sandstone ready for shipment.

under the saw on tracks. A continuous, multiple-strand wire on large reels runs over the slab immersed in abrasive grit, cutting large, thin sheets.

In order to meet quality demands, the above production procedure involves considerable waste. Approximately 1/3 of the rock handled in the development of a quarry is culled into waste or "muck" piles. During quarrying 2/3 to as high as 80% of the rock handled is wasted off. At the cutting yard, again about 1/3 of the rock brought in is ultimately waste. some operators say that after a quarry is developed and is operating efficiently, the waste rock can be held to 60% of the total handled.

Shipping

Coconino sandstone is shipped by both rail-road and truck. A main line of the Atchison, To-peka, and Santa Fe Railroad trends east-west across the state, and through major areas of stone production. The largest rail shipments are made from Ashfork and Williams. Most of the stone destined for points in Arizona is hauled by truck. Also, large quantities are shipped out of the state via truck. particularly to the west coast.

Some Coconino sandstone producers prefer shipment by rail, but customers often prefer truck delivery. Trucking allows for "back door delivery" to individual jobs or to dealer's yards, and obviates double handling. In addition, large dealers in construction materials may haul with their own trucks, and some trucking companies are also in the materials business. The larger producers ship approximately equal amounts by truck and rail. Loads are. of course, larger on railroad cars. (See discussion of transportation and freight rates be-low.)

Currently. approximately 70% of Coconino sandstone produced is shipped to the west coast. particularly to Los Angeles. San Francisco, and Seattle. About 10% is used in Arizona, and 20% goes to midwest and eastern markets. Some is being shipped as far as Alaska. Canada, and Hawaii. With only the post-war period of development, Arizona's Coconino sandstone is becoming well known throughout the United States.

Costs

Under present conditions, and granting con-siderable variation between different operators, the proportions of costs for extracting and processing Coconino sandstone are approximately as follows:

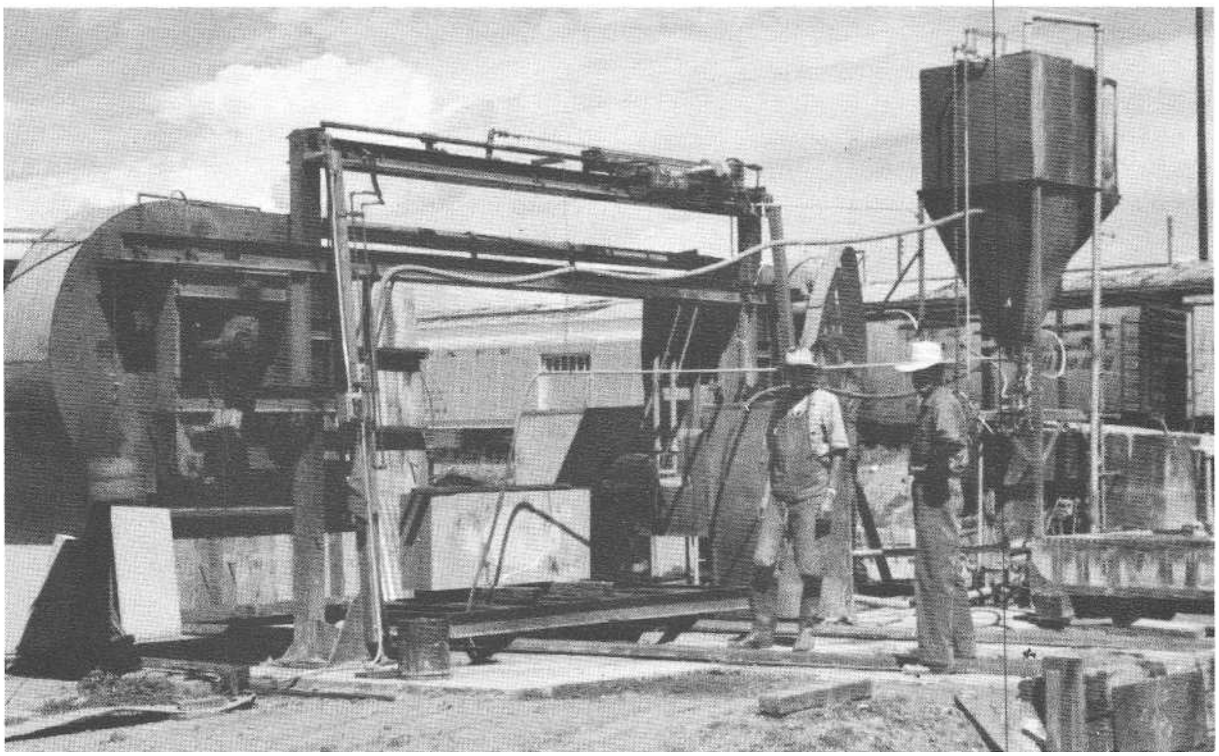
Quarrying	30%
Haul quarry to yard	9%
Cutting, grading, packaging	30%
Haul to destination (customer)	
Overhead, development, profit	31%

Specifications, products, trends in use

The qualities that make Coconino sandstone popular are due to several characteristics that make it an excellent building stone. First, of course, is its lasting natural beauty. Attractive colors are avail-able, and coupled with its general linear form the stone is highly adaptable architecturally. The popular, informal, rustic effects may be attained, as well as the more formal requirements of public buildings, churches, and office buildings.

Physical characteristics of this stone also make it desirable. It is durable, it does not contain minerals that oxidize or weather, causing stains, it can easily be kept clean, and it can be cut to clean edges. Moreover, it competes well with brick and other manufactured materials in close tolerance to dimensions. One producer is marketing 117 sizes, with thickness of 1/ 16 inch intervals. Either, or both split faces and parting surfaces may be ex-posed. Special orders may be filled to the most ex-acting architectural needs. Flagstone in large sheets is desirable for particular purposes. Thus, variety itself allows a wide range of uses.

Prior to World War II, only small amounts of dark red, weathered, surface rock were available; the unweathered rock beneath the soil had no value. This flagstone was used primarily for very rustic settings, and although considerable amounts are sold today, the trend in quantity has been to semi-formal uses. As the Coconino sandstone be-came popular, a basic change in stone use was taking place. Due to new developments in use of steel and cement, demand for stone blocks for structural purposes was supplanted by a much greater need for decorative veneers, facings, and



Stationary wire saw cutting Coconino sandstone.

urn. Specifications became more rigid. In order to meet both design and structural needs, new production techniques from quarry to final delivery had to be devised for this stone. Thus, grading in quarries assures firm, smooth-surfaced rock of consistent color; the new, multi-toothed, guillotine cutter makes cleaner split faces; close tolerance in thickness allows designers freedom and promotes speed and efficient use of material by masons.

As a result, products now being produced are numerous. Large and small operators produce flagstone in a variety of colors, thicknesses, and grades. Cut stone is produced in thickness from 1/2 to 12 inches, and in forms for ashlar strip for veneer, for treads, sills, lintels and copings. Table tops and large sheets are available. Broken stone is available for informal landscaping. Colors may be matched, and special orders for extraordinary products are solicited. At least one company is packaging do-it-yourself kits of stone cut to dimensions suitable for building home improvements, such as barbecue fireplaces and planters. At least one company is marketing sized and color-grade granules for roofing.

Problems

Some of the problems facing the sandstone industry in Arizona are normal to the growth of any new industry. Developing new markets and new products, meeting more and more rigid specifications, and developing research are common needs. other problems are peculiar to Arizona's sandstone industry:

1. A *skilled labor force* has had to be created. The State's small population, and location remote from traditional stone producing areas conspire to provide few experienced stone workers. As fluctuating markets are becomin stabilized, working conditions are becoming better.

2. *Handling of waste* is a problem that will eventually be reduced, possibly by new by-products, or by mechanization, or by improved quarry techniques. At present, demand for high quality forces high waste factors on most operators.

3. Mechanization has had to grow with the industry and markets. A few years ago, nearly all work was done by hand. Today, light and some heavy machinery are used. As the industry grows, the eventuality may be machines designed expressly for handling Coconino sandstone.

4. Improvement of products is a continuing problem. Although a certain amount of sandstone will always be demanded for its unique characteristics, volume production and sales will depend on meeting competition of brick, artificial stone, aluminum, glass and other materials that may be substituted for stone in designs. This means primarily holding costs down by efficient production, and making a product that may be installed easily and cheaply.

5. New exploration techniques are needed to provide good quarries. Again, as the industry grows, capital will become available for more thorough field exploration, and research may develop criteria for choosing quarry sites.

In the total picture, none of the problems appears insurmountable. Resourcefulness, determination, and dedication to quality have already made the Coconino sandstone famous. Operators have confidence in their raw material, and end users have confidence in the products.

Moenkopi formation

Sandstone from the Moenkopi formation (Triassic) has been used extensively for construction in Northern Arizona, and has been shipped out of Arizona as building stone. The Moenkopi formation is exposed over wide areas in Navajo and Apache Counties," and in northern and eastern Coconino County. It consists of uniform shades of maroon and chocolate-colored sandstone and shale beds. The sandstone occurs in beds from a few inches to several feet thick, separated in places by thin partings up to thick beds of shale. The sandstone is generally massive within beds, and does not split easily, as does the Coconino sandstone. Although vertical jointing is common, large blocks may be quarried in places, and the stone may be cut and shaped. Fairly new buildings on the campus of Arizona State College at Flagstaff are made of sandstone from the Moenkopi formation.

Moenkopi sandstone deposits along the railroad from Flagstaff to Holbrook have been quarried extensively. This hard stone commonly caps mesas, making quarrying somewhat easier. Deposits on the Navajo Indian Reservation are reported to be good for dimension stone.

DeChelly sandstone

In a description of dimension stone on the Navajo-Hopi Indian Reservations, H. Wesley Peirce gives considerable data on the DeChelly sandstone (Permian) . Comparisons are made with the Coconino sandstone. Regarding stone as a whole in this area, he reports, "Of the sandstone deposits, the upper unit of the DeChelly sandstone offers the best potential for a good commercial stone."

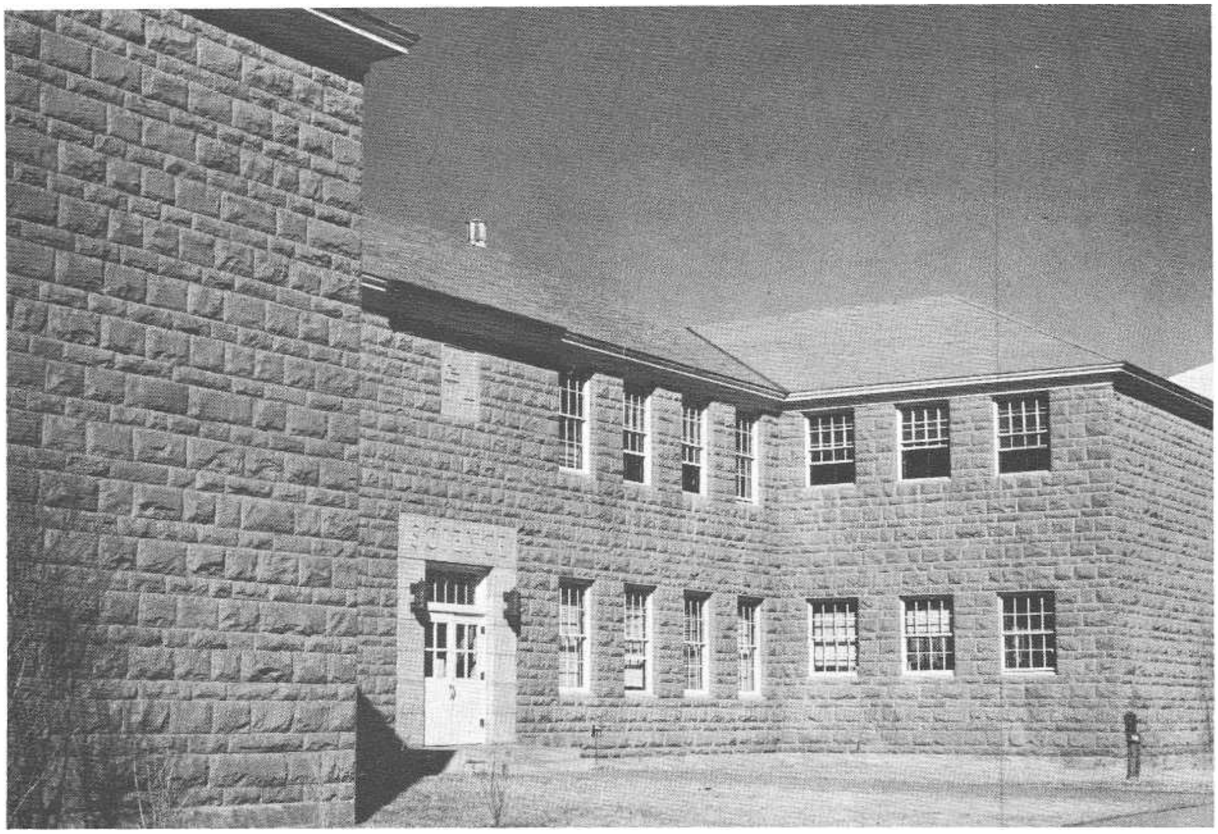
MARBLE

Occurrances of marble as a geologic rock type are numerous but widely scattered in Arizona. Many varieties are available, and many deposits have had intermittent production. Past production includes saw blocks and polished slabs, but current production consists almost entirely of crushed marble for terrazzo, roofing materials and exposed aggregate. Increased markets, and the installation of modern extraction and processing facilities could make Arizona marble compete favorably with any other source of this traditionally elegant stone.

Due to the variety of types of marble and of geologic settings, neither a general description such as for the Coconino sandstone is sufficient, nor are detailed descriptions of individual deposits appropriate here. Therefore, the following consists of pertinent general features, with some detail concerning certain regions having common characteristics.

Geology and Areal Extent

Geologically, marble deposits are generally treated as a part of limestone and dolomite stratigraphy. That is, the basic sedimentary units are limestone and dolomite, and these have been more or less metamorphosed to marble. In some places, the metamorphism is local, creating small and irregularly-spaced marble deposits, and in other places the marmarization is continuous and wide-spread. The type of marble in any deposit is due



Recent use of Moenkopi sandstone.

essentially to first, the nature of the original formation, its composition, bedding, intercalated layers such as shale and sandstone, fossils, and structure. Secondly, the types and intensity of metamorphism determine the character of the marble. Thus, if a pure limestone, white and without intercalated beds of shale or sandstone, has been subjected to folding (dynamic metamorphism) only, the mineral calcite ($CaCO_3$) making up the limestone may be recrystallized to a white and otherwise featureless, massive marble. On the other hand, an impure limestone, perhaps dolomite[9] ($CaMg(CO_3)_2$,) containing iron and other colored oxides, and containing shaley and sandy partings or beds, may have been subjected not only to folding and faulting, but to intense thermal metamorphism, and metmorphism created by the introduction of other materials through veins or impregnation by solutions. Here, obviously, the resulting marble will be greatly different from the original rock. It may be colored, possibly with several hues, veined and streaked with new minerals, or the original rock may have been fractured and the fragments cemented by a metamorphic matrix. Thus, the more abundant the variety of original and introduced minerals, and the more intense the crustal movement, heat, and pressure, the more complex in color and texture the marble will be.

It may be seen that the more varigated marbles have undergone severe changes that obscure the original character of the limestone formation. Age correlations are, therefore, difficult at best. In Arizona, although some Cretaceous limestones are locally marmarized, the bulk of the marble deposits are Permian to Devonian in age. In some cases, early detailed dating has been abandoned for the general age of Paleozoic undivided," or even Paleozoic and Mesozoic undivided. Also, it may be seen that contrary to the consistently similar geologic settings of deposits of Coconino sandstone, marble deposits are likely to vary greatly even in the same region.

Marble deposits are particularly abundant in the southern and western parts of the state. De-posits that have been exploited, although not all inclusive, may be grouped roughly as follows:

1. Harquahala Mountains
2. Tucson region
3. Dragoon and Chiricahua Mountains

1. *Harquahala Mountains*, including the Little Harquahala Mountains.

Here, Paleozoic and Mesozoic limestones have been locally marmarized in a zone trending north-east from about 10 miles southeast of Hope in Yuma County, across the boundary and into Maricopa County to about 12 miles southwest of Aguila. In a country rock of granite, gneiss, and schist, sedimentary beds have been altered to marble and quartzite largely by metamorphic action related to Cretaceous andesitic volcanics, and diabasic dikes.

Probably the best exposed marble, and fairly representative of the area is in a zone on the north-west side of the Harquahala Mountains, where limestone with intercalated shale seams and limey sediments have been folded and faulted and intruded by basic material. Irregular masses of dark gray, dark brown, and reddish brown, veined marble are present together with irregular masses or large blocks of white, pink and green marble. On the weathered surface, the former is dark brown, while the highly-colored marble is largely a dirty white or gray color.

Production in the area appears to have been concentrated on the brightly-colored stone. This is probably dominantly white, but is colored pink and green near veins and dikes. Metamorphism pro-gressed away from the intrusive features, largely along original bedding planes. The resulting stone is vari-colored; in places is consists of alternating pink, green and white beds of various thicknesses from less than an inch to more than one foot thick, and in other places a mottled pink and green is present. Some of the original shaley seams have been converted to a greenish-gray mica.

This attractive rock appears to he localized in large blocks, at most several tens of feet in longest dimension. The dark, reddish-brown portion is mostly dense, fine-grained, and tough, probably with some silification. The colored facies are fine to coarse-grained, dense in small units, but tend to part along veins and micaceous bedding planes; they have a frosted appearance in both fresh fractures and polished slabs.

2. Tucson region.

Deposits of white marble are being exploited north, southwest, and southeast of Tucson. In Pinal County, north of Tucson and about 5 miles southwest of Oracle Junction, a small area of coarsely-crystalline marble dated with Carboniferous and Devonian formations occurs on Precambrian granite country rock; the total area of the marble deposit is less than one square mile, but substantial reserves are present. Original bedding and stratification have been lost. As deep as present workings show, the pure white, dense rock is fairly highly fractured.

Approximately 30 miles southwest of Tucson, along the west side of the Sierrita Mountains, Pale-ozoic beds are present in northwest trending bands. The formations are up to mile wide and extend over more than 8 miles. Marmarization has generally produced a massive to highly fractured, fine to coarsely crystalline, white to gray marble, being exploited for roofing and other crushed rock uses.

The geology of the Sierrita Mountain region is complex. The Paleozoic beds lie within an area of Cretaceous sediments and granitic intrusions. These have been affected by intrusion of both Cretaceous and Tertiary lavas which, together with intense faulting, further complicate the picture. Nevertheless, in any one locality, the geology of substantial deposits of marble may be determined.

In areas currently being worked, pure white mar-ble is sought. Exposures show considerable variation in color, texture, and fracturing. Discernible bedding is fairly regular, but fracturing is also fairly intense. The rock breaks along what may be bed-ding planes, with beds being 2 inches to 2 1/2 feet thick and an average of about 9 inches. Iron stain and some pale pink and green zones are present. In addition, apparently discontinuous sandy and shaley facies are present. The white marble is reported to be a very high lime rock.

Approximately 27 miles southeast of Tucson, and 6 or more miles south and southeast of Mountain View, other deposits of white marble are being exploited. Here again, Paleozoic beds occur in complex structural relations with Cretaceous sediments, and with younger granite and diorite porphyry intrusions; some of the marble may be Cretaceous in age. Dirty-gray on the weathered surface, the marble is brilliantly white, and is medium to coarsely crystalline in fresh exposure. Fracturing is fairly intense, but none of the quarries extend to very great depth.

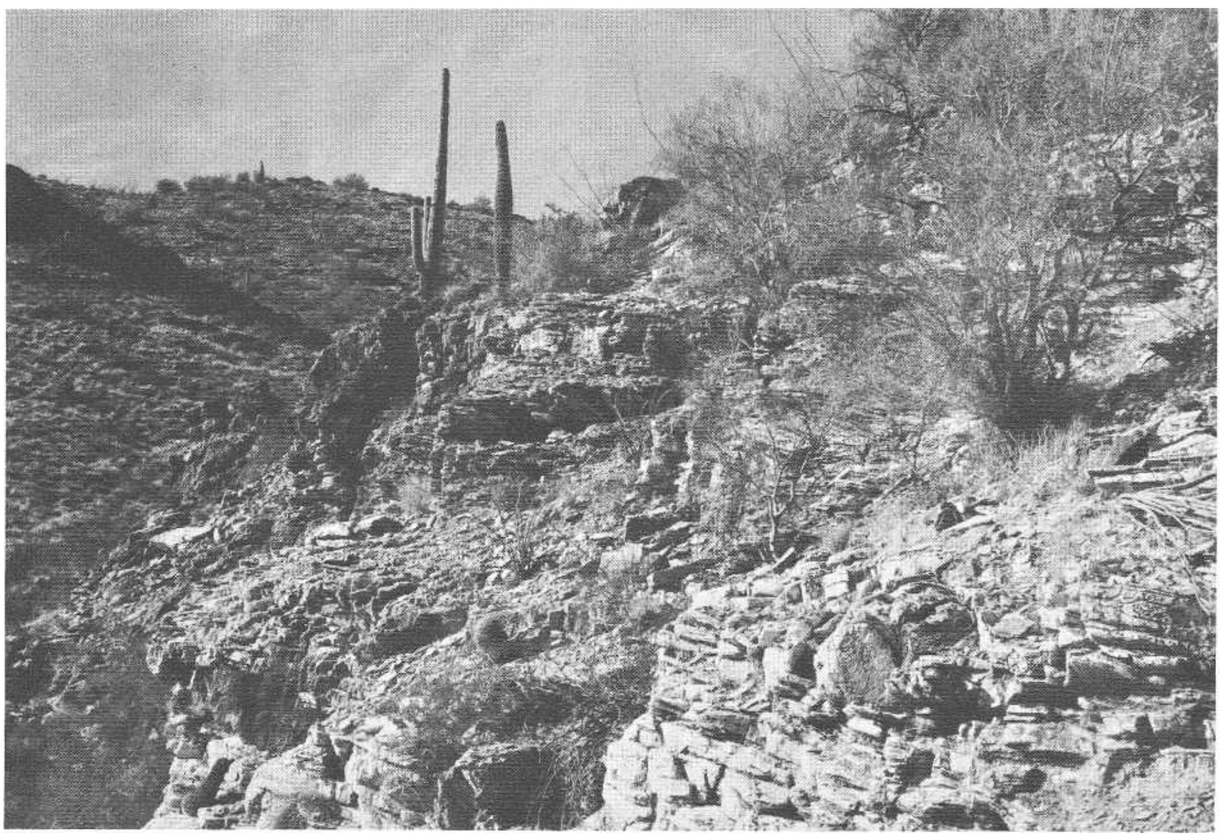
In the northwest corner of Santa Cruz County, about 3 miles east of Amado, Paleozoic beds include another deposit of white marble that has been quarried in the past. The areal extent is not great, but local reserves may be large. Here, the Paleozoic beds have been intruded by a Laramide granite.

3. Dragoon and Chiricahua Mountains area.

Perhaps the best known marble deposits in Arizona occur in Cochise County at the north end of the Dragoon Mountains and the north end of the Chiricahua Mountains, grouped here because of proximity and common historical development. In 1909, L. R. Ligier, the pioneer marble prospector, stone mason, and stone sculptor, staked claims for marble on Federal land in both areas. Due to claim jumping, bitter litigation ensued. In the 1920's, after the death of the far-sighted pioneer, the claims were perfected.

At the north end of the Chiricahua Mountains approximately 15 miles southeast of Bowie, deposits of massive, white marble with dark veins occur. Here, Cambrian beds of Abrigo limestone, Carboniferous and Devonian beds, and Cretaceous sediments have been folded and faulted into complex relations with Precambrian granite and schist. The marmarized rock is fairly widespread, with

Outcrop of colored marble near Wendon.



large reserves. The stone is mostly dense, massive, and moderately free of fractures.

Spectacularly-colored marble occurs at the north end of the Dragoon Mountains, southeast and northeast of Dragoon. A number of quarries have been opened here, and are scattered over an area of more than 10 square miles. Granting some variation within quarries, in general a single color or pattern may be produced from a particular de-posit. Available colors are black, white, pink, green, maroon, gray, cream, black with gold colored veins, shades of yellow, a combined gray and gold, and a gray and vari-colored, fossiliferous breccia. In addition, a "Serpentine marble" said to resemble onyx has been reported.

In this region, the structure and metamorphism of the marmarized beds are particularly complex 1[2] Paleozoic limestones and dolomites of the Naco Group, together with Cretaceous sediments (Bisbee formation) are intensely folded and faulted, and have been intruded and otherwise affected by Tertiary granite, dikes and other igneous rocks. Structurally, the sedimentary formations are tightly folded anticlines and svnclines with axes trending north and northwest. In places, limits of the folds have been sheared by faults trending roughly parallel to the fold axes; cross faults are also common. This complex of sedimentary rock is bounded on the south and northwest by Tertiary granite and other igneous rocks which probably also underlie the sedimentary rocks at shallow depth. The metmorphic effect of the young intrusives, together with the intense tectonic deformation, has been to alter the original rocks nearly beyond identification and correlation. The combination of impure (shaley and sandy) carbonate rocks, intense metamorphism of all kinds, and introduction of plutonic materials has created the present, highly-varigated in color, veined and patterned marble. Bedding and stratification are esentially absent, faults and fractures have been filled and recemented with metamorphic minerals, and in places, brecciated rock is suspended in matrix of marmarized limestone. Only detailed study of the area can yield an accurate and complete description of the rocks.

Composition and physical character

In the Harquahala region and the Dragoon and Chiricahua Mountains, the marble is so varigated in color and texture as to lack consistent chemical composition. Doubtless, analyses of the highly metamorphosed rock would show high ratios of silicon. magnesium, iron, etc., to calcium carbonate. However, an analysis* of white marble fines from a crushing operation near Dragoon is as follows :

$CaCO_3$	98.00%
SiO,	0.62%
MgCO	0.39%
R_2O_3	0.80%
	99.81%

Also, the white marble in the Tucson region is generally "pure" consisting of 97 percent or more of calcium carbonate.

The composition of the highly-colored, veined, and varigated marbles in the Dragoon Mountains, is complex, by virtue of the new minerals created by metamorphism. Basically, the original limestones and dolomites contain impurities of quartz, iron oxide, and clay minerals. High temperatures and the introduction of new elements from nearby igneous intrusions have created a number of metamorphic minerals. Part of the green color is due to chlorite, an hydrous silicate of aluminum, magnesium and ferrous iron; and green, reddish, yellow, and even black colors may be due in part to serpentine, an hydrous magnesium silicate. Mica of various colors is also present, and wollastonite, a calcium silicate is reported in some of the marble; rarer minerals such as lime garnets further complicate the composition. Of course the ubiquitous oxides of iron are responsible for much of the col-oration, including not only shades of red, but yellow, green, brown, purple, and black and cream.

The attractiveness of the stone is enhanced by the colors and textures, streaks, bands and patterns created by metamorphism and the attendant min-erals. But large amounts of these minerals may weaken the rock, complicate cutting and polishing, and causes pitting and staining in use. In both the Harquahala and Tucson regions, the marble is firm and dense in small fragments up to as much

**Courtesy of Mr. D. G. Ligier, Dragoon, Arizona* as 2-3 feet in longest direction. But present quarry faces show fairly closely-spaced fracturing and jointing. This may be due to current quarrying by blasting for granule production, or to the fact that few, if any quarries have been exploited to depths well below the weathered and fractured surface material. In the Dragoon and Chiricahua Mountains saw blocks more than 6 feet in length, and a minimum of 2½ - 3 feet in thickness have been produced in quantity. Here too, the quarries have not been developed to depths assuredly below the weathered zone. Deposits near Tucson are being worked primarily for crushed stone for roofing, terrazzo, plaster, etc. The purest white reflective stone is sought. Thus, sandy and clayey seams are avoided, but in places the accompanying iron stain causes rejection of gray and yellowish stone.

The weight of the Arizona marbles is neither heavier nor lighter than normal. Dragoon marble. presumably originally dolomitic and containing heavy accessory minerals, has been tested at 186 pounds per cubic foot. High lime marbles made dominantly of calcite, may be as low as 170 pounds per cubic foot.

Production, products, shipping, and costs

Two general types of construction materials have been produced from Arizona marble deposits; one, *cut and polished slabs, sheets and blocks,* and two, granular materials for *roofing, terrazzo, plaster, copings, exposed aggregate, and landscaping.*

By far the largest part of the marble produced for *cutting* and *polishing* has come from the Dragoon and Chiricanua Mountains. As much as 4,000 tons is reported to have been produced in this area around 1950, when substantial production of saw blocks was attained. The blocks were shipped to California, Missouri, and New York, and as far as Canada, where they were cut, polished, and finished to flooring, wall facing for store fronts, fire-places and interiors and monuments. No large-scale, permanent cutting and polishing mills have been established in Arizona.

Saw blocks were produced by first clearing a face in firm rock. Then pneumatic drills (drifters) on rigid quarry bars cut rows of holes on all sides, followed by broaching, and the blocks were loaded on trucks and hauled to the railroad for shipping. Attempts were made, to make blocks approximately 6 feet long and at least 2/$_2$-3 feet in width and thickness: smaller sizes are acceptable, but less desirable.

The cost of quarrying marble saw blocks can vary widely, due largely to the waste or recovery factor. After a quarry is well established, a basic cost of $1.50 per cubic foot is expected: larger blocks not only cost less per cubic foot to quarry, but bring better prices. Colored marble should sell for $7.50 per cubic foot up - $15.00 per cubic foot would probably be normal in standard blocks. 10-10½ square feet of slab or sheet marble are expected from 1 cubic foot. After polishing, prices of colored marble are in the magnitude of $4-12 per square foot.

Today, the only marble being produced for cutting and polishing is in small blocks which can be cut and finished on light equipment. Small production for copings, fireplace fronts and special jobs is reported from several areas, including the quarries of pink and green marble near Wendon.

The bulk of today's marble production in Arizona is *granular* or *crushed stone.* Nearly all of the active quarries in the Harqualhala, Tucson, and Dragoon-Chiricahua regions have at least intermittent production, and quarries in several other areas are reported to have had substantial production in the past. At least 4 plants are producing regularly, if not continuously.

After prospecting by examination of outcrops and bulldozing surface material, production of crushed marble entails first removal of overburden. Most present quarries are on hillsides, where overburden is light and can be pushed to lower elevations away from actual quarry sites. This is followed by air drilling and blasting, with heavy charges to induce fragmentation. Broken rock is moved by front-end loader to a truck which hauls to a grizzly. One operation includes a shaker screen under the grizzly to remove fines, clays and dirt. Another operation uses a dragline to remove broken stone from the quarry to a truck loading arrangement. From the grizzly, the stone is truck-hauled to processing plants. Processing usually consists of passing the stone through a grizzly, through primary jaw and secondary roll crushers, screening to size with return of oversize, and bagging. With this general process, specifications are considered easy to meet.

Granules are produced in all gradations from fines to 2 inches in size. Larger pieces, including rubble are produced for masonry and landscaping. The bulk of the white marble of the Tucson area is produced for roofing granules which have a high insulation factor through reflection; white terrazzo chips are second in demand. 65-70% of the colored marble from the Dragoon Mountains is used as terrazzo, with roofing material demands being second. Considerable colored, rough marble for wall work and decoration is produced. Other uses are growing, but are currently minor. Much of the Tucson area marble is consumed in Arizona, with some shipment to the west coast. Destination of the colored marbles is about evenly divided between Arizona and California, with eastern markets being developed.

For the two basic uses, prices F.O.B. plant are approximately:

	White	Colored
Roofing granules	$15-18/T	$19/T
Terrazzo	$15-19/T	$22-30/T

Costs of producing crushed marble vary according to types of operation, haul, and waste. Quarry waste varies considerably, being 2-5% in established colored stone quarries, and as high as 35% in relatively new white marble operations. Processing waste is about 15%, including 2% culls and 13% powder. Powders are generally saved for possible future use.

Reported quarry costs vary from $2.00 to $4.50 per ton, and processing is about $9.00 per ton. Truck haul over rough roads for any appreciable distance may be as high as 10¢ per ton-mile,

Serrated quarry face due to removal of marble saw blocks.

with haul on pavement being 5¢ - 7¢ per ton-mile. A breakdown of average costs is summarized:

BREAKDOWN OF AVERAGE COSTS OF CRUSHED MARBLE PRODUCTION

	per ton
Labor, materials, maintenance	
Quarrying	$ 2.50
Hauling	1.20
Crushing	3.25
Indirect costs	
Overhead	1.50
Quarrying	.75
Hauling	.50
Crushing	.80
Total	$10.50 per ton

Specifications and trends

Presuming availability of colors, the requirements for crushed marble are few and can be met. Sizing must be accurate, the particles must he clean and free of powder, and colors must be consistent and not subject to stain.

On the other hand, specifications for dimension stone, monuments, and statuary marble are far more rigid. The stone must be firm, cut smoothly, take a high polish, and have consistent color, veining patterns, and fossil and breccia distribution. It must be free of minerals that weather to pits, holes, or stains. Statuary and memorial marble must be free of any structural flaws. Unless vein patterns are desired, specifications for white marble slabs include freedom from stains, discolorations, and veins and cracks; closer attention is given to firmness than with highly-colored and textured stones.

Traditionally, marble chips have been used for terrazzo. Experiments are made with other materials, but to date no substitute or alternate has provided serious competition. The infinite design possibilities of terrazzo are beginning to capture builder's interest as their demand diminishes for the quick, cheap, rudimentary construction that followed World War II. Also, more efficient grinding and polishing equipment, as well as the precasting of both slabs and shaped units should reduce costs. Cost of terrazzo chips could be substantially reduced by larger volume production at quarries and procesing plants.

The use of marble granules for "mop down" roofs has grown with the development of low angle roofs. Here the architectural trends probably determine most of the demand; likewise for marble granules used as exposed aggregate and in copings for swimming pools and other structures.

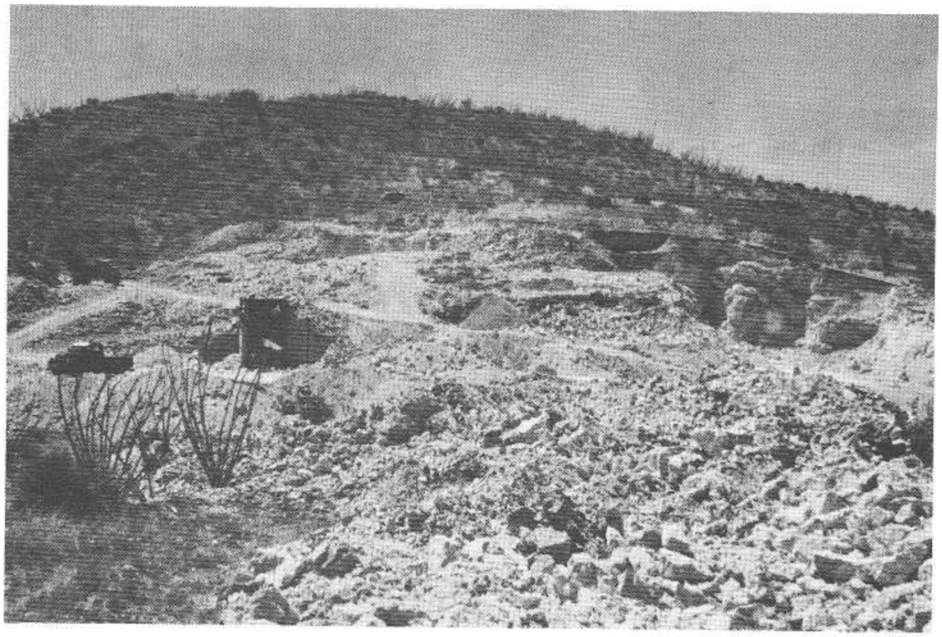
For marble used as dimension stone, there is a reawakening to the adaptability and beauty of this ancient stone. Few rock types are easier to cut, and no polished surface can exceed the interest of texture, pattern, and color. This, together with high durability and strength, and low maintenance. make it fitting for most decorative architectural requirements.

Arizona marble can compete in quality and beauty with the best European sources. Moreover, it is one of the few highly colored and patterned marbles in the western hemisphere. Varieties are exceeded only by the reserves, of which colored stone alone are in the hundreds of million of tons. If less than 1/10 of estimated reserves are suitable for cutting and polishing, more than 7 square miles could be covered with marble, each square mile with a different color or pattern.

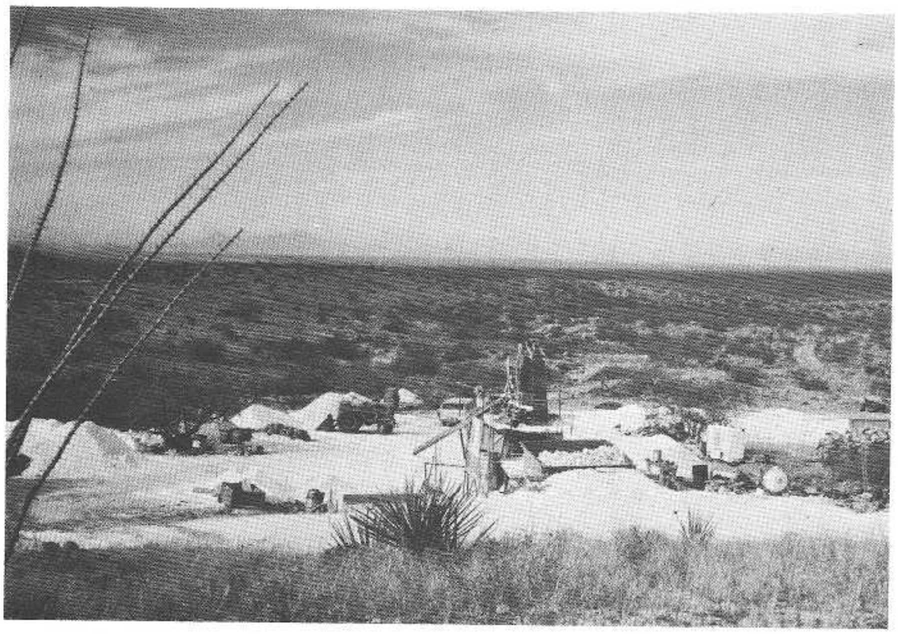
Problems

Because of differences in production techniques, products, and markets, the problems of increasing and stabilizing crushed marble production are considerably different from those connected with polished marble.

Techniques for quarrying and processing *crushed marble* are fairly well established for modest production. The primary goal at this point must be increased markets. Larger demand for terrazzo, 'mop down' roofs, and exposed aggregate in construction will require the greatest increase in production. Substantial increases in production will provide a basis for more mechanization and eventual lower prices for products. Stability will accrue only when the products are consistently competitive with other building materials. In addition, methods should be devised for more accurate exploration of deposits. In some quarries, extraction costs are unduly high because new production sites must be found before an optimum amount of material has been removed, Geologic examination, coupled with exploratory drilling of properties could remove much of the hazard of unanticipated shaley, sandy,



White marble quarry.



Crushed marble plant.

New quarry opened for crushed white marble.

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and stained zones. Also, more consistent rock, allowing closer quality control may be found at greater depths below the weathered zone.

Renewed production of Arizona m*arblc for polishing* will consist, in essence, of starting a new type of industry in this area. with problems of development of deposits and production techniques, creation of markets, and meeting present day specifications.

The problems may be grouped as follows:

1. Proper choice of deposits to be worked, based on geologic examination and drilling, must be made to insure adequate re-serves and efficient production with the least waste. This may require some development work to obtain stone from depths below surface weathering.
2. Financial requirements will probably be large, relative to other stone operations. The built-in difficulties attending small-scale extraction operations in today's economy are well known. Indeed, it is probable that the only successful production will be obtained by *an* operation including not only quarrying of saw blocks, but cutting and polishing and marketing the stone for final use. Mechanization is essential, and the use of the latest and best production techniques, such as wire saw quarrying of blocks, is indicated.
3. Standardization of shapes and sizes is essential, in order to compete with other materials in cost of installation. Large demand is most likely to come from building and other construction, where the choice of materials to be used often depends on the ease and speed of handling.

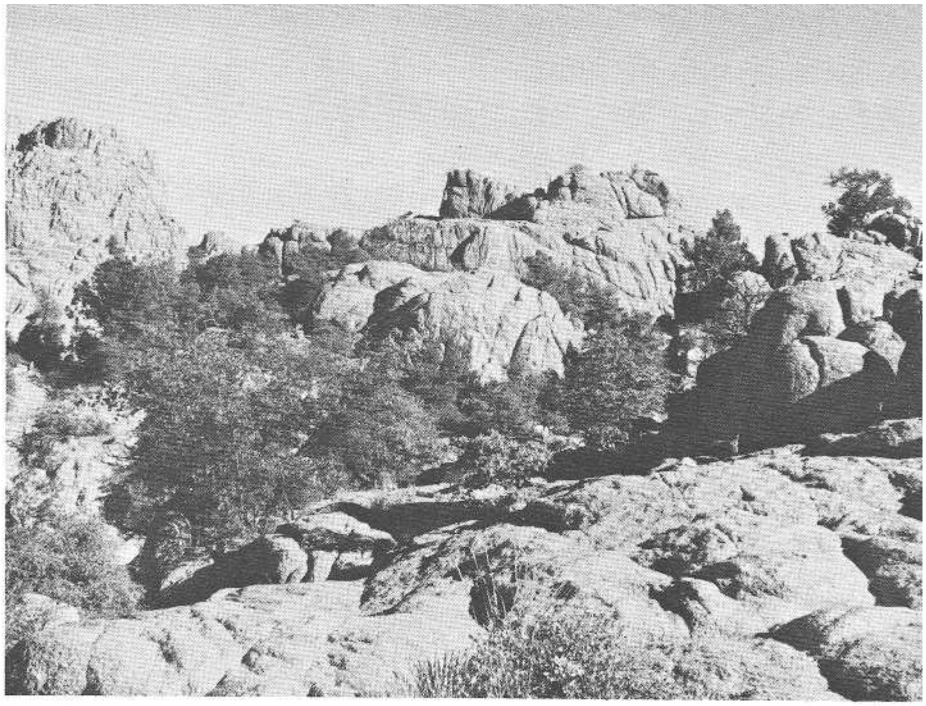
TUFF

Tuff may be considered at this time as a neglected stone. Yet its unique characteristics give it a potential of becoming a standard construction material in modern practice. Being light in weight and easy to shape, its history as a fundamental building material is ancient in many parts of the world. It has been used extensively in Mexico with unmitigated success, and from colonial days to the present. Early settlers in Arizona found it not only convenient to produce, but particularly functional as an insulation from severe heat and cold. As with all building stone, for a recent period its quality has been overlooked in favor of the novelties of more modern materials. But the combination of increased population creating markets. new production techniques. and architectural fashion trends should renew interest in Arizona's excellent deposits of tuff.

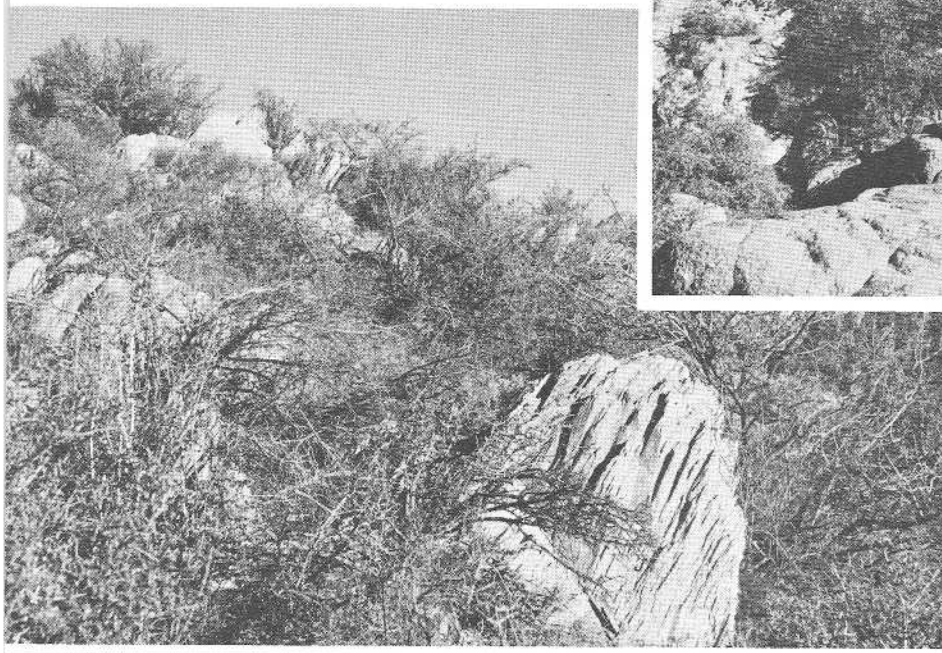
Terminology and general geology

Specifically. and geologically, the word *tuff* refers to cemented volcanic ash; a pyroclastic rock.[13] [18] Variations include *tuffite,* a general term applied to rocks containing not only ash, but also other detrital material both volcanic and surface in origin. *Tuff breccia* includes fragments that are much larger than ash. In *a welded tuff,* the particles have been indurated or consolidated at least in part by retained volcanic heat and gases. If, during its origin, the tuffaceous materials flowed, the resulting rock is *a tuff lava,* and may be known as an *ash flow*. A common misuse is the word *tufa* or tufa-stone, which properly applies to the cellular, calcareous sinter or siliceous sinter deposits of mineral springs. Most Arizona deposits of tuffaceous material having a potential as building stone would more accurately be called tuffite, tuff breccia or welded tuff, as the case may be, but for general use the term tuff is practical.

Tuff deposits have their origin in volcanic action. The many varieties are understandable when the complexities of volcanism are considered. During eruption of a volcano, not only is lava usually emitted, but solid and semi-solid fragments, bombs, dust, cinders and ash, as well as water vapors and other gaseous materials are ejected, all at various temperatures. Sometimes these materials are ejected simultaneously, and at other times only one at a time. Also, as these materials come up through the earth's crust, they may break off and carry with them large and small fragments of other rock. Finally, after being deposited, the materials may be shoved, reheated, fractured, covered, or intruded by other volcanic ejecta. Arizona was an active

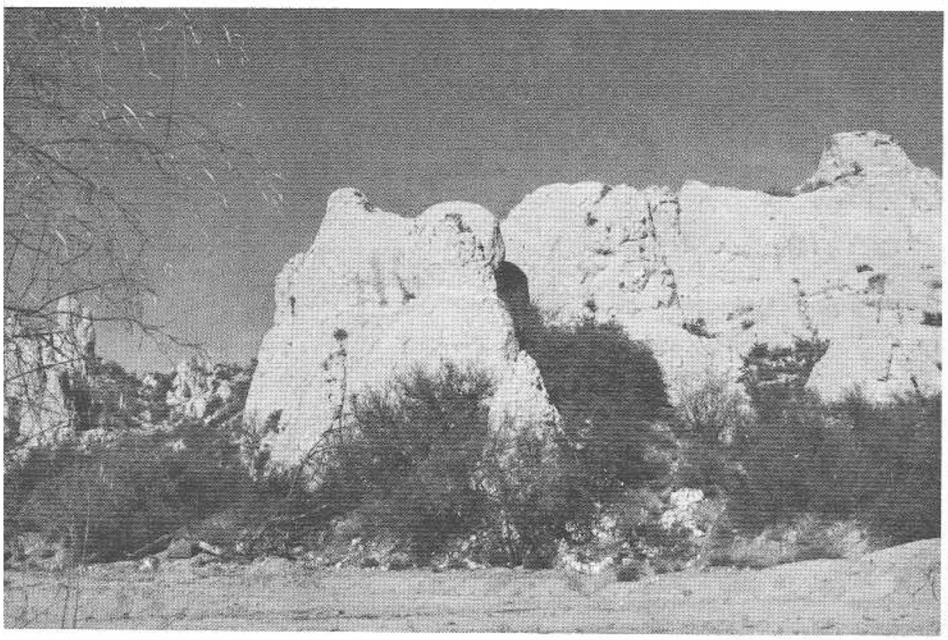


GRANITE



SCHIST

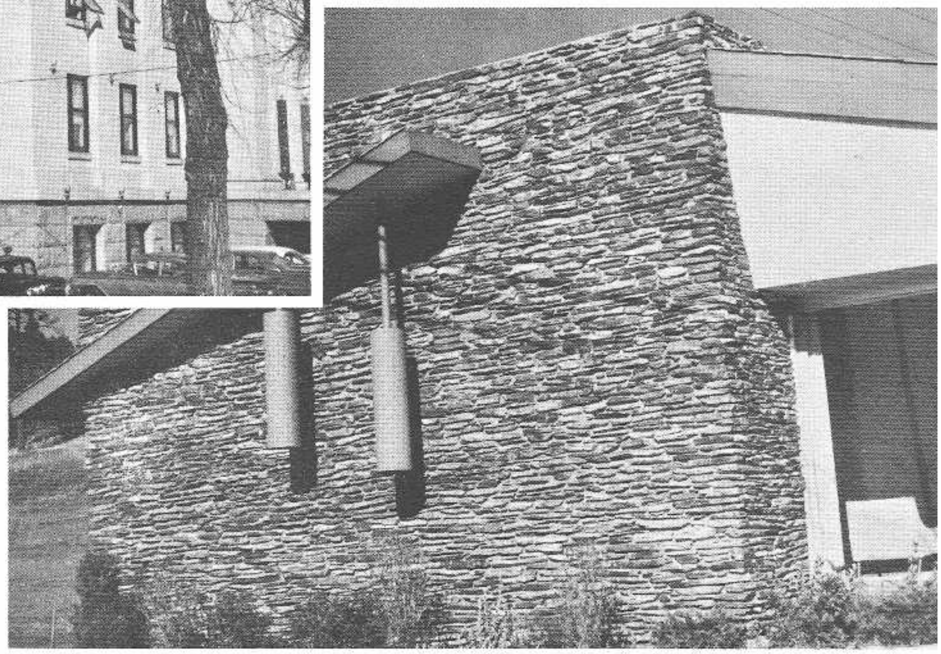
IN NATURE...........



TUFF

SANDSTONE

GRANITE



SCHIST

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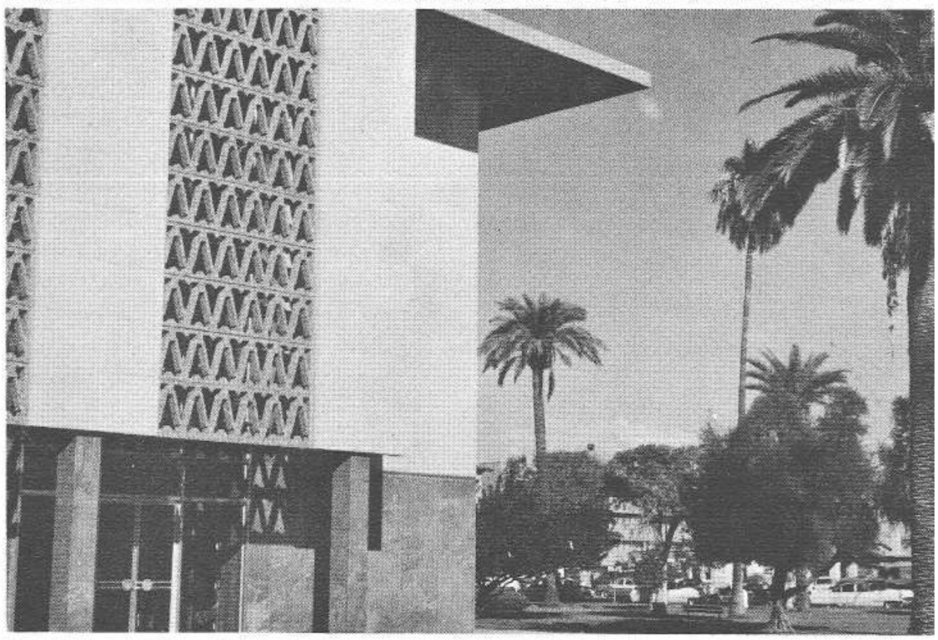
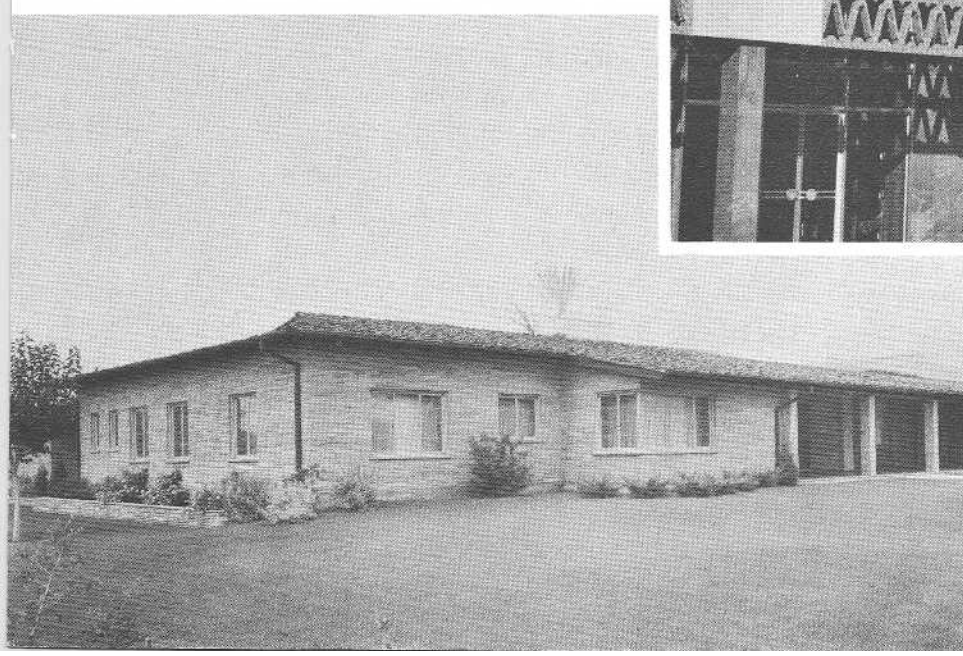


TUFF

SANDSTONE



volcanic area from some time in the Cretaceous period into the Quarternary period. Therefore, the resulting deposits visible today are generally complex in size, composition and structure.

Character of representative deposits

Deposits of tuff are numerous in Arizona. They are, of course, associated with other volcanic rocks that are scattered throughout the state. The range in area of deposits that have been worked is from north of Kingman to south of Wendon on the west, and from north of Holbrook on the east to the southeast corner of the state. Only deposits representative of areas or types are discussed here; many others of equal quality and potential exist.

On the Navajo Indian Reservation in central Apache and Navajo Counties, deposits of tuff in the Bidahochi formation (Tertiary) are common. These are ably described in Mineral Resources, Navajo-Hopi Reservations. Arizona-Utah,[16] and are reported only generally here. At least three dozen deposits of tuff are reported. The tuff beds are mostly whitish-gray in color, are 2-6 feet thick, contain some clay and sand beds, have a wide range in chemical composition, and consist dominantly (70-85) of glass shards (ash,) with the remainder "being quartz, feldspar, hornblendes, rutile, glass and garnet fragments." the stone is light in weight. fine-grained and porous; the grains and fragments are not tightly bonded, but compressive strengths of 2,000-3,000 pounds per square inch are reported.

In the southeastern corner of Cochise County, tuff deposits are associated with Tertiary rhyolite (lava.) In one area, a welded, porphyritic, rhyolitic tuff (see analysis below) is present over at least 150 acres. The stone occurs in colors of white, a sand-colored huff, and a soft pink. The colored matrix is dense, fine-grained, well-bonded and en-closes crystals of sanidine, biotite and magnetite, as well as fragments of tuff and siliceous material.

Density measurements of two samples of this tuff are reported to average about 2.1, which gives a weight of approximately 131 pounds per cubic foot. Other samples are said to compensated in part by higher strength; the aver-age compressive strength of this tuff is probably well over 5,000 pounds per square inch, and may be more than many competent sandstones. Porosity-permeability tests of two samples show the volume of water absorbed per volume of rock to be 9.7%' and 4.4%. This tuff is generally massive, and will yield large saw blocks. It may be cut with ease with a diamond saw, and quite adequately with a carborundum saw.

Petrographic analysis of pink tuff from southeast part of Cochise County*

	%
Groundmass of cryptocrystalline and microlitic material too small to identify, shows some flow	73.0
Sanidine, a potash feldspar typical of rhyolites	11.2
Quartz, as fresh crystals of silica	7.0
Voids (openings in the groundmass)	1.8
Rock fragments	5.8
Cristobalite and tridymite, varieties of silica, as secondary minerals	0.5
Biotite (dark mica, an accessory mineral)	0.3
Magnetite (an iron oxide, another accessory mineral)	0.3
Apatite (?)	0.1
Total	100.0

A third notable area of tuff is the vicinity of San Carlos in southeastern Gila County and north-western Graham County.[4] Considerable production has been reported from several deposits in this area characterized by Tertiary and Quaternary volcanics, particularly basalt. The tuff is mostly fine-grained, white to gray, with some pumice and andesite pebbly fragments. In places the "pebbles" are stratified in zones. The material reportedly de velops a case hardened effect with prolonged exposure. It cuts easily into large blocks, and has been used with considerable success.

In the vicinity of Clifton, Greenlee County, an off-white tuff, largely free of "pebbles" is easily carved and has been used locally with success.

At Canyon Lake on the Salt River, Maricopa County, a generally buff-colored, but also gray and white tuff with fragments of andesite and rhyolite has been in intermittent production.

Another notable area of tuff is near Kirkland in Yavapai County, where deposits associated with

** Courtesy of Mr. D. G. Ligier, Dragoon, Arizona*

Tertiary and Quaternary basalt have been operated intermittently since before 1900. The deposits are irregularly distributed over an area of perhaps a square mile, and extend to depths of 100 feet in places.

The stone is consistently light gray in color, and is composed of a fine-grained matrix of glass shards, enclosing small but easily visible quartz and sanadine crystals, and including fragments of dark volcanic rock. The latter fragments range in size from tiny to pebble and cobble size; they are not evenly distributed, and in places form strata or beds, giving the stone a pebbly appearance. The dark fragments are mostly obsidian and aggregates of glassy fragments.

The stone is not as firm and well-bonded as some other tuffs, but is correspondingly very light in weight. Its compressive strength has been tested at 3, 200 and 3,400 pounds per square inch, and its weight is 88-115 pounds per cubic foot. It is, of course, highly porous, and its insulating character has been found by long experience to be very good.

A tuff deposit notable for its unique colors is located on the northeast side of the Eagle Tail Mountains, Yuma County. Called "mint stone," the rock in general has a unique soft green color, but also includes bands of lavender, purple and white material. The bands range from fractions of an inch to more than a foot wide, and are composed individually of dense, massive, welded ash to beds composed dominantly of very coarse fragments of purple, black, and maroon-colored volcanics with a small awount of fine-grained matrix. Fairly large reser^v^es are available, but are limited by complex structure. The tuff beds apparently lie between lavas, and the whole sequence has been faulted, tilted, and intruded by other volcanics. Thus, the beds of tuff are blocky, and are not continuous over great distances. Intermittent production is carried on.

In the vicinity of Kingman, Mohave County, tuff was quaried in years past for extensive local use. The stone is largely a light-colored reddish pink, with some dark to black zones. "It is medium-grained and fairly uniform in texture and dresses well." [20] Small, but distinguishable phenocrysts of biotite, feldspar and quartz are present.

Also in Mohave County, about 5 miles south-east of Wickieup, a green stone classed as tuff is notable. Although reserves are not large, the stone is unique in its soft, apple green color, and that it is opalized and otherwise silicified. It occurs as a bed 8-12 inches thick, included in Quaternary basalts, with overburden up to 50 feet consisting of tuff and altered tuff. The stone is hard and dense, with varigated bands of shades of green. Current production is under way.

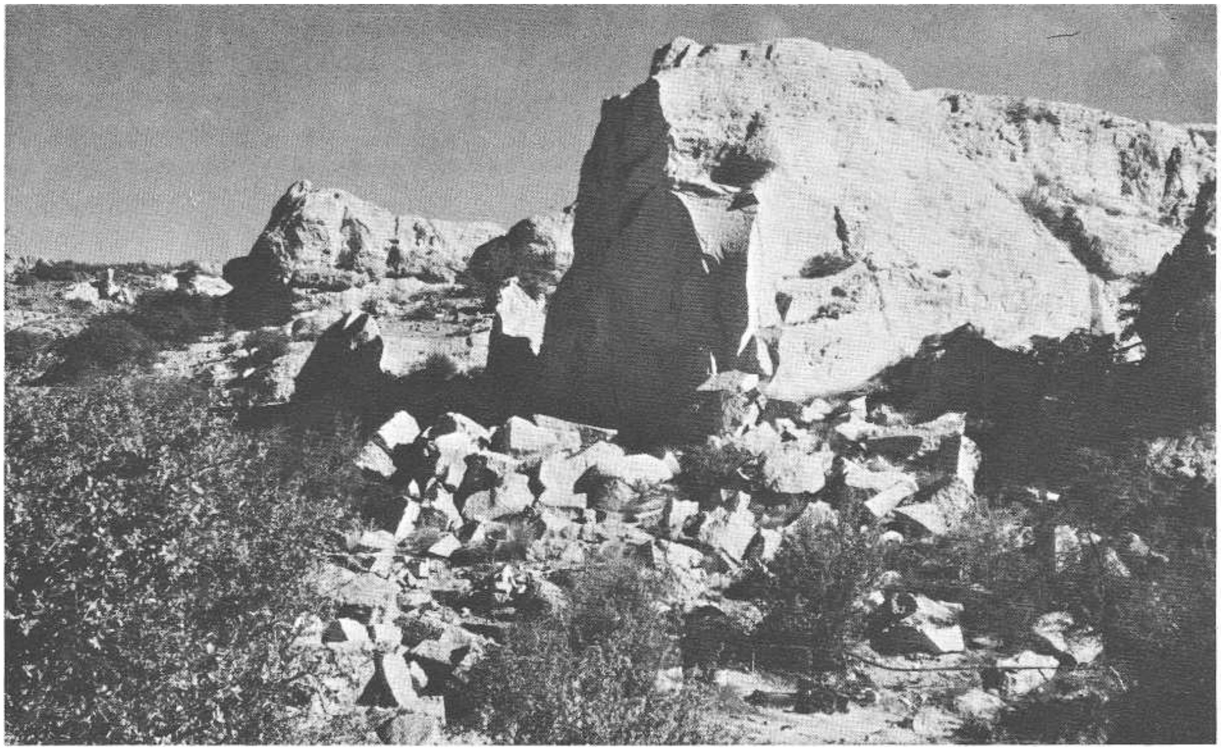
Production

Much tuff has been used locally in Arizona over many years. In 1909, Schrader[20] wrote, "The most important building stone in the region is the rhyolitic tuff underlying Kingman Mesa." and, "The most important buildings in Kingman are built of it." The production history consists of intermittent operation of many quarries; therefore, production data are scant and inaccurate. Tuff has been exported from Arizona in considerable quantities, but not sufficient to sustain continued production.

Recently, more than 33,000 square feet of curtain walls in additions to the state capitol were made of tuff; 8 to 10-ton saw blocks were quarried near Kirkland, and hauled by truck to a Phoenix cutting yard, where a sand and water saw cut rough slabs that were trimmed by diamond saw. Currently, some quarries are being worked for rough stone for wall facing and landscaping. Also, substantial quantities of the green colored "mint stone" have been quarried since World War II. Thus, although one quarry operator believes that tuff can be produced for about one-third the cost of marble, production has never been stabilized on a continuous basis.

Problems

Two problems are fundamental to growth of a stable production of tuff. *First,* larger markets for slabs and dimension cut stone must be developed. Tuff is a relatively unknown rock type, and its characteristics as a building stone must be called to the attention of builders and designers. Its con-tinued, successful use in comparatively small quan-



Massive tuff.

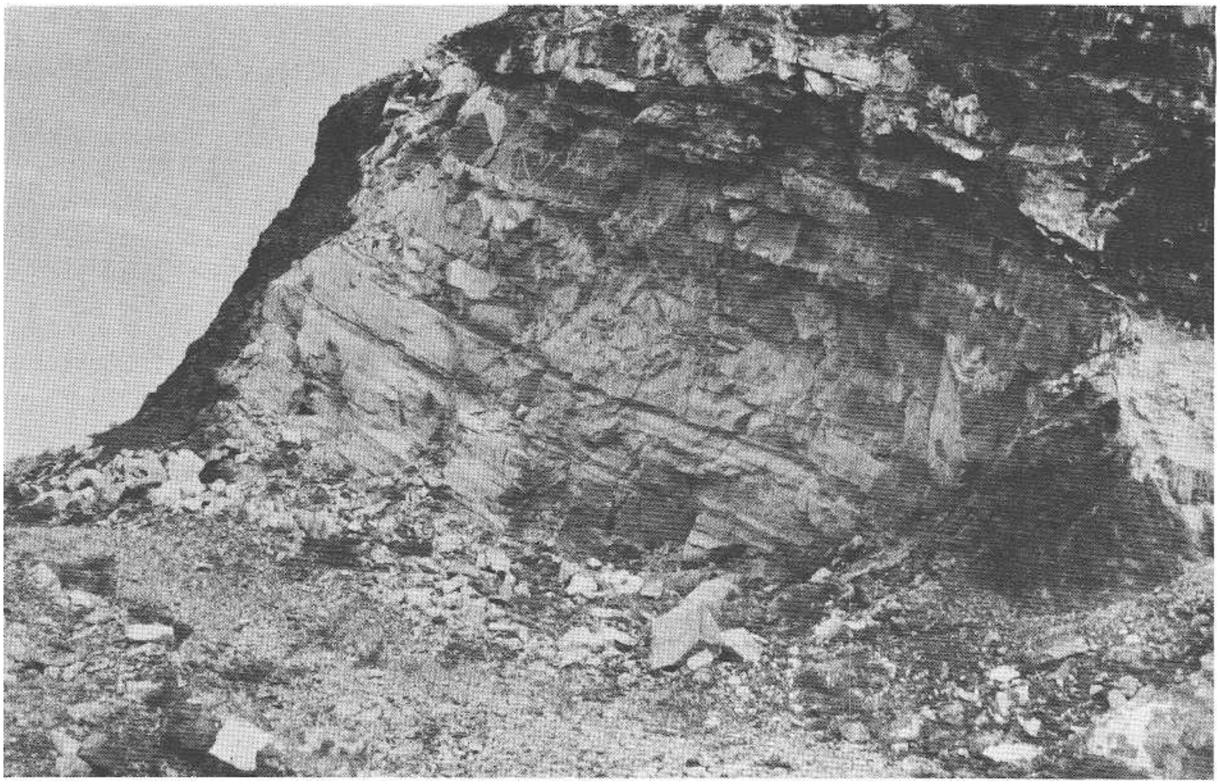
tities over the years is not sufficient advertising in today's rapid and highly competitive building economy. All building stones have some disadvantages, and these must be studied with a view toward overcoming them, or circumventing them with proper design. Below is a general evaluation of the characteristics of tuff :

Advantages*	Disadvantages*
Light weight	Low tensile strength
lower shipping cost	Permeable
ease of handling	high absorption
light weight construction	may be weakened b} freezing when wet
High insulation quality	Will not take polish
Variety of colors	Some deposits thin and or small
Variety of textures	
Can be worked easily	
Can be cut to dimension	
Compressive strength adequate to high	
Low production costs	

The *second* fundamental problem is to establish operations consisting not only of quarrying, but also of milling and finishing. As in the case of marble, integrated production from quarry to market holds the most promise of stable success. Not only is there an obvious financial advantage in an integrated operation, but techniques of production may be improved; detailed characteristics of a particular rock may be learned in the quarry and passed on to the benefit of cutting and trimming operations. Also, stocks of various sized dimension stone may be built up, and special orders are easier to fill if quarrying and processing are integrated. It is not too visionary to conceive of a cutting and trimming yard being supplied saw blocks from a number of quarries, in order to market a greater variety of products.

In addition, mechanization is essential. Wire saws requiring little attention can be adjusted to saw block production and slabbing; handling of saw blocks must be systemized. Quality control

** It should be noted that some features create both desirable and undesirable characteristics. For example, the more porous types of tuff are very light in weight and are good insulators, if the pores or spaces are connected, the stone may be permeable and have less strength. Also, notable is the variety in character of various deposits; if low permeability is needed, a tightly welded tuff from one source may excel a very light tuff from another source.*



Green tuff deposit in Eagle Tail Mountains. Note beds cut by dark volcanics.

must be increased by closer evaluation of deposits and of quarry sites, in order to reduce waste in slabbing and trimming.

GRANITE

By a casual glance at the geologic map of Arizona, one may see that the state contains an unlimited supply of granite as a rock type. Of course, not all of this rock is suitable for building stone, but out of the wide areas and many varieties, doubtless numerous excellent sources could be developed. For many years, granite has been used as a building stone and for monuments within Arizona, but out-of-state markets have not been developed. Probably the largest use has been for public buildings, such as the Yavapai County Court House in Prescott, and parts of the state capitol in Phoenix.

Specifically, granite refers to a very particular rock type, but practically, the term applies to all related[13 18] or "granite type" rocks, including granite-porphyry, diorite, gabbro, and some gneissic-textured rocks. These rocks are common in Arizona, but are confined essentially to the southern, southwestern and western parts of the state. Many of the mountains in these parts of the state are composed of granite type rocks of various geologic ages. Because of market conditions and past access and transportation problems, most of them have not been prospected for possible granite quarries.

For purposes here, only a few granite deposits are mentioned. Near Cochise Stronghold in Cochise County, a very good, even and fairly coarse-grained gray granite (granodiorite) can be quarried in large blocks. In Greenlee County, north of Morenci, large reserves of a coarse-grained granite with aplitic veins and zones are available. This granite has an over-all wine pink color due to dark red feldspars. Small amounts have been quarried from large residual boulders. A similar deposit of smaller reserves is near Clifton. Part of the state capitol building was built of granite from north of

Salome, in Yuma County. A "black" granite (granodiorite?) is reported [6] northeast of Helvetia, Pima County. In Yavapai County, inexhaustible supplies of a dark gray to white granite (quartz diorite) are available, particularly in the Prescott region. In Maricopa County, abundant reserves of gray, white, and pink granite may be found; notable are the mountainous areas in the northeast part of the county, and also south of Phoenix where a gneissoid granite was quarried for part of the state capitol. Similarly, Mohave, Yuma, Pinal, and Santa Cruz counties contain large areas of massive granite.

Granite and related rocks have certain well-known good characteristics for building stone. They are particularly strong and durable, and have low porosity; they are available in sleek homogenous textures, or in veined and patterned textures with swirls and irregular zones of fine-grained to coarse-grained matrices. The stone takes and keeps a high polish that brings out colors. On the other hand, it is a hard and dense stone, more difficult to quarry and cut than others.

In prospecting, assuming an available rock satisfies needs of appearance such as texture and color, probably the most important quality to be determined for granite is strength in large blocks. First, it should be noted that in arid climates such as in Arizona, granite characteristically erodes by disintegration. That is, being a crystalline rock composed essentially of the three minerals, quartz, feldspar, and mica, all having different coefficients of expansion, changes in temperature open cracks and cleavage planes. Moisture penetrates; alternating cold and extreme heat over geologic ages cause the "fresh" rock to break down, or "weather" to sharp, angular fragments. This resultant material is locally called "disintegrated granite," and incidentally has considerable use in landscaping and other ground coatings. In places, outcrops of granite are weak and punky, being in the process of disintegration to depths of more than 10 feet. It is most important to realize that a surface of weathered granite may conceal an entirely different looking fresh rock at depth, and may mask an excellent de-posit of building stone.

Further, prospecting for firm granite should include careful evaluation of jointing, fracturing, cleavage, and other lines or zones of weakness. Wide areas of some Arizona granites contain closely-spaced joints that were formed during cooling of the magma. These may preclude quarrying of large saw blocks. Other areas may be massive, but contain faults and fracture zones that must be avoided in quarrying. Also, most even-textured granites have more or less subtle cleavage, or directions along which the stone may break more easily; quarrymen know this as "grain" and "rift". Fortunately, granite is abundant enough in Arizona that problems of firmness and strength may be met by relatively little and inexpensive exploration.

SLATE

Good slate in the classic sense is the least abundant of the major building stone types in Arizona. Most slate used as building stone is a hard, durable, finely-crystalline, metamorphic rock with strong cleavage in one plane.[14] It is commonly blue-black, known as `slate colored,' but also occurs in shades of gray, red, green, and purple. The metamorphism that has created slate from clay and shale beds is low-grade; more intense metamorphism creates phyllite and schist. Thus, in Arizona it is not generally as common a rock type as schist.

The largest use of slate [24] has been for roofing plates, but many other products utilize its unique character, such as blackboards, electric panels, billiard tables and laboratory and other table tops. As a building stone it is also used structurally for wainscoting, sills, mantels, steps, etc., and is currently a popular material for flooring.

Most occurrences of slate in Arizona are more properly phyllite, and some are known as `mica slate.' However, southwest of Walker, in the Bradshaw mountains of Yavapai County, deposits of excellent slate are reported. It occurs in shades of green, brown, and black, and is hard and smooth, with good cleavage. Development is said to be under way to remove sheets for cutting.

Near Sunnyslope, north of Phoenix in Maricopa County, a deposit of largely blue-black and green colored slate has been worked for a number of years. It tends to be micaceous, and is hard and firm. It can be split into fairly large sheets. No production of cut or dimension slate is reported from this deposit, but it is highly prized for rough, masonry walls.

Also, in the Sierra Ancha District north of Globe, Gila County, a hard, banded "ribbon slate" is reported. It is said to be banded in dark shades of red, gray, and purple.

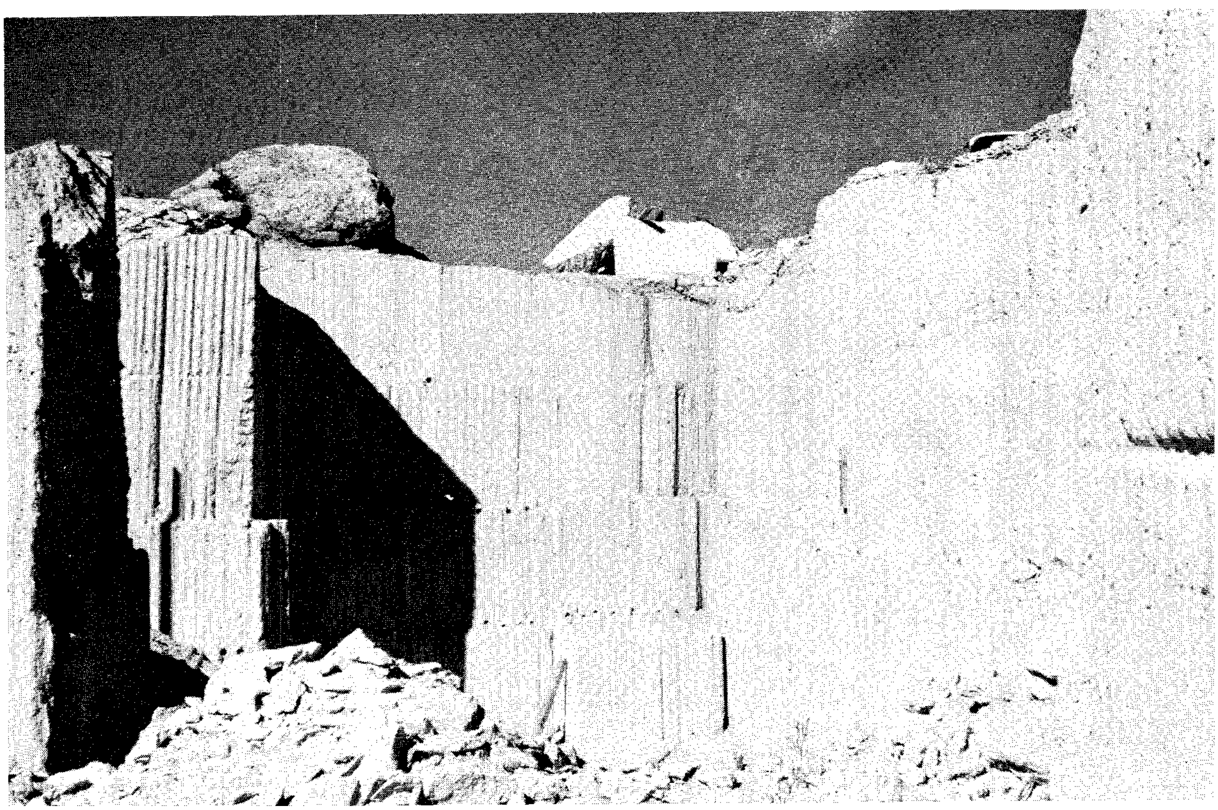
Doubtless other deposits of slate are available in Arizona. Systematic prospecting in areas of metamorphic rocks should bring to light much good material for building stone. The Precambrian rocks of the mountainous southerly and westerly portions of the state hold the best possibilities.

LIMESTONE

Limestone, including dolomite, is common in Arizona, but in recent years it has seldom been utilized for building stone. As with other types of stone, it has been used locally in the past; no post-war production is reported.

Limestone is a sedimentary rock composed essentially of calcium carbonate, or when dolomitic, it includes magnesium carbonate. It is characteristically dense, compact, microcrystalline, and white in pure form. When it has been metamorphosed and recrystallized to the point of taking a polish, it is called marble. Normally, limestone has been de-posited over wide areas." Thus, the Kaibab lime-stone (Permian) and the Redwall limestone (Mississippian) crop out in many places on the sedimentary plateau of northern Arizona. In the south-ern part of the state, several other Paleozoic and Precambrian units, such as the Modoc, Escabrosa, Martin, Abrigo, and Mescal limestones are present; these are marmarized in places. In addition, lime-stone and limey or calcerous beds suitable for build-ing stone are included in other formations that are dominantly shale or sandstone, as for example,

Saw block quarry in light gray tuff.



limestone lenses in the Navajo sandstone.[16]

Clearly, limestone is abundant in Arizona, needing market demand and systematic prospecting to provide suitable production areas. The advantageous potential quarry operation methods in Arizona merit attention here. In many parts of the United States, suitable building stone deposits are on nearly flat land, or in topography requiring expensive vertical lift of stone from quarries. But in Arizona, many good deposits are located on hillsides, or in such topographic positions that quarrying to great depths below surrounding surfaces need not be anticipated. Particularly notable are such formations as the Kaibab limestone, which may be found in thick, massive beds capping mesas. Under such conditions, large volume removal of stone may progress horizontally rather than vertically, and in many cases, flow of materials from source to loading for shipment may be entirely by gravity.

SCHIST

Schist is a rock type that is not traditionally considered to be a common building stone, probably because it does not readily lend itself to precise cutting or shaping. Nevertheless, since World War II, thousands of tons have been produced in Arizona, and out-of-state shipments are becoming a significant factor. Apparently, the variety of both subtle and brilliant colors available has made this stone a popular wall facing.

Arizona is peculiarly endowed with large supplies of schist. Although young (Mesozoic) schist is reported, as in Yuma County, most of it occurs in the oldest of rocks, Precambrian in age. Rocks of this age, particularly common in southern and western Arizona,[11] are only scantily available or even absent in many other states. Modern architectural trends requiring color and textural relief to otherwise monolithic structures have brought numerous, small quarries of schist into operation.

Production methods are simple. This metamorphic rock generally cleaves into irregular, platy pieces, due to the common orientation of platy minerals, largely mica. After overburden is removed, firm rock is exposed by light blasting, and pieces that may be handled by one or two men are pried loose and loaded for shipment. Due also to the cleavage, *many* surfaces are weathered to attractive colors, even at considerable depths. The material is *hard*, but may be shaped by masons without extraordinary difficulty. The slabby shape of most stone also makes it adaptable to palleting for shipment.

Currently, the material having the so-called desert colors, shades of red, yellow, and brown are popular. Several small operations are being developed in the Tucson area, but the largest production is in the vicinity of Phoenix. One of the oldest quarries is in Sunnyslope, north of Phoenix. Highly colored schist is quarried north of New River in northern Maricopa County, and near Mayer in Yavapai County. Also, extensive deposits have been developed elsewhere in the Bradshaw Mountains, south of Prescott, and in the vicinity of Tucson.

MISCELLANEOUS STONE

Arizona has deposits of a number of rock types that have been used for building and related purposes, but because of lack of data, or specific potential in the building industry, they are classified here as miscellaneous stone. This does not mean that any one of them is unimportant, or indeed, may not become a strong factor in the stone industry. A change in production techniques or consumer desire or knowledge of deposits, as in the case of schist, could warrant detailed study in the future. Generally, their production has been erratic and small due to their rarity, types of deposit, difficulty of being worked or lack of markets. Together, however, they comprise a group that adds to the necessary variety of available stone, and thereby increases the potential of the industry as a whole.

Rhyolite and porphyry

Grouped here are all of the light-colored volcanic rocks including dacite, rhyolite porphyry, and tuffaceous rhyolite, that are abundant throughout the state, excepting, of course, tuffs as previously described. Being volcanic in origin, they are either characteristic or related to the many Tertiary and Cretaceous rock areas in the state, and gradations between them are common. As a whole, they lack the light weight and cuttability of tuff, the cleavability of sandstone and slate or the ability to take polish as granite and marble. Nevertheless, the variety of colors and textures, and the relative abundance give them a strong potential as building stone. Perhaps the availability of tuff has caused them to be overlooked.

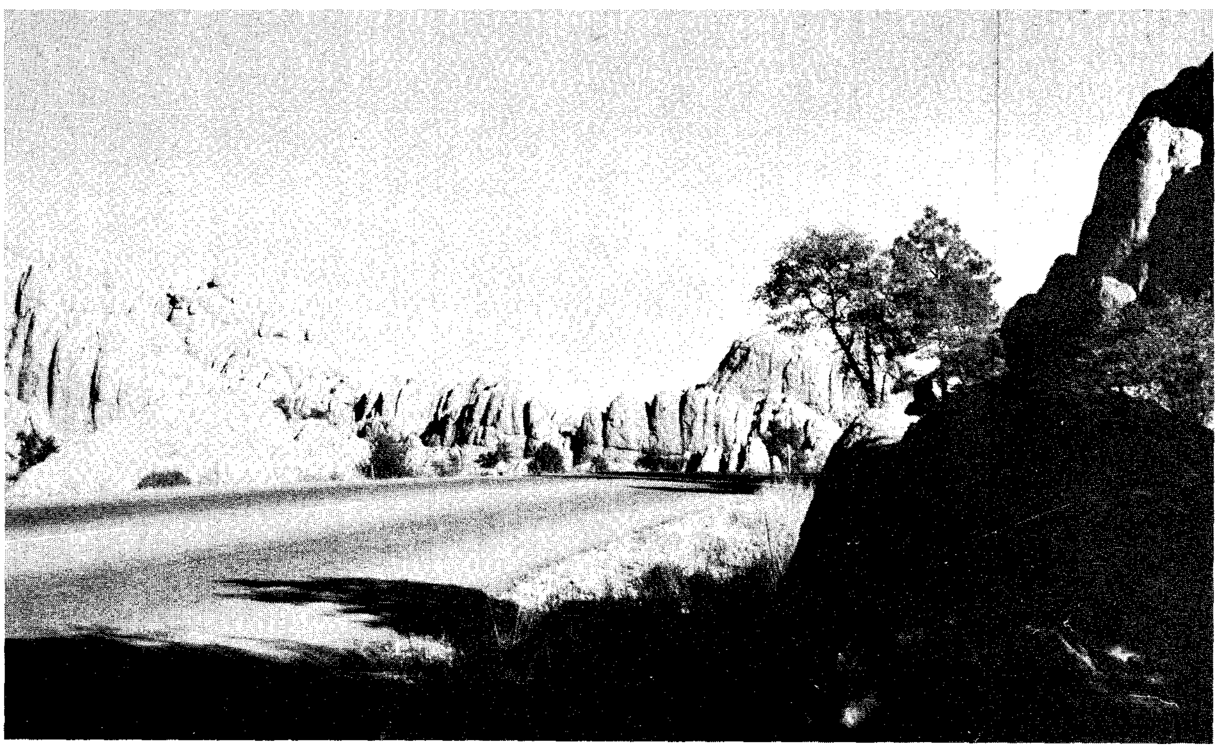
In Greenlee County near San Carlos, a tuffaceous rhyolite has been quarried. It is fairly massive, reddish in color, and in places it has attractive banding of reddish and light colors such as cream. Northeast of Wickenburg, Maricopa County, a rhyolite with bands and halos of red to brown is reported. It is fine-grained and can be cut to good building stone. Another deposit west of Alamos Springs in Yuma County is prized for the halo bands of salmon-pink to red in a light gray back-ground. Regarding halo bands, in places some fine-grained rhyolites have a fairly regular jointing and fracture system, allowing alteration (oxide) to affect the rock along the planes of fracture, and more or less into the rock, probably along flow lines. When quarried, the rock tends to have colored bands parallel to fractures. Interesting and attractive patterns and "designs" may also be ex-posed by cutting such rock.

Of particular current interest are the many surface deposits of both residual and transported boulders of rhyolite porphyry. Weathering has created shades of red, brown, pink and even lavender that make the rock desirable in masonry walls and landscaping. Large areas near urban centers in Arizona have been cleared of this surface material; shipment out-of-state is also reported.

Basalt and scoria

In parts of the United States, this heavy, dense, very hard, fine-grained, and generally dark-colored rock is a major type of building stone. Vast areas of basalt are present in Arizona.[il] Although is has had local use, no significant shipments are reported. It is

Outcrops of massive granite.



granite," [7] and includes other basic rocks such as diabase and diorite. In Arizona, it is commonly called "malpais".

Because of the weight, hardness, and subdued and somewhat somber colors, basalt has a limited potential as a dimension-cut building stone. However, currently the weathered basalt is popular for masonry walls, wallfacing, and landscaping rock. In some cases, the rounded boulders transported by erosion are desired, and in other cases, the weathered but more angular pieces near the outcrops are used.

Somewhat more difficult to obtain are the scoriaceous basalts, or scoria. This material is somewhat lighter in weight because it contains vesicules or holes due to contained gases in the original lava. The vesicules are often not connected, and may be filled with white, secondary minerals. The more representative scoria resembles clinker or slag, and is commonly red or maroon in color. Irregular deposition of scoria makes quality control difficult, but at this time large tonnages are being sought to meet an increasing demand.

Travertine, tufa, and onyx marble

These stones of ancient reputation occur sparsely in Arizona. They all originate from the same process of calcium carbonate precipitation in springs, streams, or caves. Sometimes beds are only a few inches thick, but may be scores of feet thick. Travertine is a solid, layered rock, which when pure is white, but may be colored to many hues due to contaminating elements such as iron oxide or organic material. Tufa is cellular in structure, and onyx marble is banded and crystalline. All may contain some siliceous material, and in fact, true onyx is a variety of agate, primarily silica. Being made dominantly of calcite, they are soft, cut easily, may be carved, and may take a high polish.

Onyx marble, or decorative onyx is probably the most spectacular of the three stones, and even though deposits of travertine [6] and tufa [a] are present in the state, onyx presently exceeds the others in demand. Due to the irregular deposition of onyx, quarrying of large volumes of consistent quality is difficult. The market for novelties made of onyx is well established, but the stone's greatest potential is in building materials, such as wall facings, sills, table tops, trims, floor tiles, and moldings. The relative ease of cutting and polishing may make it competitive with other textured, polished stones, in spite of the quarrying difficulties.

In Santa Cruz County, northwest of Sonoita, a type of onyx is variously reported as onyx marble and travertine.[6] It was found in a cavern in limestone on the east side of the Santa Rita Mountains. It is reported to be various shades of brown, and to be sufficiently massive and firm to be removed in large blocks.

Near Cave Creek in Maricopa County, greenish and yellowish onyx with veins of brown and red is deposited in intimate association with basalt. Although of fine quality, only relatively small pieces may be removed due to shattering by volcanics.

Near Mayer, Yavapai County, considerable onyx has been produced.[26] It is white and pale green in places, but the deposit contains much amber, brown, and yellow stone. Several openings have been made in a deposit that covers about one quarter of a square mile. In one place, a large open pit, approximately 40 feet across, has been excavated, exposing onyx on three sides; beds here vary from an inch to more than 10 feet thick, and are reported to be more than 20 feet thick elsewhere. The beds are also wavy and irregular. Adits have been dug more than 10 feet into the vertical walls of the pit.

Excellent deposits of multi-colored onyx are located approximately 20 miles north of Globe, Gila County. 300,000 to 1/2 million tons of gross material are estimated to be available with a substantial portion useable or recoverable. As many as 17 different colors of banded, crenulated, and veined material are reported. In places, the bands and crenulations are fine and tight. Elsewhere, massive white and ivory colored onyx with fine veins is present. Production consists largely of intermittent, surface work over the past two years. It is believed that consistent colors and patterns can be quarried in large saw blocks; the stone contains some vugs that appear firm. What work has been done indicates relatively little fracturing in the rock and one bed is 20 feet thick over a considerable distance. Also, the stone contains some siliceous material, agate or chalcedony, largely filling vugs. Due to the presence of the harder, siliceous material, and particularly for volume production, diamond saws are indicated for cutting.

Quartzite and Quartz

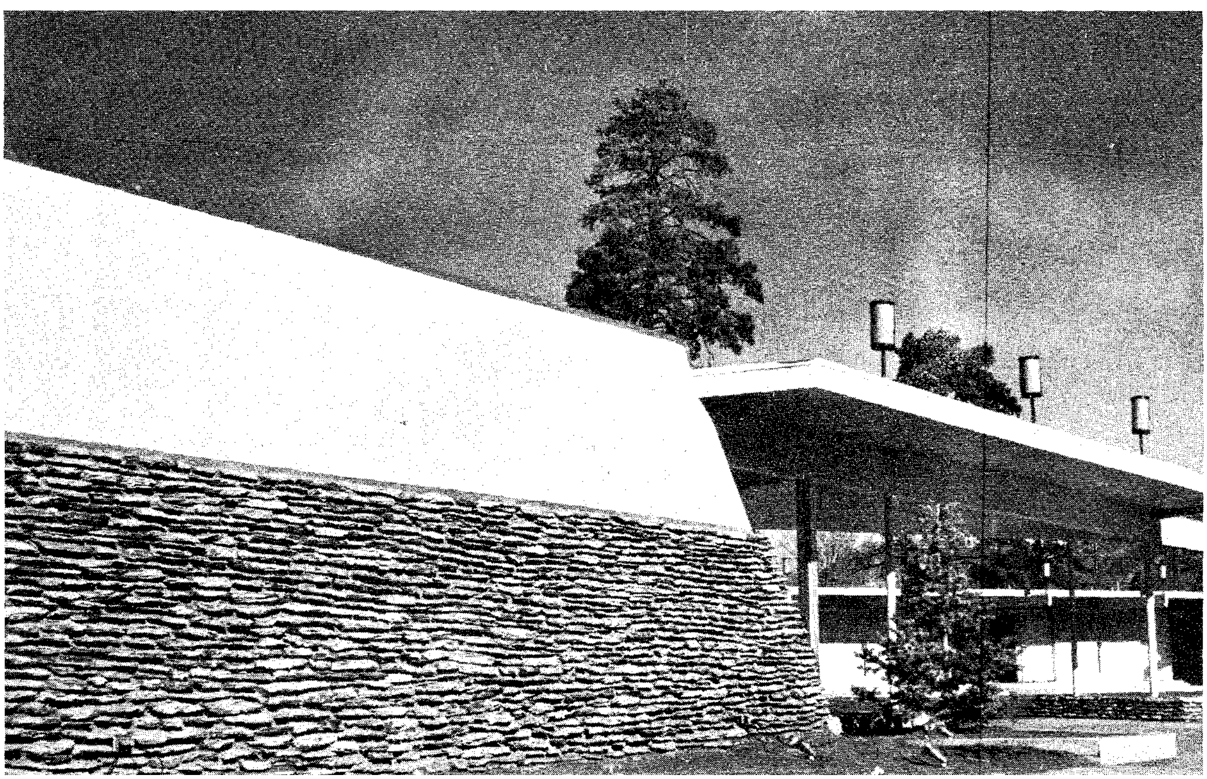
A sandstone made of quartz grains, that has been metamorphosed to the extent that the rock will break through the individual grains, is termed quartzite. Impurities in the original sandstone, or introduced by metamorphism can give quartzite almost any color and banded effect. The rock is hard and tough, and many varieties will take a good polish. Quartzite cuts and polishes with about the same ease as granite. In places such as the northeast corner of Pima County, some quartzite cleaves along bedding planes, yielding sheets, plates. and blocky pieces, depending on the thickness of the beds. Many beds are massive and several feet thick, and could be quarried for saw blocks.

At least six quartzite formations are well-known in Arizona," and this rock type is also found as members in other formations, such as associated with marble. Production of quartzite has been meager, but the many deposits in Arizona should get attention in the future.

Quartz, on the other hand, has been a common building stone for many years. As a stone, the term quartz usually refers to vein deposits, where it is often found in shades of white or milky white. Rose quartz is rarer, and currently much in demand. Commercial deposits are mostly at least several feet wide, and may compose small hills, making extraction easier. Quartz has a hardness and toughness equal to quartzite, and characteristically breaks with a glassy, conchoidal fracture.

Numerous deposits of quartz have been worked for flux in copper smelting, and these and others can be used to provide building stone. Notable deposits of rose quartz are northeast of Cave Creek in Maricopa County, in the Cerbat Mountains, near Chloride, Mohave County, and north

Schist wall (lower portion) with top of exposed quartz aggregate.



of Bagdad in Yavapai County. Although deposits of white quartz are generally not large in size, they are common in all counties except Apache, Navajo, and Coconino.

Jasper

Jasper is a hard, dense, variety of silica resembling chert in some respects. It is opaque, and occurs in colors of black, brown, and yellow, but most commonly red; it takes a high polish. Being a siliceous precipitate from cold water, it occurs in large and small irregularly-shaped masses, and sometimes in fairly widespread `beds'. Although the hardness and irregular deposition do not give it the large volume potential of some other stones, jasper is considered unique and is in demand for special uses.

Jasper may be found in every county of Arizona, but the best known deposits are in a wide area where Yavapai, Gila, and Maricopa Counties meet, between Cave Creek and Sunflower, and north along the Mazatzal Mountains. Here, red, green, and purple jasper, partly banded and crenulated is exposed in many places; some of it is associated with mercury (quicksilver) deposits. Fairly extensive and thick beds west of Sunflower have been worked. Also, deposits in northwest Yavapai County and Mohave County are reportedly being opened. Out-of-state shipments of rough, quarry run stone from various parts of the state are re-ported.

Copper-stained stone

Currently, any rock type containing substantial quantities, coatings, or stain of the blue and green, secondary or oxide minerals is in demand. The extensive copper mineralization in Arizona provides ample supplies, not only in outcrops, but in many mine dumps. The brilliantly colored secondary minerals, chiefly chrysacolla and malachite,' are difficult ores of copper to process, and are often discarded or stockpiled at mines for later use. Where the rock is firm, its value as building stone exceeds its value as ore. Numerous buildings in Arizona have wall facings of oxide copper stone, and substantial shipments to other states attest the growing desirability of this unique stone.

Magnesite

North of Phoenix near Rock Springs in Maricopa and Yavapai Counties, deposits of a white and cream-colored rock called "magnesite" may be found. It occurs over a fairly large area as beds at least ten, and possibly many more feet thick. It appears to be opalized carbonates of calcium and magnesium. Surface material varies from hard and firm to crumbly. Recent production has increased markedly.

Serpentine

A "serpentine" stone in shades of pink, gray, and purple has been reported from southwest of Globe, Gila County. The rock is said to be banded and fairly hard, and is being produced for shipment.

V AVAILABLE STONE — LAND STATUS AND ACQUISITION OF MINING RIGHTS

In the future, doubtless many new sources of stone will be developed in Arizona. The state contains vast areas that are available for prospecting, but due to the several basic kinds of land ownership, mining rights must be acquired in several different manners. For purposes of developing stone quarries, four types of land according to basic ownership may be considered; 1) private land, 2) U. S, public domain open to mineral location, 3) Arizona state land, and 4) Indian land. These types of land constitute 90 percent of the state; the other 10 percent consists of Federal lands withdrawn for military purposes, parks, reclamation projects, and other uses not open to mining. The approximate acreage and proportions of these lands are as follows:

Type of Land Ownership	Approximate Acreage	Percent
Private	10,200,023	14
U.S. Public Domain	24,451,252	34
State of Arizona	10,785,564	15
Indian	19,378,795	27
Other	7,872,366	10
Totals	72,688,000	100%

Private land

Inasmuch as all of Arizona was once Federal land, private ownership has been acquired through patents of one kind or another, such as homestead, mineral, and land grant patents, and the land is now owned in fee simple. Therefore, private land is also known as patented or fee land.

Acquisition of mineral rights on private land in Arizona is the same as any other place. Some-times land is bought outright, but more commonly lease arrangements are negotiated with owners. Some owners want a flat rental, others want a royalty on material removed or a combination of both. Prospecting should be done with the consent of owners.

U. S. Public Domain

These lands are known as Federal, or simply "U.S." lands. They consist largely of U. S. Forest lands, and of unappropriated Federal lands managed by the U. S. Bureau of Land Management.

Mineral rights for unique varieties of stone may be acquired on open public domain, under the mineral location laws applicable to lands in sixteen western states. Prospecting may be done without permit. Upon discovery of a valuable deposit, claims which are generally 600 x 1500 feet in size, are located, location notices are filed, and mining or quarrying may begin. Claim monuments and discovery work must be done according to General Mining Regulations. One may locate and mine on as many claims as necessary, and upon which a discovery is made; neither a lease nor royalty payments are required. Under certain conditions, mineral claims may be patented; that is, full rights to the land are granted the claim holders.

Under an Act of July 23, 1955, the U. S. mining laws were amended to provide for multiple use of land, restricting miner's use of the surface of unpatented claims to those activities necessary to prospecting, exploration and mining. Also, "common varieties" of sand, stone, gravel, pumice, pumicite or cinders were made non-locatable, and are subject to disposal by sale under contract. Thus, a common variety of stone could be removed only under contract, and by payment of a unit price for the stone removed.

The question of definition of "common varieties" is, of course, important to the stone industry, because rights under mineral claim location procedure are greater than that for disposal of common varieties by contract. Materials which have a distinct and special value are not considered "common varieties." It appears that such characteristics as unique coloration, ability to cleave or be split easily into slabs or sheets, or ability to be cut to dimension could cause a particular deposit of stone to be classified as uncomomn. Stone having no unique chemical or physical properties would normally be a common variety. There must be a market for the material at the time of location to make it valuable and subject to location. However, the law is so new that few guide lines have been established, and each deposit must be evaluated by itself. It may be inferred that today's market requirements of high specifications and unique appearance of products should presume the existence of many uncommon varieties of stone that would be locatable as mining claims.

State of Arizona Land

State land is also subject to entry for mining purposes; prospecting may be done without a permit. Upon discovery of a valuable mineral deposit, a claim *may* be located in essentially the same manner as on Federal land, or according to 20-acre claims set out by legal subdivision. Stone is included with other minerals, without distinction as to common or uncommon varieties.

The major differences between mining on State and on Federal land are that after location on state land, a 20-year lease is obtained, royalty on production is paid, and no patent proceedings are available; also, lessees pay an annual rental of $15.00 per claim. and hai, a preferred right to renewal of the lease on expiration. Leases may be assigned or transferred, wholly or in parts.

State lands are managed by the Arizona State Land Department. Proof of discovery is required, and for stone claims this may consist of sending a sample to the Department, along with an affidavit that the sample came from a particular claim. Royalty is payable at the rate of 5 percent of the net value, after deduction of cost of processing, costs of transportation, and applicable taxes. Rules and regulations, and instructions on procedure to obtain a mineral lease are also available. Arizona encourages mining on its land as well as throughout the State, and a substantial amount of the present stone industry obtains raw materials from State land.

Indian Land

Approximately 27 per cent of Arizona is Indian land, divided into separate Indian Reservations scattered over the state. Generally, exploration and mining rights may be acquired by negotiation. with individual tribes, under the supervision of the U. S. Bureau of Indian Affairs. Most commonly, leases are obtained for a particular area, and payment includes a fixed rental, plus royalty. Where possible, the use of Indian labor is encouraged.

Surface and subsurface

In addition to the above general ownership of lands in Arizona, attention should be called to the variations in surface and subsurface ownership. That is, title to the surface may be held by one of the U. S. Government, State of Arizona, private parties, or Indians, while title to the subsurface or mineral rights may be held by another of those four. For example, the surface rights may be owned by the State, while the subsurface is held by the Federal Government; in this case, mineral claims could be located according to Federal procedure. Or, private parties may own the surface, but the State owns the mineral rights or subsurface, making it subject to State mineral leases. Most commonly, the State or private parties own surface rights, with subsurface reserved to the Federal Government.

In any case, this divided land ownership, which could be called "vertical ownership," is a factor to be considered in exploring for stone quarry sites. Although seemingly complicated, its total effect has been to reserve large areas for mineral claim location under Federal or State laws. The U. S. Bureau of Land Management and the Arizona State Land Department make both records and help available to determine land status.

VI TRANSPORTATION AND FREIGHT RATES

No consideration of the economics of the stone industry would be complete without a realistic evaluation of transportation conditions. Length of haul, modes of transportation, availability of loading facilities, and freight rates loom large in the determination of whether or not a particular stone can compete with other materials. This is particularly true in Arizona, where the appeal of west coast markets is strong. Not only must Arizona stone compete with manufactured materials, such as glass and aluminum, but it must be competitive with stone from other states; Arizona has an obvious advantage over eastern stone moved by truck and rail, but may not be so fortunate regarding overseas haul, even from foreign countries. The importance of transportation to the stone industry may be seen by the general location of quarries near major transportation routes.

Some quarry operators rely in part on their own trucking facilities; others contract hauls, and use both truck and railroad transport. Between truck and railroad service, each has advantages that must be weighed for operation of any given stone deposit. The transportation of goods is a more complicated field than many producers in all industrial fields realize. Specialist representatives of common carriers in Arizona stand ready to analyze, and to recommend proper arrangements and adjustments to meet the conditions of new and changing industries. Their aid should be sought. Common carriers must quote rates on any and all commodities except a few specialties of "extraordinary value." They are constantly evaluating rate schedules to make them appropriate for a given volume of movement. Rates are generally first established for a particular need. Such rates may be applied to other similar needs even though they may not be wholly applicable, unless circumstances for additional and different rates are presented by shippers. Thus, more flexibility is available, particularly for new commodities or forms.

Several general principles of common carrier transportation are pertinent. Shippers should determine the difference between "class" and "commodity" rates. The former are more general, and apply to all of one type of carrier, and the latter are more detailed, for specific volumes and haul routes. Secondly, interstate and intrastate haul conditions may be different, affecting rates and franchises. Thirdly, minimum weight requirements must be considered. For example, present truck and rail-road rates for hauling stone from Ashfork to the Los Angeles area overlap according to the various minimum weight requirements. Another important factor regarding rates is the degree of finish of a product. Fundamentally, carrier's rates are based 1) the work done in hauling, 2) the particular risks encountered in handling and hauling goods, and 3) the wear-and-tear and damage done to transport equipment. It may be seen that in general the higher value goods require higher rates, and many different classifications are created. With stone, as with many other products, the more finished the material, the higher is its value. Related to this, stone producers are becoming more interested in packaging, not only for ease of handling, such as cut stone steel-taped on pallets, but for protection of products, and for merchandising of building kits. For some products, carriers rates vary according to packaging.

Railroads

Two major rail systems serve Arizona; the Southern Pacific Company in the southern part of the state, and The Atchison, Topeka, and Santa Fe Railway Co. in the northern part of the state. Both have had limited experience in hauling stone in Arizona, and consequently do not have detailed commodity rate schedules for many potential shipping points. Below is a general classification of stone for rail haul, according to degree of finishing:

1. Rough quarried, or broken stone.
2. Finished not more than sawed, dressed, or cut to shape.
3. Polished, decorated, finished.

Within the above groupings, there are, of course, many possible stone commodities. Movement of stone in the southern part of Arizona has been erratic over many years, so quoted rates may be unrealistic for specific commodities, but in the northern part of the state, stone is now being moved by rail at the following representative rates :

CURRENT CARLOAD COMMODITY RATES
FOR RAILROAD SHIPMENT

Natural stone, rough quarried, or broken

(no packaging required)

FROM: Northern Arizona, viz: Ashfork, Drake, Prescott, Seligman

TO:	Rate per 100 lbs.	Minimum lbs.
Los Angeles, California	$0.455	60,000
	.335	80.000
San Francisco, California	.445	100,000
Fresno, California	.415	100,000
Seattle, Washington	.88	100,000
	1.21	50.000
Portland, Oregon	.88	100,000
	1.21	50,000
Chicago, Illinois	.93	80,000
Kansas City, Missouri	.84	80,000
Milwaukee, Wisconsin	.93	80,000
Houston, Texas	.75	80,000

Other features related to rail transportation that should be considered are loading sites and processing sites. Most stations have public loading tracks (team tracks) and also have some leasable industrial sites on trackage (industry track). All named stations have sidings, and these are more numerous than commonly believed. Moreover, between stations railroad companies have rights of way of an average of about 100 feet on both sides of tracks, which under certain conditions may be used for additional facilities. Thus, if volume of haul warrants, processing plants *may* be located adjacent to rail loading facilities.

Trucking

A number of substantial interstate and intrastate motor carriers serve Arizona. They, as well as the railroads, are eager to expand services, and help develop new industries in Arizona. Hence such services as new accounting methods to save paper work by shippers, and arrangements to spot trailers for loading at shipper's convenience are offered. Some independent carriers haul stone under negotiated contract, but common carriers haul according to established class or commodity rates. Below is a sample of present truck rates for stone shipped to the Los Angeles, California, area:

CURRENT COMMODITY RATES FOR TRUCK SHIPMENT*

COMMODITY: viz: flagstone, gravel, gypsum rock, lime rock.

TO: Los Angeles, California, area

FROM:	Rate	Min. Wt.	Per Ton	Miles	Per Ton Mile
Kingman	$.51	20,000	$10.20	381	$0.0267
Seligman	.51	20,000	10.20	414	.0246
Ashfork	.51	20,000	10.20	425	.0240
	.43	30,000	8.60	425	.0202
Williams	.60	20,000	12.00	445	.0269
	.50	30,000	10.00	445	.0224
Flagstaff	.68	20,000	13.60	465	.0292
	.65	30,000	13.60	465	.0279
Prescott	.43	30,000	8.60	372	.0231
Phoenix**	.41	20,000	8.00	392	.0204

VII LABOR MARKET

Even a modest growth. of the stone industry in Arizona implies a need for skilled and semi-skilled labor. The number presently employed in this field is not only not known, but is difficult to determine, because of the many small operations being carried on at irregular intervals. From a general knowledge of the production of stone during 1960, it appears that approximately 200 persons consider the major portion of their living as being made in stone production. At least that many again derive some of their income from stone production, including the part-time prospector who sells an occasional load, and the seasonal worker in established quarries. Many others have some knowledge of stone through its distribution, sale, and use in construction. Of all of these, few are considered skilled stone workers. The industry is new in Arizona, and many of those who are skilled became so through experience over the last few years.

In addition to what is considered to be a plentiful general labor market, Arizona's unique climate is often used to attract specialists in many fields. The Arizona State Employment Service of the Employment Security Commission can readily obtain qualified workers in any field, through the highly efficient nationwide clearance program; they report that 30,000 inquiries annually are received from out-of-state skilled and semi-skilled workers desiring to relocate if employment could be provided. Therefore, any shortage of properly trained and experienced personnel for the stone industry should be only temporary.

The ultimate personnel needs of an expanded stone industry fall into three categories. First, efficiency in production can undoubtedly be in-creased by skilled quarryman. Even though each rock type has its own peculiar characteristics to be learned and mastered, competent stone workers from one part of the country can readily adapt themselves to a new type of rock. Second, an expanded stone industry would presume closely associated milling and processing, requiring skilled operators of wire saws and diamond and other rigid saws, and of grinding and polishing equipment. Third, much of the present quarry and processing practice requires workers qualified to operate light and heavy machinery. A more integrated, mechanized industry would add further to these requirements.

Arizona's large mining industry could doubt-less provide many qualified workers for the above projected needs. Many people in the present stone industry have mastered the intricacies of particular rock types. Further personnel needs can be solved through the national clearance program of labor placement.

VIII DEPLETION ALLOWANCE, TAXES, AND INSURANCE

Contrary to popular opinion, tax depletion allowances are not limited to oil and gas production. Dimension and ornamental stone, and stone for aggregate, and road materials are all included in depletion allowance schedules as well as uranium, copper, and other minerals. In order to keep producers of irreplaceable natural resources on an even tax basis with manufacturers whose need for depreciation (depletion) allowances for capital replacement is obvious, Congress has provided that a certain portion of gross income from a mining or quarrying operation may be deducted before calculating taxes. In most industries, the cost of the capital investment being depleted is known, or can be evaluated, and a depreciation schedule can be set up for its replacement. But in mining or quarry-

** Rates as of 2-10-61, shown in Interstate Freight Carriers Conference, Inc., Local and Joint Freight Tariff No. 1-E, MFICC No. 7, first revised page 311, items 5620 & 5630.*

*** Commodity: viz: Building stone, NOI, flagstone, gypsum rock, lime rock.*

ing, the reserves of ore or stone are the capital being depleted; this capital is difficult to evaluate and to schedule replacement or eventual loss, so the somewhat arbitrary basis of a percentage of gross income is used. That is, it is asumed that if a certain portion of gross income from a property is not taxed, the money saved will eventually equal the value of the deposit.

Thus, the following depletion allowances apply in the stone industry:

Dimension and ornamental stone 15%*
Common varieties of stone—including those
sold for concrete aggregate, ballast,
road material, riprap, rubble, or similar
purposes - 5

Inevitably, taxes are an important consideration in any business. Historically, Arizona has been sympathetic to mining industries, and today continues to encourage development of its resources. Taxes facing the stone industry are not excessive. The most notable assessment is the state-wide sales tax, as follows:

Wholesale sales tax .... 1 %$_2$
Jo
Retail sales tax -*3%*

In addition, attention should be drawn to the requirement for State Industrial Insurance. This insurance is paid on employees, and the amount varies according to the job, or type of work, and to the experience record within an industry.**

IX POTENTIAL

Arizona stone has the potential of being a well-known, highly desired, and industrially important construction material. In order to realize the full potential, people in the stone industry must recognize the use-position stone is in, relative to other materials. Then the resources in Arizona, and the status of the state's present industry must be evaluated. An expanded and stable stone industry will develop, if modern production and marketing methods are diligently applied.

Although concrete block, steel, aluminum, and glass have replaced stone in some uses, this should not be looked upon as a crippling blow to the stone industry. True, heavy structural needs, i.e., foundations and bearing walls, are more efficiently met by other materials. Also, when rapid construction is urgent and essential, such as after World War II, the durability, low maintenance and beauty of stone may be sacrificed temporarily.

However, excepting these two circumstances, several factors should combine to create a rennaissance in the stone industry. First, of course, the tremendous volume of construction in the United States has made part of the use of new materials additional rather than replacement. Stone is being made to compete in cost with other materials by standardizing sizes and shapes, and by volume and integrated production. Also, architects and designers are abandoning rigid concepts of stone use, making stone fit designs rather than designing to fit stone. Moreover, the very use of new materials mentioned above, contrives in two ways to promote use of stone; one, by creating a need for textural and color relief from the coldness of manufactured materials, and two, by providing structural members to support stone work in circumstances other-wise unfeasible.

Therefore, one may look with optimism toward a steady growth of the stone industry, roughly parallel to normal construction needs. Assuming the post-war building gap to be essentially closed, construction needs should in turn be parallel to population growth. If, then, the potential of Arizona's stone industry may be linked with population growth, the state is indeed fortunate. Within the optimum transportation zone, the Pacific South-west, population trends are awesomely upward. Projections show [3] that by 1970, five states bordering Arizona (Colorado excluded) will comprise a 25,000,000 market.

Considering the present status of the stone industry in Arizona, one may first conclude not only that the variety of raw material is wide, and that many unique stones are available, but also that the reserves are more than ample in most cases, and almost unlimited in others. Second, one should freely conclude that as an industry, stone production in Arizona is in its infancy. Only since World War II, have population and construction growth warranted much more production than would fill local needs.

** Not to exceed 50% of net income **computed** without allowance for **depletion.***

*** Further general information regarding taxes is available from the Arizona Development Board and **detailed** data are, of course, available from the Arizona State Tax Commission,* How, then, may this burgeoning industry with ample raw materials realize the indicated potential? On the basis of study of stone production problems, mention of some of the means has been made previously in this text. A more formal listing of general needs follows.

1. Volume markets and production

In today's cyclical economy, stability in most industries is achieved only with large and diversified markets that are fed by volume production. Certainly, to be important in the vast construction industry, Arizona stone must be produced in quantities able to meet needs that arise or that may be developed. The products may excel in beauty and durability, but they must also be competitive in quality, adapatability to construction methods, and in cost. To some extent, volume demand will increase without stimulation, but it can be hastened by concerted effort on the part of Arizona stone producers. Advertising and promotion are necessary phases of any marketing.* The potential to business interests and to the State as a whole justifies increased effort in market creation. With notable exceptions, producers have concerned themselves largely with production problems and quality control. The need for a state-wide trade association should be considered, state agencies should be given data by which they can publicize the industry, and individual producers must plan for larger sales and promotion programs.

A combination of three rock types may lead the way toward volume markets. Sandstone, marble, and tuff all have the potential of meeting most market demands; all can be produced in large quantities; all can be cut or split to standardized dimensions without undue cost; all have a variety of unique colors and textures. Sandstone is becoming well established, and marble is a traditionally desirable polished stone. Tuff excels in light weight, insulation, and ease of cutting, along with soft colors and textures.

2. Mechanization

If markets are increased. stone producers must look to mechanization to achieve large volume production with competitive costs. One of the most promising mechanical devices not yet used in Arizona is the quarry wire saw. Consisting essentially of a continuous, twisted wire cable run through pulleys, the saw cuts a groove by carrying abrasive materials across the stone. Various devices keep the wire taut, and the groove clean and straight. Long cuts may be made, and once a cut is started. little attention is required. Also, as permanent quarry sites are established, producers may look to more permanent stone loading and handling equipment for processing in quarries.

3. Integrated industry

Sandstone is now quarried, hauled, processed, and marketed by some operators. Other standstone producers and nearly all other operators perform only one or two functions. For sufficient profits, and to remain stable and competitive, it is probable that all dimension stone producers, and certainly producers of stone to be polished must anticipate performing all functions from quarry to final sales.

Capital

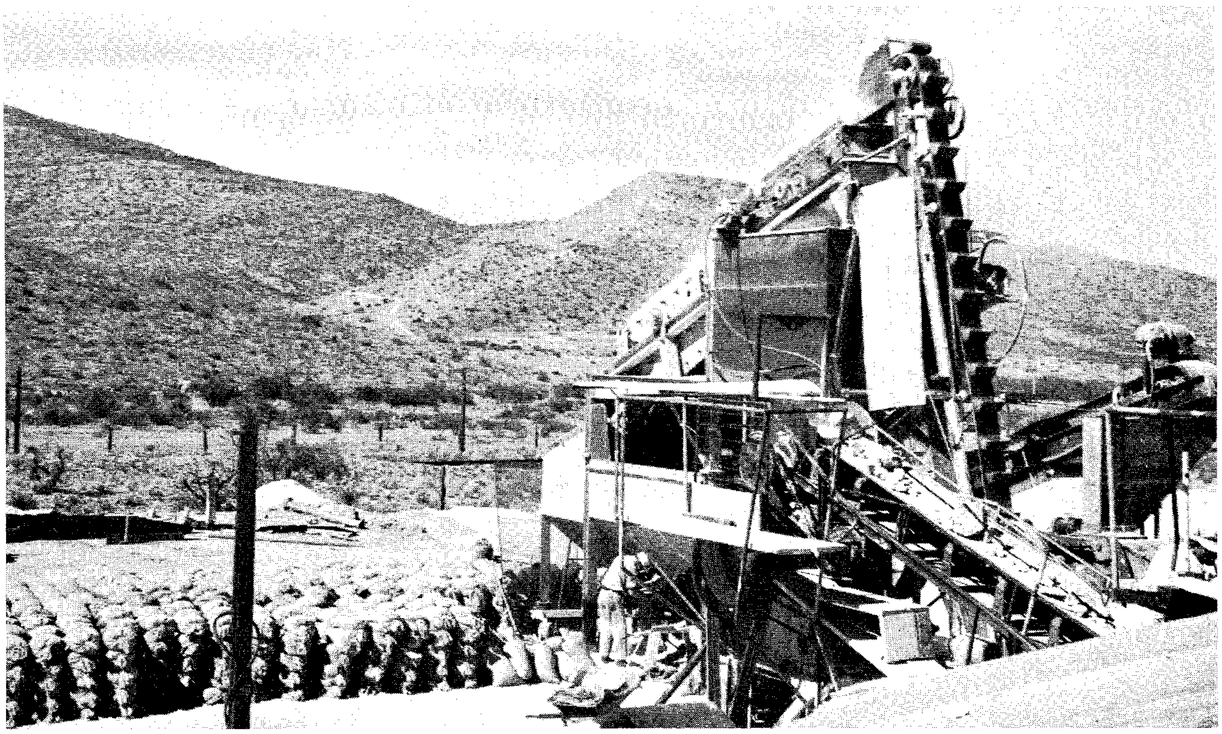
Without doubt, investment capital is necessary to implement all other general needs. Some operators maintain that capital is all that is needed, but the records show that investment capital by itself will not necessarily produce the stability that combined volume markets and production, mechanization and integration can produce.

Research and exploration

The organizations and efforts made to create volume markets, as well as individual producing firms must contribute to research and exploration. New techniques are needed in finding deposits, or in determining the proper quarry sites in known deposits. Hardly a quarry in Arizona has reached depths sufficient to know the true nature of unweathered or fresh rock. New quarrying techniques and processing methods may be developed, and quarry and plant layouts to utilize favorable terrain are needed. Techniques may be devised for production of more than one type of stone in a single processing plant; production of some of the less produced stone, such as rhyolite, quartzite, and onyx could possibly be dove-tailed into production of sandstone, marble, or tuff.

Also research is needed to meet and to help

In this regard, the industry suffers somewhat from lack of precision in terminology. Architects, designers, and builders are humanly attracted to materials whose characteristics they can visualize and measure. This fault faces all new industries, and can be remedied by cooperation among producers and with users, create new trends. Shapes and dimensions must conform to requirements of steel, concrete, glass and other materials. Stone producers must work with producers of pre-cast slabs containing exposed aggregate, and may even be able to develop pre-fabricated masonry units; not only the cost of stone, but the time needed to handle it during construction must be competitive with other materials.



Colored marble being crushed, screened to size, and bagged for shipment.

X GLOSSARY

1. AGGREGATE — The mineral material, such as sand, gravel, shells, slag, or broken stone, or combinations thereof, with which cement or bituminous material is mixed to form a mortar or concrete.[13]
2. ASHLAR — Rectangular blocks having sawed, planed, or rock-faced surfaces, contrasted with cut blocks which are accurately sized and surface tooled,[24] may be laid in courses.
3. BASALT — A fine-grained, extrusive (volcanic) rock, basic in composition, and generally dark-colored and hard.
4. BEDDING — Collective term signifying existence of beds or laminae in a rock; planes dividing sedimentary rocks of the same or different lithology.[13]
5. BROACH — To drill or cut out material left between closely spaced drill holes. Also, a mason's sharp pointed chisel for dressing stone.
6. CHANNELING MACHINE — A track-mounted machine operating steel bars in a chopping action that cuts narrow channels to remove blocks of stone.[14]
7. CROSS-BEDDING — The arrangement of laminations of strata transverse or oblique to the main planes of stratification.[13]
8. CURBING — Slabs and blocks of stone bordering streets, etc.
9. DACITE — A fine-grained, extrusive (volcanic) rock, intermediate in color and composition between basalt and rhyolite.
10. DOLOMITE — A sedimentary rock composed of carbonate of calcium and magnesium; resembles limestone.
11. EXPOSED AGGREGATE———Phrase applied to the larger pieces of aggregate purposefully exposed for their color and texture in a cast slab or in concrete or paving.
12. FIELD STONE —Loose stone scattered by natural processes over the ground surface.
13. FINES — The powder, dust, silt-size, and sand-size material resulting from processing (usually crushing) rock.
14. FLAGSTONE — Thin slabs of stone used for flagging or paving walks, driveways, patios, etc. It is generally fine-grained sandstone, siltstone, or slate, but some limestone and thin slabs of other rocks may be used.
15. FREESTONE — A stone that may be cut freely in any direction without splitting.
16. GRAIN—The second easiest cleavage direction in a rock.? (Compare to rift.) Also, particles (crystals, sand grains, etc.) of a rock.
17. GRANITE — A fine to coarse-grained, igneous (plutonic) rock consisting of quartz, feldspar, and mica, with accessory minerals. *Granite-type* rocks include those of similar texture and origin.
18. IGNEOUS———One of three great classes of rock, igneous, sedimentary, and metamorphic; solidified from molten state, as granite and lavas.
19. LAVA — A general term applied to igneous rocks such as basalt and rhyolite, that erupted from the earth by volcanic action.
20. LIMESTONE———A common sedimentary rock composed of calcium carbonate; includes many varieties.
21. MALPAIS_ Literally, *badlands* refers to the dark-colored rock, commonly lava, in rough terrain.
22. MARBLE — A metamorphic rock composed essentally of calcite and/or dolomite, generally a recrystallized limestone. In the trade, it includes most calcareous rocks that will take a polish.13 [18]
23. MARMARIZED__Refers to the process of recrystallization of limestone to marble.

24. METAMORPHISM — The change or alteration in a rock caused by exterior agencies, such as deep-seated heat and pressure, or intrusion of rock materials.
25. OBSIDIAN — A glassy phase of lava.
26. OPALIZED — The introduction into a rock of siliceous material in the form of opal, a hydrous silicate.
27. PHENOCRYST—In igneous rocks, the relatively large and conspicuous crystals in a finer-grained matrix or ground-mass.
28. PORPHYRY — An igneous rock in which relatively large and conspicuous crystals (phenocrysts) are set in a matrix of finer crystals.
29. PUMICE — An exceptionally cellular, glassy lava, resembling a solid froth.
30. QUARTZITE — The metamorphic equivalent of a quartz sandstone, in which the grains have recrystallized or have grown together.
31. RIFT — The most pronounced or easiest (see grain) direction of splitting or cleavage of a rock. Rift and grain may be obscure, as in some granites, but are important in both quarrying and processing stone.
32. RHYOLITE— A fine-grained extrusive (volcanic) rock, acidic in composition, and generally light-colored.
33. ROCK — A general term applying geologically to any naturally formed aggregate or mass of mineral matter, whether or not coherent, constituting an essential or appreciable part of the earth's crust; includes formations, and loose masses such as sand, gravel, or clay beds, as well as hard and solid masses such as granite or limestone; sometimes synonymous with stone (see below.)
34. RUBBLE — Rough, irregular pieces of broken rock.[13] In the trade, it is sometimes confused with ashlar; ruble may be partly trimmed or squared, or may be irregular, or both (rough squared.) [7]
35. SANDSTONE — A consolidated sedimentary rock composed of sand grains.
36. SCALE — Thin lamina or paper-like sheets of rock, often loose, and interrupting an otherwise smooth surface on stone.
37. SCHIST — A loose term applying to foliated metamorphic rocks; generally medium or coarse-grained, with more or less parallel orientation of lamellar minerals such as mica, allowing it to split easier in one or two directions.
38. SCORIA — Irregular masses of lava resembling clinker or slag; may be cellular (vesicular,) dark-colored, and heavy.
39. SLATE — A very fine-grained metamorphic rock derived from clayey sediments, and having excellent cleavage along one plane due to micaceous minerals.
40. SPLIT — Division of a rock by cleavage.
41. STONE — Sometimes synonymous with rock, but more properly applied to individual blocks, masses, or fragments taken from their original formation or considered for commercial use.
42. STRATIFICATION—A structure produced by deposition of sediments in beds or layers (strata), laminae, lenses, wedges, and other essentially tabular units.[13]
43. STRIP — Removal of overburden or waste material. Also, elongate or linear pieces of cut stone.
44. TERRAllO—A type of concrete in which chips or pieces of stone, usually marble, are mixed with cement and are ground to a flat surface, exposing the chips which take a high polish.
45. TUFF — Cemented volcanic ash; many varieties included.
46. VUG — A cavity in rock; sometimes lined or filled with either amorphous or crystalline material; common in calcareous rocks such as marble or limestone.
47. WEDGING — Splitting of stone by driving wedges into planes of weakness.
48. WIRE SAWN — A method of cutting stone by passing a twisted, multi-strand wire over the stone, and immersing the wire in a slurry of abrasive material.

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Contains national and some state statistics on production and value, partly by types of material and uses; general industrial data; includes brief world review.

26. Wilson, Eldrid D. and Roseveare, George H. "Arizona Nonmetallics." Ariz. Bur. Mines Bulletin 155, 1949. *Brief summary of stone activity in Arizona immediately after World War II*

XII AGENCIES CONCERNED WITH STONE

1. Arizona Department of Mineral Resources, Phoenix, Arizona.

    Information on stone quarries, stone prospects, production, producers, and operators.

2. Arizona Bureau of Mines, University of Arizona, Tucson, Arizona.

    Information on stone quarries, stone prospects, geology of Arizona, stone processing.

3. Arizona Development Board, Phoenix, Arizona.

    Information and aid in industry development.

4. Arizona State Land Department, Phoenix, Arizona.

    Leases state land for mining and quarrying, information on land status.

5. Employment Security Commission of Arizona, Phoenix, Arizona.

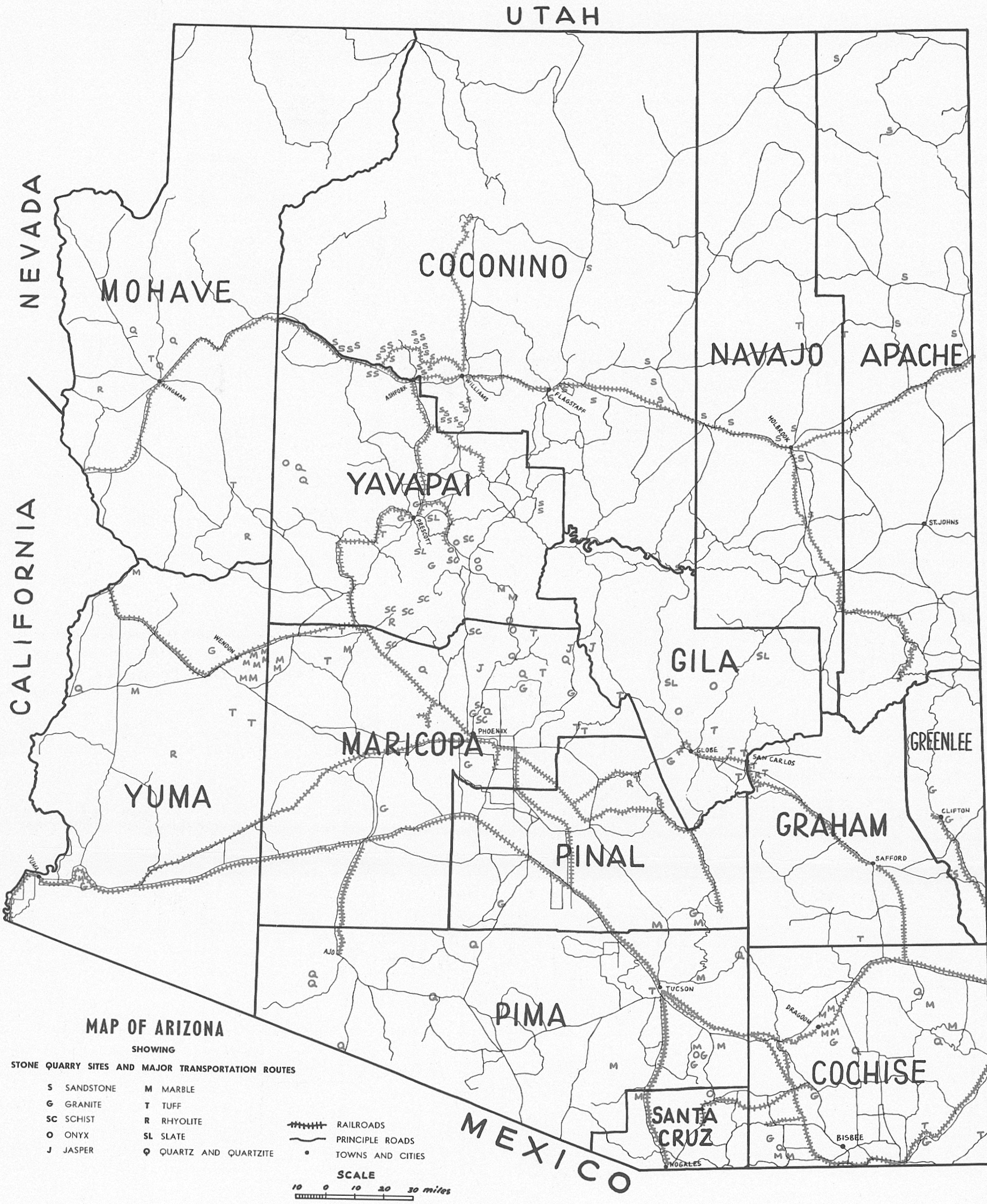
    Aid in labor placement; information on unemployment compensation.

6. U. S. Geological Survey, Phoenix and Tucson, Arizona.

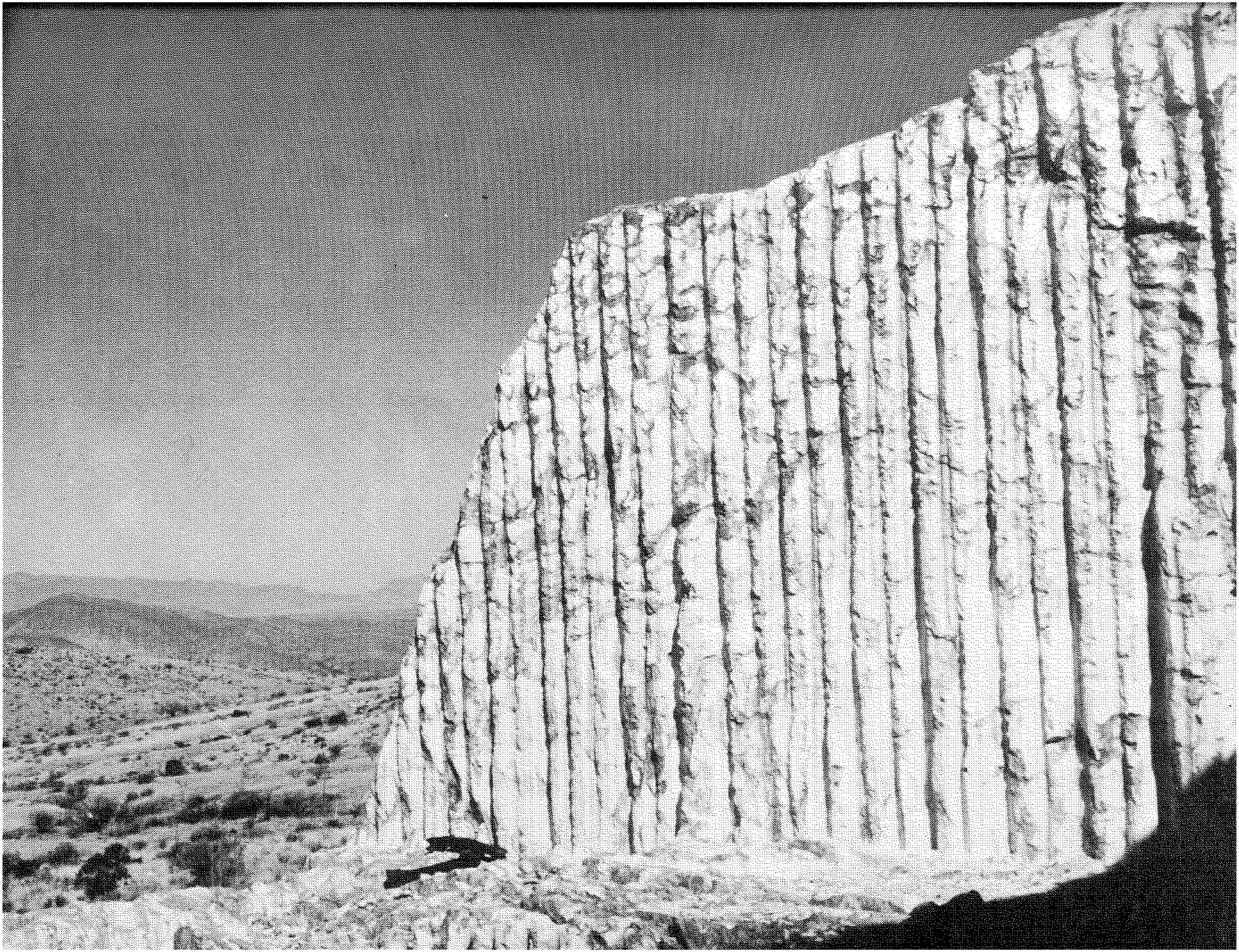
    Information on geology of Arizona and on water supplies.

7. U. S. Bureau of Land Management, Phoenix, Arizona.

    Information on mining and quarrying rights on federal lands, and information on land status.



MAP OF ARIZONA
SHOWING
STONE QUARRY SITES AND MAJOR TRANSPORTATION ROUTES



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