Sources of Lightweight Aggregates in Colorado

PREPARED AS A PART OF THE PROGRAM OF THE INTERIOR DEPARTMENT FOR THE DEVELOPMENT OF THE MISSOURI RIVER BASIN

by

ALFRED L. BUSH[1]
Geologist
U. S. Geological Survey

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SOURCES OF LIGHTWEIGHT AGGREGATES IN COLORADO

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ABSTRACT

Most of the sources of lightweight aggregates in Colorado are in the mountainous central region, and are, therefore, some distance from the major marketing centers of the state. Large deposits of clay and shale, however, are present both east and west of the mountain belt and are readily accessible to the marketing centers.

Materials in Colorado that are suitable for use as lightweight aggregates are pumice, scoria, perlite, obsidian, vermiculite, welded tuff, clay, shale, slate, diatomite, fuller's earth, slag, and cinders. Some of these materials are used in their raw state; others require processing or are by-products of manufacturing processes. Large tonnages of some of the suitable materials are available, but others are present only in minor amounts.

INTRODUCTION

The increased efficiency in construction during recent years has focused attention on improving building materials. One of the points of attack has been to reduce the dead weight of concrete. Three methods are in general use to achieve this reduction: 1) substitution of lightweight aggregates for sand and gravel aggregates; 2) addition of materials that produce voids by sublimation, evaporation, or liquefaction during setting of the concrete; and 3) addition of materials that react with concrete to produce gas voids and hence tend to lighten the concrete.

The present study of sources of materials in Colorado suitable for use as lightweight aggregates for concrete is in response to the need for lighter-weight concrete, a need that is indicated in part by the numerous requests for information that have been received by the U. S. Geological Survey.

Most of the investigation was done from February through July 1947. At that time no adequate compilation of information on lightweight aggregate materials, their characteristics, manufacturing processes, or sources was available. The study was divided, therefore, into two phases: intensive search of the technical literature on lightweight aggregates and of the geologic literature of Colorado for occurrence of materials, and a reconnaissance field examination of the most promising deposits. In the search of the literature approximately 1000 articles and other publications were reviewed. Brief field examinations were made of 175 deposits; of these, 39 merit somewhat detailed description, and 41 others appear to warrant further investigation.

In May 1951 the technical and geologic literature was reviewed and the bibliographies were brought up to date. As the literature on the technical aspects of the lightweight aggregates industry has been adequately compiled since this project was begun in 1947, this phase of the subject is treated only briefly in this paper; the reader is referred to the technical bibliography at the end of this paper for additional information.

Definitions

The term "lightweight aggregate" refers to all materials used as aggregate that are suitable for use in producing a concrete that weighs from 70 to 100 pounds per cubic foot. Both limits are somewhat elastic; concrete weighing up to 120 pounds per cubic foot is considered to be at the upper limit of lightweight concrete and a vermiculite concrete weighing only 25 pounds per cubic foot also has been produced.

The term "normal-weight aggregate" where used in this paper refers primarily to sand and gravel aggregates. The resulting concrete weighs about 150 pounds per cubic foot.

Suitable Materials

Suitable lightweight aggregates can be classified as: 1) those that can be used in their natural state; 2) those whose usability depends on some kind of processing; and 3) those that are byproducts of other manufacturing processes. Materials in the first two classes can be further classified into: 1) those that result from explosive volcanism; 2) those that are of sedimentary origin; and 3) those that result from some kind of alteration of pre-existing natural materials. Suitable materials are classified and briefly described in table 1.

Characteristics

The light weight of the aggregates is due in large measure to the high percentage of contained voids. The texture of the mass may be vesicular, cellular, frothy, or accordionlike. The ideal aggregate is porous but impermeable; it contains many small enclosed voids with little or no connection between the voids. Although no aggregates meet these requirements perfectly, some do approach the ideal closely.

When lightweight aggregate is used in concrete, the weight is reduced sufficiently to permit considerable reduction in footings and foundations, and placement is facilitated. The large number of enclosed voids in the aggregate makes lightweight concrete a good thermal and acoustic insulator. As a result, accessory insulation can be reduced considerably, or eliminated completely. However, because of the large number of voids, lightweight aggregates have rough or jagged surface textures, and many produce harsh-working concrete. Because of differences in specific gravity the lightweight aggregates tend to segregate from the cement in concrete, and the coarse aggregate tends to segregate from the fine during transportation and stock-piling.

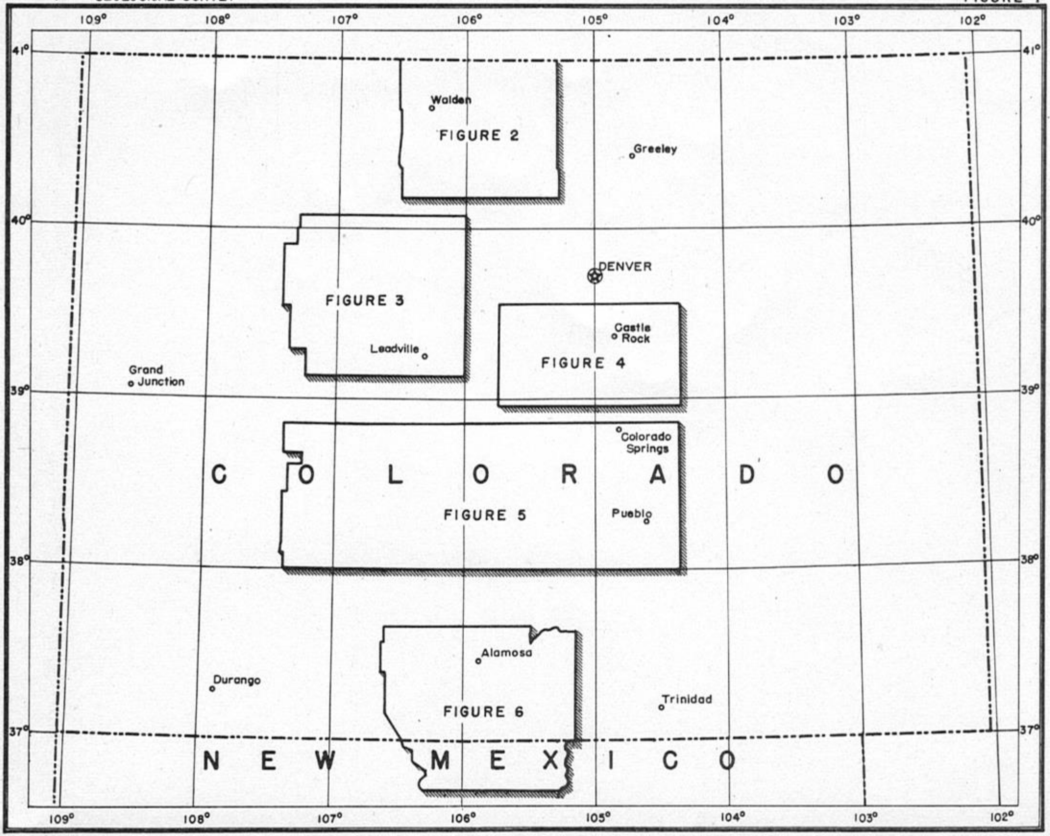
The compressive strength of bulk lightweight aggregate is generally less than that of normal-weight aggregate, primarily because of the porous structure. This lower strength prevents the use of lightweight aggregate interchangeably with normal-weight aggregate, on a volume-for-volume basis, in dams, abutments, and heavy-load-bearing foundations. Lightweight aggregates generally cost more than normal-weight aggregates for two reasons: 1) sources of many of the lightweight aggregates are less widely distributed and less conveniently located with respect to mar-

Table I. -- CLASSIFICATION AND PROPERTIES OF LIGHTWEIGHT AGGREGATE MATERIALS

ORIGIN	MATERIAL	TEXTURE (before expansion)	COMPOSITION	COLOR	EXPANSION	TEXTURE (after expansion)	WEIGHT POUNDS PER CUBIC FOOT (loose expanded aggregate)	TRADE NAMES 1/	REMARKS
Products of explosive volcanism	Pumice	Frothy, extremely vesicular	Rhyolitic	White to brown	None	Frothy, extremely vesicular	30-60	Agite, Pumalex, Basalite Pumalite	Volcanic glass, commonly ejected as fragments
	Scoria	Clinkerlike highly vesicular	Basic	Dark red to black	None	Clinkerlike, highly vesicular	45-55	Volscor	Volcanic glass, many fragments in the form of volcanic bombs
	Perlite	Glassy, nonporous	Rhyolitic, also dacitic and andesitic	Gray to black	By controlled heating to about 6X	Cellular, frothy	6-16	PerAlex, Bildrok, Dantore, Ryolex	Similar in composition to obsidian, but water content 2 to 5 percent. Concentric, shelly structure
	Obsidian	Glassy, nonporous	Rhyolitic, also dacitic	Red to black	By controlled heating	Cellular, frothy	About 25	Fluftrok, CBM (Continental Basic Material)	Marked conchoidal fracture. Water content below 2 percent
	Pumicite	Shards, porous	Rhyolitic	White to tan	None	Shards	Not known	None known	Volcanic ash, very low strength
	Welded tuff	Tuffaceous, porous	Rhyolitic	White to gray to pink	None	Tuffaceous, porous	120-130	None known	Indurated volcanic ash
Deposits of sedimentary origin	Clays, shales, slates	Nonporous	Organic and bituminous clays, shales and slates	Generally dark or black	By controlled heating	Cellular	Generally 30-60	Haydite, Rocklite, Gravelite, Cel-Seal, Vesicullite, Globulite, Lytag, Lelite, Solite, Aglite, Lite-Rock	Many types expand, generally red, ferruginous types are unsuitable
	Diotomite, diatomaceous earth, diatomaceous shale	Some types cellular and friable	Siliceous and clayey, some types petroliferous	Light to dark	By controlled heating	Cellular	30-50	Diacrete, Raylite, Airox, Thermo-Rock, Celite	Some use unexpanded, because of natural light weight
	Fuller's earth	Fine-grained, claylike	Hydrous aluminum silicate	White to brown	By controlled heating	Cellular	40-60	Nodulite	Quantitatively minor use
Alteration of pre-existing materials	Vermiculite (Jefferisite)	Micaceous	Hydrated silicates, of somewhat indefinite composition	Green to brown	By controlled heating to as much as 16 X	Accordion-like	6-15	Zonolite, Alexite, Permalite	Alteration of hornblende, biotite, phlogopite. Generally low strength
By-products of manufacturing processes	Blast-furnace slag	Viscous liquid	Best slag is: 35-38% SiO_2. 44-47% Ca O + Al_2O_3, Mg O, Fe O low S	Dark	By controlled heating	Cellular	35-60	Pottsco, Celocrete, Waylite, Superock, Tuff-Lite, Foamslag, Cellastone	Zinc smelter slag has also been used successfully
	Cinders	Cellular	High ash content, low combustibles, sulfide and sulfates	Dark	None	Cellular	40-60	Corlite	Best material from high-temperature combustion of coal and coke
	Flyash (and Coke breeze)	Ashy	High ash content	Not known	By controlled heating	Cellular	35-55	Sinter-Lite	Flyash results from high-temperature combustion by pulverized coal
Miscellaneous materials	Rice hulls (and wheat hulls)	Cellular, fibrous	Organic	Light	None	Cellular, fibrous	Not known	Ricement	Generally low strength
	Wood fibers	Cellular, fibrous	Organic	Light	None	Cellular, fibrous	Not known	Durisol	Generally low strength
	Hailstones (and wax pellets)	Non-porous	Water, wax	Not significant	None	Non-porous	Not known	Porete	Converted to liquid by heat of setting and removed from concrete
	Foaming compounds	Does not apply	Powdered aluminum, vinsol rein, hydrogen peroxide	Does not apply	None	Does not apply	Does not apply	Aerocrete, Bubblestone, Iporite	Materals not used as light weight aggregate

1/ See Technical Bibliography for references on manufacturing processes.

FIGURE 1



INDEX MAP OF COLORADO AND NORTHERN NEW MEXICO, SHOWING THE AREAS COVERED BY FIGURES 2 - 6

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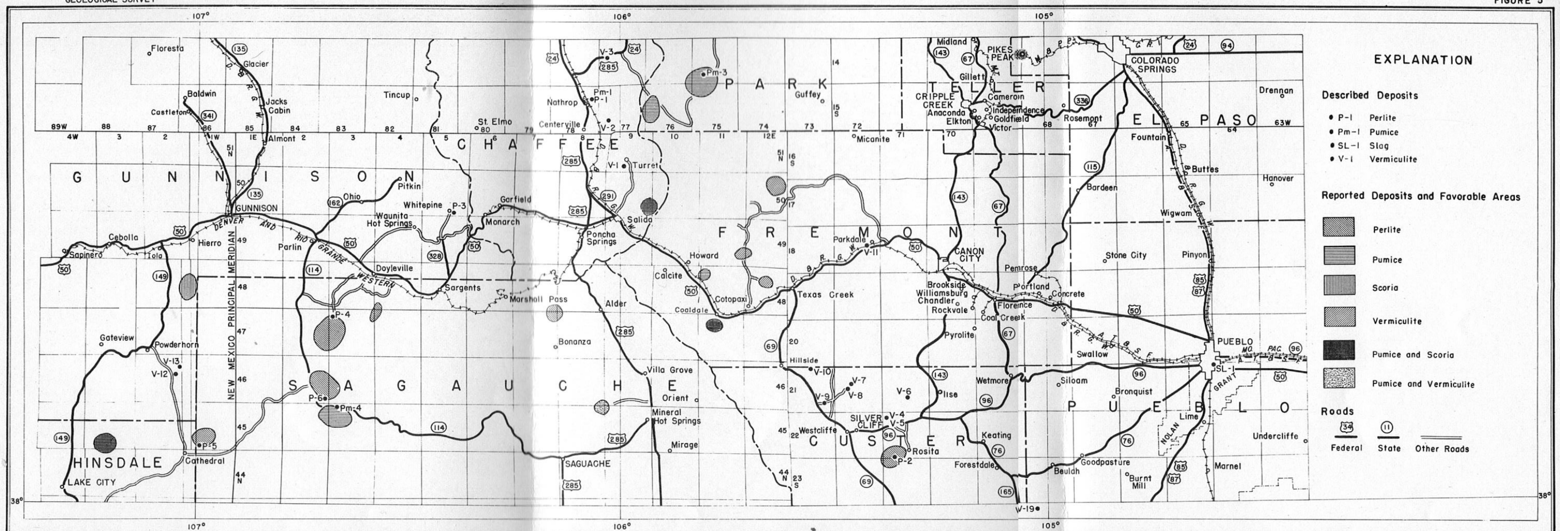
FIGURE 5

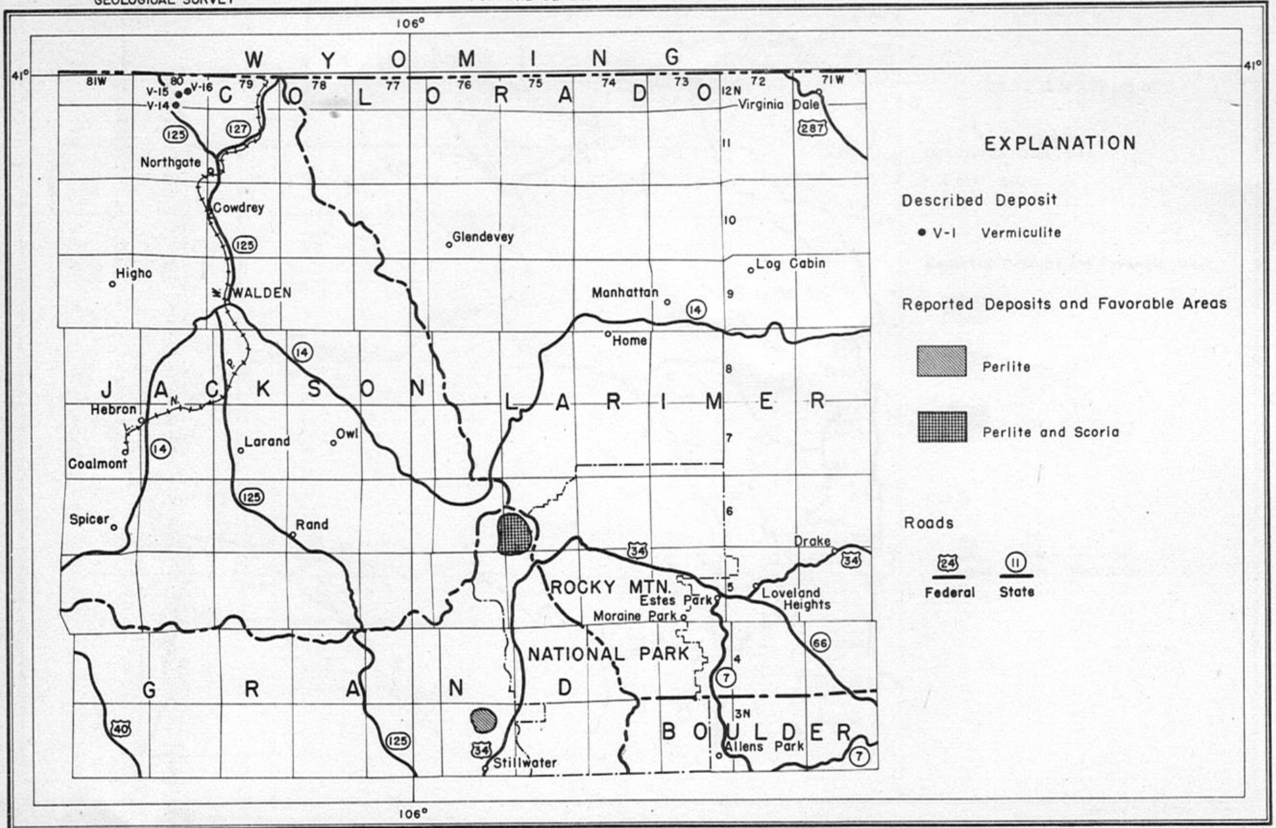


Base from U. S. Geological Survey
Base Map of Colorado

MAP OF A PART OF CENTRAL COLORADO, SHOWING THE LOCATION OF DEPOSITS OF LIGHTWEIGHT AGGREGATES

Compiled in 1947 by A. L. Bush

10 0 10 20 30 Miles
Scale



Base from U.S. Geological Survey
Base Map of Colorado

Compiled in 1947 by A. L. Bush

MAP OF A PART OF NORTH-CENTRAL COLORADO, SHOWING THE LOCATION OF DEPOSITS OF LIGHTWEIGHT AGGREGATES

10 0 10 20 30 Miles
Scale

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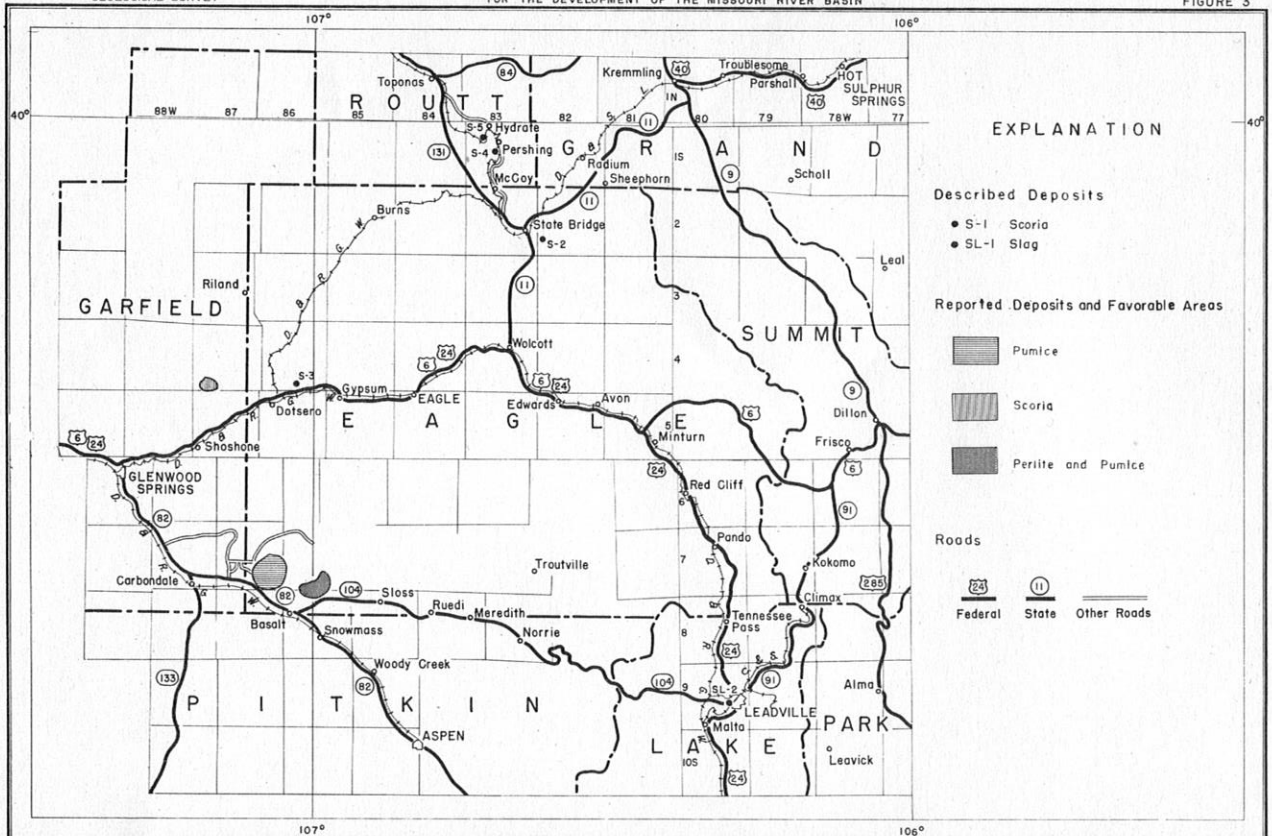
FIGURE 3



Base from U. S. Geological Survey
Base Map of Colorado

Compiled in 1947 by A. L. Bush

MAP OF EAGLE COUNTY, COLORADO, AND PARTS OF ADJACENT COUNTIES, SHOWING THE LOCATION OF DEPOSITS OF LIGHTWEIGHT AGGREGATES

Scale: 10 0 10 20 30 Miles

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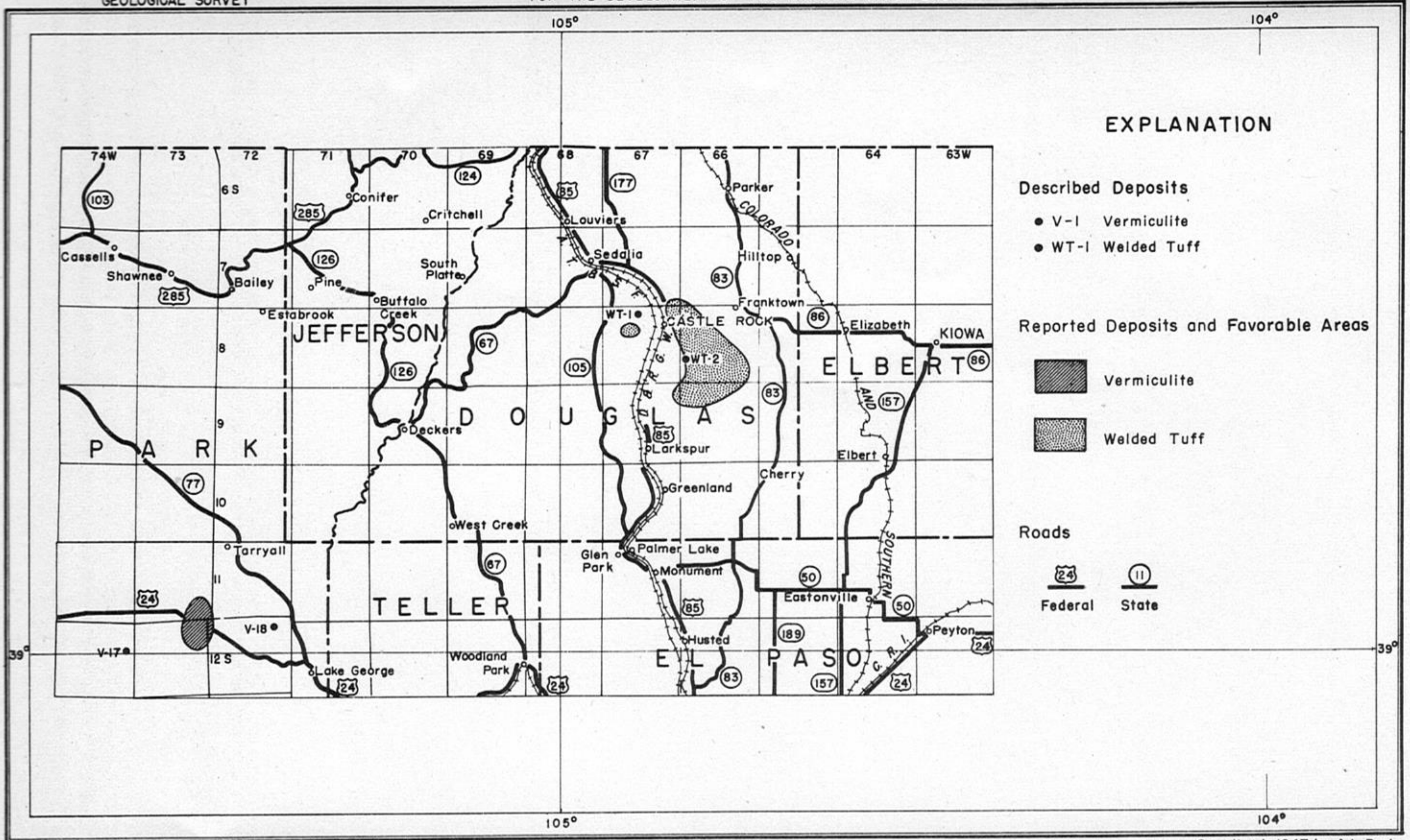
FIGURE 4



Base from U.S. Geological Survey
Base Map of Colorado

Compiled in 1947 by A. L. Bush

MAP OF DOUGLAS COUNTY, COLORADO, AND PARTS OF ADJACENT COUNTIES, SHOWING THE LOCATION OF DEPOSITS OF LIGHTWEIGHT AGGREGATES

10 0 10 20 30 Miles
Scale

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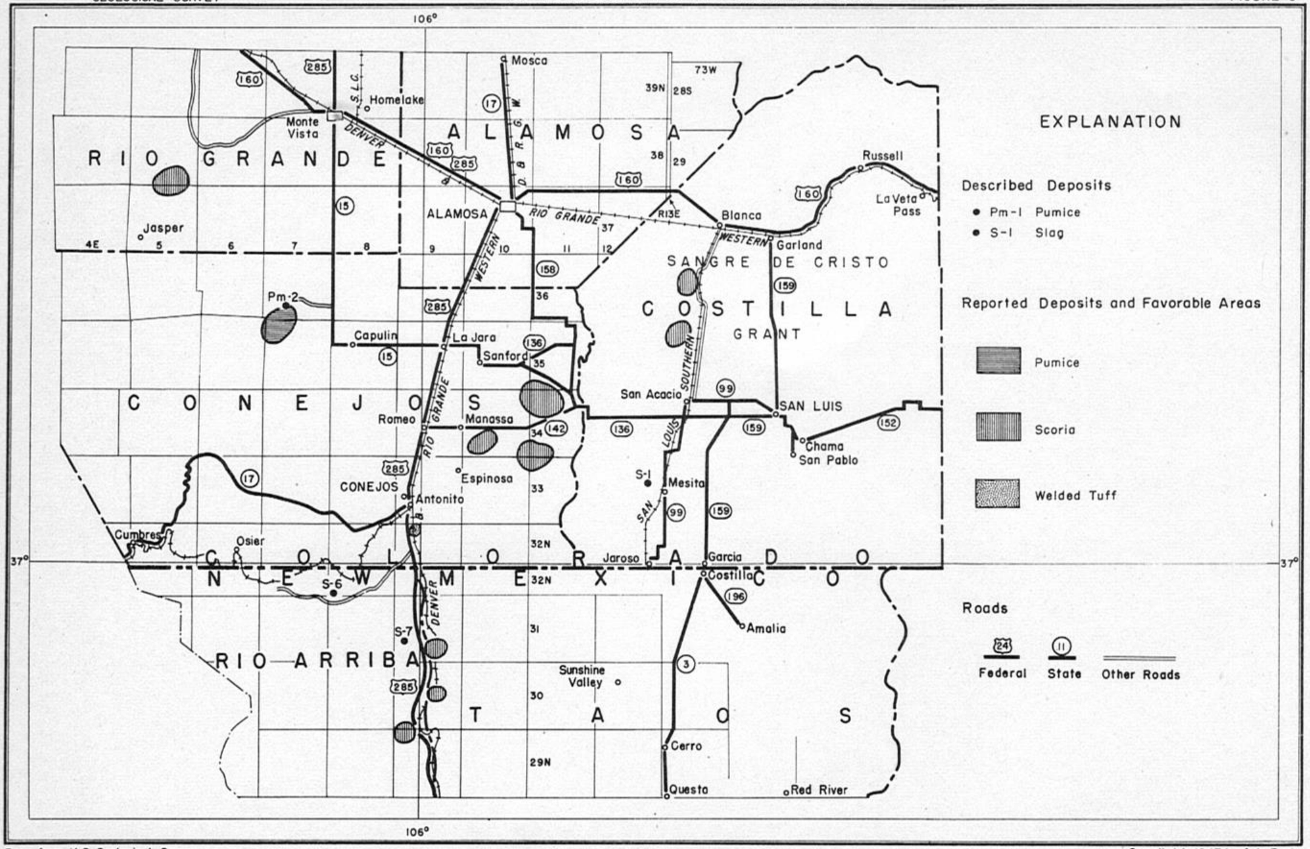
FIGURE 6



Base from U.S. Geological Survey Base Map of Colorado

Compiled in 1947 by A. L. Bush

MAP OF A PART OF SOUTH-CENTRAL COLORADO AND NORTH-CENTRAL NEW MEXICO, SHOWING THE LOCATION OF DEPOSITS OF LIGHTWEIGHT AGGREGATES

10 0 10 20 30 Miles

keting centers, and 2) many of the lightweight aggregates require processing before they can be used.

Lightweight concrete has a lower modulus of elasticity and may exhibit greater shrinkage than normal-weight concrete. It may be easily nailed or sawed, however.

Scope of Field Investigation

In May and June 1947 many deposits of pumice, scoria, perlite, vermiculite, welded tuff, obsidian, volcanic ash, and clinker (natural slag) were briefly examined during a 5-week field reconnaissance of deposits of lightweight aggregate materials.

Major effort during the field investigation was directed to a reconnaissance for those materials (pumice, scoria, perlite, vermiculite) well known to be suitable for use as lightweight aggregates. Because of its low compressive strength, vermiculite is not as widely used as a lightweight aggregate as some of the other types of materials. Numerous vermiculite deposits were examined, but only for their suitability as lightweight aggregate and not for other possible uses.

Minor emphasis was placed on the examination of deposits of materials that were considered to be, at the time of the examination, less suitable, or of unknown suitability for use. These materials include obsidian, volcanic ash, pumicite, welded tuff, and clinker (natural slag).

Many deposits of natural slag or clinker were examined; most of them are in western and northwestern Colorado. The slag is present where shales and clays overlying coal beds have been fused and reddened by the combustion of the coal along the outcrops. None of the materials inspected was suitable for use as a lightweight aggregate, largely because the natural slag is too heavy and too variable in weight and porosity.

Colorado has many large deposits of clay, shale, and slate that are suitable lightweight aggregate materials. Available tonnages are tremendous. Many of the deposits are easily accessible and are close to the major marketing centers of the state. Many of the clay and shale deposits are described in published maps and reports, some of which are included in the appended geologic bibliography. Further information can be obtained through the use of the Bibliography of North American Geology, published by the U. S. Geological Survey. The geologic map of Colorado, published by the United States Geological Survey in 1935, is also of value. Because these deposits are so numerous and widespread, no attempt was made to examine them individually.

Recent promising developments in the expansion of obsidian indicate the feasibility of its use as a lightweight aggregate. The known deposits should be investigated, and a reconnaissance search for new deposits seems warranted. Volcanic ash from some deposits also has been expanded successfully by controlled furnace heating. In their natural state, both volcanic ash and pumicite are friable and have very low compressive strength. As such they are not suitable for use as lightweight aggregate materials. In view of the successful expansion of the ash and the possibility of expansion of pumicite, it is suggested that ash deposits and the fairly extensive pumicite deposits of eastern Colorado be examined and that the materials be tested for expansibility.

Acknowledgments

The geologic literature on Colorado has been freely consulted and has been indispensable in a reconnaissance investigation of this kind. The writer is also indebted to many members of the Geological Survey for unpublished geologic information on Colorado, and to many persons throughout the state for both courtesies and information; particularly to the late Fred Jones, Colorado State Commissioner of Mines, to R. D. Wilfley and C. W. Taylor, of the Alexite Engineering Co.; to officials of the Portland Cement Association; and to Dr. J. C. Haff, W. B. Cheek, and G. W. Grover. The Research and Geology Division of the U. S. Bureau of Reclamation at Denver, Colo., very kindly performed numerous tests and petrographic determinations on samples submitted by the writer.

The study was conducted under the supervision of E. B. Eckel, Chief of the Engineering Geology Branch of the U. S. Geological Survey.

LIGHTWEIGHT AGGREGATES

Deposits of suitable lightweight aggregate, examined by or reported to the writer, are tabulated by counties in table 2. Individual deposits are described in the text; the location of the deposits and the highway and railroad net are shown in figures 1 to 6. The short time available for the field reconnaissance prevented detailed geologic examinations and estimates of reserves.

Most of the descriptions are of deposits of suitable materials that were actually examined. Reported but unexamined areas of suitable materials and areas that appear to be favorable for further investigation are mentioned.

The deposits have been classed as suitable or unsuitable on the basis of their physical and chemical characteristics and their size. Economic factors have not been considered in detail. It should be noted that the market for aggregate is highly competitive. The high transportation charges on relatively inaccessible lightweight aggregates may be prohibitive for some of the deposits discussed below.

Table 2.—Distribution of known and possible sources of lightweight aggregate in Colorado.

County	Aggregate Type	Refer. No. Map	Location
Chaffee	Perlite	P-1	T.15 S., R.78 W., secs. 11, 12, 13
	Pumice	Pm-1	T.15 S., R.78 W., secs. 11, 12, 13
	Vermiculite	V-1	T.51 N., R. 9 E., sec. 28
	Vermiculite	V-2	T.15 S., R. 77 W., sec. 29 (?)
	Vermiculite	V-3	T.14 S., R.77 W., sec. 14
	Pumice and/or scoria	———	T.50 N., R. 9 E., SE¼;
	Pumice and/or scoria	———	T.50 N., R.10 E., SW¼
Conejos (including portions of Rio Arriba and Taos Counties, N. Mex.)	Pumice	Pm-2	T.36 N., R. 7 E., sec. 29
	Pumice	———	T.35 N., R. 7 E., NW¼
	Scoria	S-6	T.31 N., R. 8 E., sec. 6 and T.32 N., R. 8 E., sec. 31; Rio Arriba Co., N. Mex.
	Scoria	S-7	T. 31 N., R. 9 E., SW¼ Rio Arriba Co., N. Mex.
	Scoria	———	T.34N., R.11 E., NW¼

County	Aggregate Type	Refer. No. Map	Location
	Scoria	-------	Area surrounding township corner between T.33N., R.10 and 11 E., and T.34 N., R.10 and 11 E.
	Scoria	-------	T.34 N., R.10 E., SW¼
	Scoria	-------	T.31N., R. 9 E., SE¼ Taos Co., N. Mex.
	Scoria	-------	T.30 N., R. 9 E., center; Taos Co., N. Mex.
	Scoria	-------	T.29 N., R. 9 E., NW¼; Rio Arriba Co., N. Mex.
Costilla	Scoria	S-1	2 miles west of Mesita (unsectionalized area)
	Scoria	-------	6 to 7 miles so. of Blanca (unsectionalized area)
	Scoria	-------	11 to 13 miles so. of Blanca (unsectionalized area)
Custer	Perlite	P-2	T.23 S., R.71 W., secs. 5 & 6 and T.22 S., R.71 W., secs. 32 & 33
	Perlite	-------	T.22 S., R.72 W., sec. 9
	Vermiculite	V-4	T.22 S., R.71 W., sec. 7
	Vermiculite	V-5	T.22 S., R.71 W., sec. 7 or 8
	Vermiculite	V-6	T.21 S., R.71 W., secs. 22 & 27
	Vermiculite	V-7	T.21 S., R.72 W., sec. 16
	Vermiculite	V-8	T.21 S., R.72 W., secs. 16&17
	Vermiculite	V-9	T.21 S., R.73 W., sec. 26
	Vermiculite	V-10	T.21 S., R.73 W., sec. 3 or 4; & T.20 S., R.73W., sec. 33 or 34 (partly in Fremont Co.)
Douglas	Welded tuff	WT-1	T.8 S., R.67 W., sec. 3
	Welded tuff	WT-2	T.8 S., R.67 W., sec. 13 and T.8 S., R.66 W., secs. 19 & 30
	Welded tuff	-------	T.8 S., R.67 W., NE¼
	Welded tuff	-------	T.8 S., R.66 W., W½
	Welded tuff	-------	T.8 S., R.66 W., SE¼
	Welded tuff	-------	T.9 S., R.66 W., NW¼
Eagle	Scoria	S-2	T.2 S., R.82 W., sec. 30
	Scoria	S-3	T.4 S., R.86 W., sec. 23
	Pumice	-------	T.7 S., R.87 W., SE¼
	Pumice or perlite	-------	T.7 S., R.86 W., SW¼ (and adjoining areas)
Fremont	Vermiculite	V-11	T.18 S., R.72 W., sec. ?
	Vermiculite	-------	T.49 N., R.11 E., SE¼ and T.49 N., R.12 E., SW¼
	Vermiculite	-------	T.48 N., R.12 E., no. central
	Perlite	-------	T.50 N., R.12 E., NE¼
	Pumice	-------	T.48 N., R.11 E., NW¼
	Pumice or scoria	-------	T.47 N., R.10 E., NE¼, and T.47 N., R.11 E., NW¼

County	Aggregate Type	Refer No. Map	Location
Garfield	Scoria	--------	T.4 S., R.87 W., SW¼
Grand	Scoria and/or perlite	--------	T.6 N., R.75 W., SW¼
	Obsidian or perlite	--------	T.3 N., R.76 W., no. central
Gunnison	Perlite	P-3	T.50 N., R.5 E., sec. 35 (?)
	Pumice	--------	T.50 N., R.1 W., SE¼
	Scoria	--------	T.48 N., R.1½ W., (and adjoining areas)
	Vermiculite	V-12	T.46 N., R.2 W., sec. 14
	Vermiculite	V-13	T.46 N., R.2W., sec. 12
Hinsdale	Pumice or scoria	--------	T.45 N., R.3 W., SW¼
Huerfano	Perlite or volcanic ash	--------	T.25 S., R.70 W., sec. 10 and nearby areas
Jackson	Vermiculite	V-14	T.12 N., R.80 W., sec. 34
	Vermiculite	V-15	T.12 N., R.80 W., secs. 26&35
	Vermiculite	V-16	T.12 N., R.80 W., sec. 26
Lake	Slag	SL-2	T.9 S., R.80 W., at Leadville
Park	Pumice	Pm-3	T.14 S., R.75 W., secs. 28 & 32 (and adjoining areas)
	Pumice	--------	T.13 S., R.75 W., W½
	Pumice	--------	T.15 S., R.76 W., W½
	Vermiculite	V-17	T.12 S., R.74 W., sec. 13
	Vermiculite	V-18	T.12 S., R.72 W., sec. 11
	Vermiculite	--------	T.12 S., R.73 W., NE¼
Pueblo	Slag	SL-1	At Pueblo
	Vermiculite	V-19	T.24 S., R.68 W., sec. 5 or 8
Rio Grande	Pumice and/or perlite	--------	T.39 N., R.7 E., NW¼
	Scoria	--------	T.37 N., R.5 E., NE¼ and T.38 N., R.5 E., SE¼
Routt	Scoria	S-4	T.1 S., R.83 W., sec. 16
	Scoria	S-5	T.1 S., R.83 W., sec. 17
Saguache	Perlite	P-4	T.47 N., R.3 E., secs. 6 & 7
	Perlite	P-5	T.45 N., R.1 W., SW¼
	Perlite	P-6	T.46 N., R.2 E., sec. 36
	Perlite	--------	T.44 N., R.2 E., and nearby areas.
	Perlite	--------	T.47 N., R.2 E., E½ and T.47 N., R.3 E., W½
	Perlite	--------	T.46 N., R.2 E., SE¼ and T.46 N., R.3 E., SW¼
	Perlite	--------	T.47 N., R.4 E., NW¼
	Perlite	--------	T.47 N., R.7 E., NE¼ (and adjoining areas)
	Pumice	Pm-4	T.45 N., R.3 E., NW¼
	Pumice	--------	T.45 N., R.3 E., NE¼ (and adjoining areas)
	Pumice	--------	T.46 N., R.2 E., NW¼
	Vermiculite and/or perlite	--------	T.45 N., R.8 E., NE¼ (and adjoining areas)

Pumice

The known or reported deposits of pumice are concentrated in two main areas. Several deposits lie north, east, and south of Salida in Chaffee, Park, Fremont, and Custer Counties. Another group of deposits is in a zone peripheral to the San Juan Mountains on their north and east flanks. Most of the pumice is suitable for use as a lightweight aggregate and two of the deposits are of large extent. All the deposits are some distance from the railroads and the major marketing centers of the region.

Pm-1, *Nathrop-Ruby Mountain deposit, Chaffee County* (fig. 5)—Small to moderate-sized deposits of both pumice and perlite are present on the flanks of Ruby Mountain, near Nathrop, Colo. They are in T. 15 S., R. 78 W., secs. 11, 12, and 13, at an approximate altitude of 8000 feet. They lie on the east side of the Arkansas River, 0.8 mile east of the Denver & Rio Grande Western Railroad at Nathrop. They are approximately a mile south of the nearest road and at the time of the examination were not accessible by car or truck. Bulldozing and blasting would be required to extend this road to the deposit.

Pumice, associated with pumiceous tuff, is sparsely exposed on the east and northeast flanks of Ruby Mountain. At the north end of the mountain pumice is exposed for a thickness of 50 feet over an outcrop length of 75 feet. It also crops out in an exposure 70 feet thick and 80 feet long at about the same elevation, some 300 feet to the south, along the east flank of the ridge. The outcrops appear to represent parts of the same deposit, whose attitude, although not easily determinable, appears to be about horizontal. The pumice cannot be traced to the west or to the south.

The pumice is aeolian in origin and probably has not been reworked since it was laid down. A perlite flow, 10 to 15 feet thick, overlies the pumice deposit. The rocks that underlie the pumice do not crop out. At the north end of the ridge perlite is underlain by a red and black obsidian flow. The relations of the pumice, perlite, and obsidian are not clearly understood.

The deposit consists of fragmental pumice in a matrix of fine pumiceous material. Many fragments are 4 to 5 inches in maximum diameter with a few blocks as much as 2 feet wide and 1 foot thick. Most of the material is between 1 and 2 inches in longest dimension, but some is ¼ to 1 inch. The pumice is white to gray at the base and grades upward into pink to light red. The coloring appears to be a surficial stain on the fine-grained pumiceous matrix.

As a great thickness of younger rocks, which form the bulk of Ruby Mountain, overlies the deposit, it is amenable to opencut mining for only a short distance back from the outcrop.

Pm-2, Capulin or Alamosa Creek deposit, Conejos County (fig. 6)—Despite the considerable evidences of explosive volcanism in the San Luis Valley, the Capulin deposit is the only occurrence of pumice known to the writer. It is in sec. 29, T.36 N., R. 7E., at an altitude of about 8100 feet, approximately 11 miles by road from Capulin and about 19½ miles from the Denver & Rio Grande Western Railroad at La Jara, Colo.

The pumiceous beds have a moderate dip (8°-10°) to the east and in a short distance pass below a pyroxene-andesite flow that in turn disappears below the floor of the valley. The deposit is intermittently exposed for about 1000 feet along the dip in a steep bank on the south side of Alamosa Creek.

The pumiceous beds are reworked, partly stratified, and interbedded with numerous layers of coarse "gravelly" conglomerate. The exposed section contains about 135 feet of pumiceous beds in a total thickness of about 220 feet. There are a few pumiceous beds that range in thickness from 1 to 14 feet, and one largely covered interval of about 80 feet that is apparently pumice but is probably composed of similar interbeds of pumice and "gravelly" conglomerate. A pyroxene andesite flow overlies a mica andesite flow and underlies the interbedded pumice and conglomerate.

Because of the dip and the interbedding of the deposit, the easily minable extent is small. It is doubtful if production from this deposit is economically feasible.

Pm-3, Black Mountain deposit, Park County (fig. 5)—A brief field examination suggests that this pumice deposit in southwestern South Park is the largest in Colorado. It is in T. 14 S., R. 75 W., secs. 28, 32, and adjoining areas, at an altitude of about 9600 feet. It is 18 to 19 miles south of U. S. Highway 24 at Hartsel, Colo., and is about 45 miles by road from the Denver & Rio Grande Western Railroad at Buena Vista. The road from Hartsel to the deposit is fair to poor in dry weather.

Pumice is ubiquitous in the float for at least a mile in all directions from the exposure examined. At the exposure the pumice is 18 feet thick and is relatively horizontal in attitude.

The pumice is associated with pumicite and pumice sand and overlies unconsolidated sand and gravel. In a few places it is altered to a non-swelling type of bentonite. A faint bedding in the material is attributed by some to deposition in a large lake. The writer considers the deposit to be of aeolian origin, because of the general obscurity of the bedding and the absence of sorting and reworking.

This and other pumice deposits lie north and west of Black Mountain, which is possibly the source of the pumice. Black Mountain is a composite volcano of probable early Tertiary age, composed of the products of both explosive and relatively quiet eruption. There is an increase in the size of the ejected material toward the cone, a fact that is interpreted to indicate the direction of the source,

As the deposit is nearly horizontal in attitude and is covered by very little overburden it can be mined easily by bulldozer or power shovel.

Pm-4, Cochetopa Dome deposit, Saguache County (fig. 5)—Both pumice and perlite are present near the south edge of Cochetopa Dome, and the deposits of both materials are among the largest in the state. The deposit is in T. 45 N., R. 3 E., NW¼, and adjoining areas, at an approximate altitude of 9500 feet. State Highway 114 crosses the northern part of the area about 5½ miles west of Cochetopa Pass. The deposit is about 25 miles from the nearest railhead at Parlin, Colo., on the Denver & Rio Grande Western Railroad. The base of the pumice is not exposed in the area examined but up to 10 feet of pumice is exposed in road cuts along State Highway 114.

In general the pumice deposit is flat-lying in attitude. It is 1 to 2 miles long and may be as much as a mile wide. The pumice deposit is considered to be of aeolian origin, as conspicuous bedding and evidences of sorting and reworking are absent. It may be expected, therefore, to vary somewhat in thickness, both as a result of irregularities in the pre-pumice topography and the present-day topography. Although the deposit may not be fully continuous throughout this area, very large tonnages are available.

The quality of the pumice is somewhat varied. Several outcrops show fragmental pumice in an ashy matrix, a mixture that is not suitable for aggregate. Further prospecting and sampling are necessary before the exploitable tonnage can be estimated.

The pumice deposit is on the valley floor about 1½ miles south of the edge of Cochetopa Dome. The dome at this point is marked by cliffs of perlite 80 to 100 feet high. The rocks between the northernmost pumice outcrops and the perlite cliffs are not exposed; the relations between the two are obscure. Volcanic ash is associated with the pumice, both in the ashy matrix and as a deposit that crops out about a mile northeast of the pumice deposit.

The pumice is covered in places by as much as 2 feet of overburden, although elsewhere no overburden may be present. Mining would consist of removing the overburden and loading trucks by bulldozer or power shovel; or, as an alternative, operations could be started from the bottom of one of the gullies that traverse the area and the working face could be carried forward by power shovel alone.

Other areas (figs. 3, 5, and 6)—Pumice (and/or scoria) is reported in the vicinity of Salida in Chaffee County. Its location is not definitely known, but it is believed to be at "Crater Mountain," about 5 miles east of the city.

In Conejos County, an area in and near T. 35 N., R. 7 E., NW¼, south of deposit Pm-2, is suggested as meriting further investigation. Pumice is reported in Eagle County, on the Blue Creek flats northwest of Basalt, and on Basalt Mountain, north-northeast of Basalt. According to local information the areas can be reached only on foot or by horseback.

A small deposit of pumice, reported to lie southeast of Howard in Fremont County, was not examined. A pumice deposit south of Coaldale could not be located in the time available. Pumice near Gunnison in Gunnison County has been reported, but the deposit could not be located. In Hinsdale County pumice or scoria in the vicinity of Devil Lake on the Cannibal Plateau is reported, but it was not located, as the area is accessible only on foot or by horseback.

Pumice is reported in Bassem Park in southwestern Park County, not far from deposit Pm-3. The deposit was not seen, but because of its location near an area of large, known deposits, it merits examination. Large pumice deposits are reported in T. 13 S., R. 75 W., W½, in Park County north of deposit Pm-3. These deposits were not examined in detail, and are not shown on the figures. An expansible pumice sand is reported in Rio Grande County, but it could not be found. The location given in table 2 is approximate.

Two areas in Saguache County are regarded as favorable for pumice. The area south and west of the deposit described as Pm-4 merits further investigation. The second area lies some 5 miles to the northwest, peripheral to the western edge of Cochetopa Dome. From a distance this material resembles pumice, but it is not classed definitely as such, as high water in Cochetopa Creek prevented access and close examination.

Scoria

The known deposits of scoria are concentrated in two general areas: 1) three deposits close to the northern border of Eagle County and a fourth some 25 miles to the southwest; 2) three deposits in the San Luis Valley, two of them in Rio Arriba County, New Mexico. Because of their proximity to the Colorado boundary these two deposits have been included in the study.

At the present time deposits of scoria cannot be considered major sources of lightweight aggregate for Colorado. The deposits are few and relatively isolated, and available tonnages are somewhat limited. None of the deposits were in operation at the time of the examination.

S-1, Mesita deposit, Costilla County (fig. 6)—This is the only known deposit of scoria in the Colorado part of the San Luis Valley. It is in an unsurveyed township at an elevation of about 8000 feet. A dirt road extends 0.8 mile from the deposit to a gravel road 1.2 miles west of the San Luis Southern Railroad at Mesita, Colo. The deposit, which forms a low, roughly oval dome, is about 1800 feet long, 1400 to 1500 feet wide, and as much as 60 feet thick. This thickness is estimated by measurements from the top of the dome to the highest point where dense to scoriaceous boulders of an underlying basalt flow appear in the float.

The scoria is in the form of bomb fragments ranging from 1 inch to 4 inches in diameter. Some rounded blocks are as much as 8 inches across. A few very large masses approximately parallel to the surface are 12 feet across and 2½ feet thick. Many of the larger masses have been brecciated and recemented. Most of the scoria is dark grayish black. A lesser but considerable amount is red to pink, and there are minor amounts of bluish-black and green-black scoria. The reddish scoria seems to overlie the black, although the relations are somewhat obscure. The black scoria is reported to be somewhat stronger than the red and produces less fines during crushing and handling. The weights of the two kinds of material are about equal.

The dome is the remnant of a cinder cone. No trace of the original crater remains, and the scoria probably overlies the actual vent. Basalt flows underlie the scoria and form the floor of the valley for some distance in all directions.

The weight of the mine-run scoria is about 900 pounds per cubic yard (33 pounds per cubic foot). Crushing increases the amount of fines and raises the weight of the product to 1270 to 1290 pounds per cubic yard (47 pounds per cubic foot). The workings consist of a series of interconnecting opencuts with a maximum depth of 8 feet. They cover an area about 600 by 300 feet. The mining has consisted of bulldozing the scoria to a ramp where it is dumped via a chute into trucks. The scoria was transported about 2 miles to a crushing and grading mill in the town of Mesita. No figures are available for past production but it is reported to have been relatively large.

S-2, Mount Saunders deposit, Eagle County (fig. 3)—The Mount Saunders scoria deposit in northern Eagle County is of more geologic than commercial interest. Larger, more easily accessible, and more easily worked deposits (see deposits S-4 and S-5) are nearby. The deposit is in T. 2 S., R. 82 W., sec. 30, at an altitude of about 7100 feet. It is about 1½ miles by fair and poor roads from the Denver & Rio Grande Western Railroad at State Bridge, Colo.

The scoria mantles a pre-existing ridge composed of basalt flows. No accurate thickness of the scoria can be given, but the thickest parts appear to be on top of the ridge. The ridge is about 350 feet high, and basalt flows crop out to a height of about 250 feet. The exposure of scoria is about 3000 feet long and up to 800 feet wide.

A volcanic neck 65 feet high marks the vent from which the scoria was ejected. This neck (known locally as Mount Saunders) is in the center of a relatively deep gully that divides the ridge. Its location quite definitely dates the eruption, as the neck is younger than the development of the present drainage system. The neck is composed of a scoriaceous agglomerate, and is mantled at its base by a loose volcanic-pebble agglomerate.

Almost all of the scoria is in the form of bombs or bomb fragments. It is predominantly red and is quite varied in weight. There are numerous unexpanded and partly expanded bombs and some dense boulders intermixed with the