Promising Marginal Aggregates for Low-Volume Roads

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The need to use marginal materials for highway construction is becoming more crucial as the availability of conventional materials becomes scarce. Responding to this need, a study was undertaken to gather data on the engineering properties and field use of aggregates of marginal properties. The study involved personal contacts (including interviews), critical evaluation of case histories, and a comprehensive literature search into the engineering properties of marginal materials. This paper contains aggregate (geologic) descriptions, indexes, and pertinent engineering properties of eight marginal materials currently available for construction and maintenance of low-volume roads. Case histories that indicate the response of pavements in service and guidelines for using the materials are presented with references to specific use in variable environments, indicating beneficiation when desirable. The study concludes that (a) volcanic aggregates, although soft and porous, can be used as a base or surface with proper admixtures; (b) disintegrated granite, in spite of becoming soft when wet, can be used over a well-drained subgrade; (c) marginal limerock aggregates would normally require sand or coarse aggregate as an admixture; (d) soft caliche, depending on its texture, would warrant admixtures such as fly ash; and (e) partly decomposed sandstone can be used in a low-volume-road base without treatment; however, decomposed sand should be stabilized with cementing agents such as portland cement or self-hardening fly ash.

Commonly used aggregate materials classified as acceptable materials for highway construction are in short supply and are expensive. More than one-third of the area of the United States has a limited or severely restricted supply of good aggregates available for road building. In many western areas, aggregates are inaccessible because of rugged mountains or long haul distances. Eastern urban development has made aggregates inaccessible, and those that are accessible need to be used for high-volume roads. As an alternate to normally acceptable material, several agencies (county, state, and federal) are currently using materials defined as marginal aggregates for low-volume-road construction and maintenance; however, until now the descriptions of the material, their uses, and their performance records have not been well documented. This paper reviews a study to identify the marginal materials and their performance in relation to their engineering characteristics. The study is based on research supported by the Federal Highway Administration (FHWA) (1). A subsequent study (2), also sponsored by FHWA, presents preliminary specification requirements of aggregates for low-volume roads.

SCOPE

Marginal materials are those that do not meet standard American Association of State Highway and Transportation Officials (AASHTO) or ASTM specifications for road use and may require some type of additive or special treatment to meet their role in the environment in which they are used. There are eight natural materials described in this paper that are classified geologically into two groups:

1. Igneous: extrusive volcanics--cinders, pumice, and rhyolite; and intrusives--distintegrated granite; and
2. Sedimentary: limerock, coquina, decomposed sandstone, and caliche.

Other marginal materials identified in the FHWA study (1) include sand and gravel aggregates, which include marginal sand, pit-run and river-run gravel, and sand-clay; shale and baked shale; chert; marine basalt; stone screenings; and topsoil. Material characteristics and use of these materials, especially sand and gravel and shale, are well documented in the literature and therefore will not be dealt with in this paper. The original FHWA report (1) may be consulted for a treatise on the remaining materials.

Aggregate descriptions, index, and pertinent engineering properties of the eight marginal materials are discussed in this paper. Case histories of their response in service and guidelines for using the materials are presented with reference to specific environments. Beneficiation is indicated as desirable when needed.

The study involved personal contacts (including interviews) and critical evaluation of case histories supplemented by a comprehensive literature search. Information was sought in two areas: material (marginal) characteristics, and the field performance of those materials in paved or unpaved low-volume roads. Although no specific failure criteria were employed in the performance evaluation of field trials, the following failure attributes offered a basic framework for comparison. They include, for paved roads, surface roughness, rutting, aggregate loss, and dusting; whereas for paved roads they include surface roughness, rutting, and cracking.

IGNEOUS EXTRUSIVES

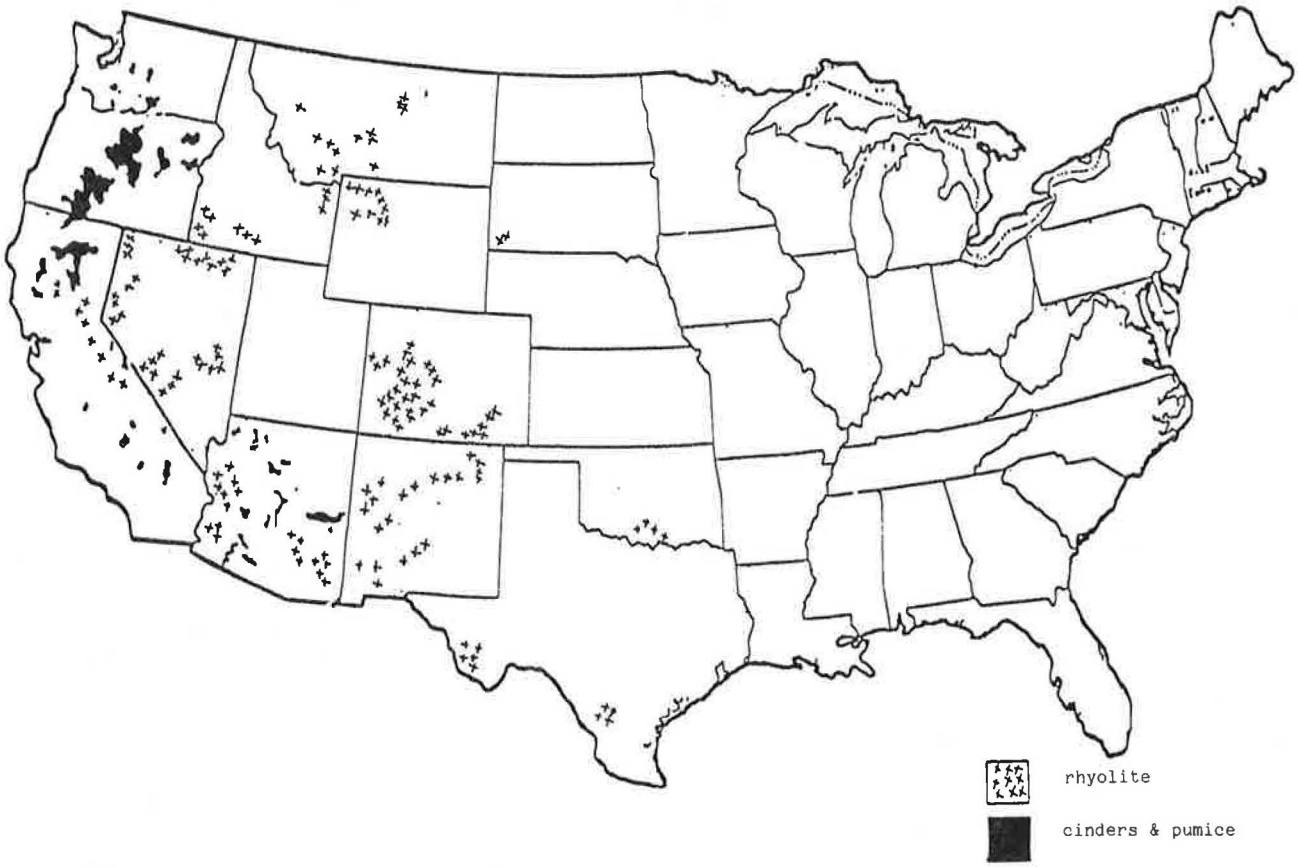
This section discusses volcanic cinders, pumice, and rhyolite. Volcanic cinder is cemented, glassy, highly vesicular aggregates formed as a result of volcanic eruptions. The fragmental sizes generally range from 0.156 to 1.25 in in diameter and vary considerably in color, both in the same and in different deposits.

California ranks first in the production of volcanic cinder in the United States and was the source of approximately 1.6 million tons, with smaller amounts used in central Oregon, Arizona, and Montana (Figure 1).

Material Characteristics and Evaluation

Color and hardness of volcanic cinders vary over a wide range from deposit to deposit. Yellowish-brown and red cinders, which contain an excessive amount of clay, are usually very soft; black and purple cinders are hard and unweathered. The grading of volcanic cinder will also vary considerably from deposit to deposit. A typical gradation would consist of 23 percent passing a No. 10 sieve, 13 percent passing a No. 40 sieve, and 3 percent passing a No. 200 sieve. Unweathered cinder generally has nonplastic fines, but weathered cinder may have a plasticity index (PI) as high as 10. The liquid limit of volcanic cinder ranges from 30 to 50 percent. Pit-run cinder may be classified as A-1-a or A-1-b, while weathered cinder is classified as A-2-4. Typically, volcanic cinder has an abrasion loss of 40-50 percent. Cinders behave similarly to any other granular material when used as an untreated road surface; their performance is dependent on gradation, plasticity, and compaction. In contrast to many other granular materials, cinder aggregates undergo compaction and consolidation under traffic. Because harder cinders usually lack fines, crushing is often required to meet the recommended gradation. Alternately, clay binder may be added to improve the cohesion of the aggregate. Highly

Figure 1. Distribution of volcanic cinders, pumice, and rhyolite aggregates.



weathered cinders are not suitable for road use unless stabilized or blended with good quality coarse aggregate, as they are likely to undergo excessive degradation during compaction.

The suggested in-place gradation (3) is as follows:

Sieve Size	Percent Passing
1 in	100
3/4 in	80-95
No. 4	35-60
No. 10	22-45
No. 40	8-25
No. 200	3-12

The gradation at the borrow should ideally be somewhat on the coarser side of the gradation band to allow for subsequent degradation under traffic. A liquid limit not exceeding 35 percent and the PI in the range of 2-10 are considered satisfactory. Los Angeles Abrasion loss as high as 50 percent may be acceptable for low-volume roads.

Pumice refers to fragmental volcanic rock that is light colored and consists of pumiceous glasses that are markedly cellular, larger than 0.156 in, and light enough to float on water. Pumice is generally nonplastic, softer than cinder, and contains particles smaller than sand size. Central Oregon deposits are usually fine textured (silt and sand size) and often behave as poorly graded sand. Because of its high porosity and low density, stabilization of pumice with additives is a requisite for its use in low-volume-road construction.

Rhyolite is a volcanic lava, glassy matrix, porphoritic porous material with a fine-grain texture. It occurs in varying degrees of hardness; however, only pit-run, softer rhyolite is discussed here.

Rhyolite is a nonplastic aggregate with about 14-20 percent passing a No. 10 sieve, 6-12 percent passing a No. 40 sieve, and 3-6 percent passing a No. 200 sieve. The maximum size of an aggregate is generally 3 in. Its susceptibility to moisture and weathering precludes the use of rhyolite in wet areas; however, it has given good performances in low-volume roads in New Mexico. Crushing may be required to reduce the maximum size.

Case Histories of Volcanic Aggregates

A low-volume base and surface were constructed in New Mexico by using a blend of 60 percent cinder and 40 percent clay. In terms of gradation, the maximum cinder aggregate size was 1.5 in, and 5-20 percent passed a No. 200 sieve. The blend has a PI of 6-12 and a liquid limit of 20 percent. The Los Angeles Abrasion loss was 40 percent. The material has performed well, and its life expectancy is at least 20 years. The suggested index properties in Table 1 (2) show that the material properties displayed by this aggregate are within the limiting values of PI 2-15, which are suggested for a dry region. If the PI does not exceed 9, these properties would also fall within those suggested for a wet region.

A test road was built in Winema National Forest to determine the optimum type of stabilization for pumice (4). The test section included 6-in-deep base sections stabilized with cement, lime, cinder clay, and bituminous stabilizer. Use of a vibratory roller on the moistened stabilized pumice achieved a satisfactory compacted density. The lime-treated section proved to be the best, followed by the

Table 1. Suggested limiting values of aggregate properties acceptable in low-volume roads compared with AASHTO and ASTM recommendations.

Material Property	Untreated Surface Course			Untreated Base Under Untreated Surface Course			Untreated Base Under Treated Surface Course		
	AASHTO/ASTM	Wet	Dry	AASHTO/ASTM	Wet	Dry	AASHTO/ASTM	Wet	Dry
Gradation									
Maximum particle size (in)	1	1.0-1.5	1.0-1.5	1	2	2	1	2	2
Percent passing No. 200 sieve	8[a]	6[a]	6[a]	8[b]	9[b]	12[b]	8[b]	9[b]	15[b]
Plasticity									
Liquid limit (%)	35[b]	35[b]	55[b]	25[b]	25[b]	30[b]	25[b]	25[b]	30[b]
PI	4-9	2-9	2-15	6[b]	8[b]	12[b]	6[b]	8[b]	12[b]
Degradation: Los Angeles Abrasion loss (%)	50	50[b]	50[b]						

[a]Minimum. [b]Maximum.

cement section, clay section, and the bituminous section in order of decreasing performance.

Crushed rhyolite with clay has been used in the New Mexico Regional Forest for the construction of low-volume roads (according to D. Logan, Forest Service, U.S. Department of Agriculture, Albuquerque, New Mexico). This material contains 3-6 percent passing a No. 200 sieve with nonplastic characteristics. The maximum aggregate size specified was 3 in, but experience with this road indicates that the maximum size should be limited to 2 in for improved performance. However, since the average daily traffic (ADT) on this road was 10 timber trucks, each weighing 50 000 lb, the resulting surface roughness due to the 3-in maximum gravel size did not significantly affect the performance of the road.

For adequate performance under field conditions, gradation, plasticity, and compaction are the controlling factors in using volcanic aggregates for low-volume-road construction.

AGGREGATES OF INTRUSIVE IGNEOUS ORIGIN

Disintegrated granite is the only marginal material identified in this study that belongs to aggregates of intrusive igneous origin. Disintegrated granite is the result of decomposition or weathering of granite, which is composed mainly of quartz, feldspar, and mica.

Disintegrated granite is found in California (especially in the vicinity of Los Angeles, Fresno, and San Diego), Arizona, Wisconsin, Virginia, Georgia, North Carolina, Alabama, and, to a lesser degree, in other states. It should be available wherever granite can decompose and not be removed by some form of erosion. It should be most common where wet weather is prevalent.

Material Characteristics and Evaluation

Decomposed granite is generally pink due to an abundance of feldspar in the material. The grain size of the material varies from sand size to a 2-in stone. A typical gradation of the material consists of 65 percent passing a No. 10 sieve, 34 percent passing a No. 40 sieve, and 13 percent passing a No. 200 sieve. Depending on the degree of weathering and the feldspar content, disintegrated granite exhibits a range of plasticity. Typically, the PI varies from 0 to 5, the liquid limit from 25 to 38 percent, and it has a Los Angeles Abrasion loss of approximately 60 percent.

Susceptibility to weathering is the main factor that contributes to the marginal quality of disintegrated granite. The weathering process may decompose the feldspar and ferromagnesium minerals of the granite and convert once sound in situ rock into a weak, relatively friable mass of quartz grains and clay. Granite that has been shattered by fault action is particularly susceptible to decomposition by weathering.

Marginal disintegrated granite makes a good base course for secondary roads, provided they are kept dry. If the material gets wet, either due to precipitation or to subsurface water by capillarity, the fines become slippery and mudlike. For a base course, marginal disintegrated granite may be upgraded in quality when mixed with creek-run sand, gravel, stone screenings, or limestone screenings. Lime or cement treatment (3-6 percent of portland cement) is effective in improving the quality (5).

Case Histories

In the southern part of Monterey County in California, disintegrated granite has been used in road bases. The performance was excellent when the material was kept dry. Low-volume forest roads in Idaho have been constructed with disintegrated granite mixed with foamed asphalt (according to members of the Forest Service at the Geotechnical Workshop at the Second International Conference on Low-Volume Roads, Ames, Iowa, 1979). Some areas of North Carolina have used disintegrated granite for the surfacing of low-volume roads. In the Umpqua National Forest of Oregon, disintegrated granite was stabilized with 3-6 percent portland cement for the construction of base courses (5).

In Fresno County, California, disintegrated granite was used on earth roads with an ADT of 400 vehicles. The most common problem with the material was that some decomposed granite became slippery when wet. Degradation of feldspar under traffic was the main reason for slipperiness.

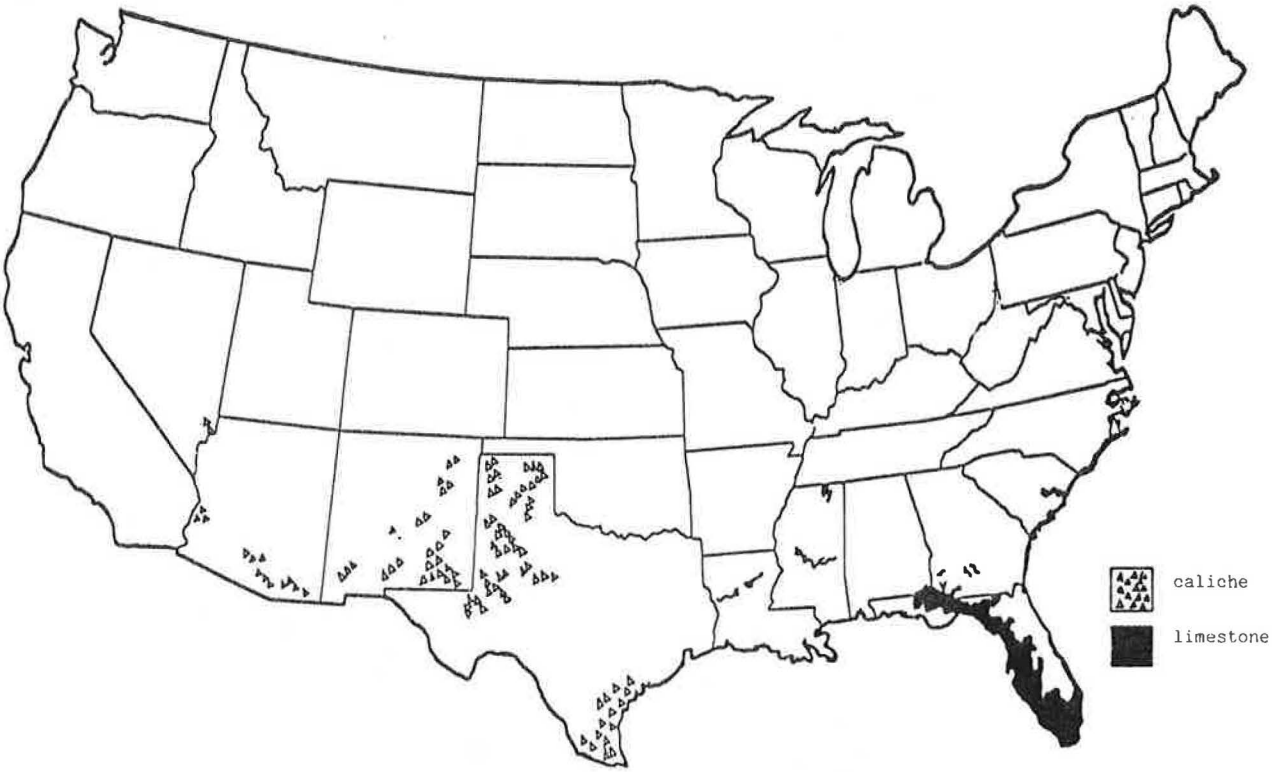
AGGREGATES OF SEDIMENTARY ORIGIN

Limerock

Limerock is a soft sedimentary deposit that consists of disintegrated shell and fragments of calcite. Four types of limerock have been identified as important for the construction of low-volume roads: oolites, coquina (fossiliferous), shell, and marl. Oolitic limerock is composed of tiny nodules of crystalline calcium carbonate held together by calcareous cement, coquina is any limerock composed mainly of fossil shells or other animal remains, shell is composed almost entirely of shell and shell fragments of recent origin, and marl applies to any soft, earthy mass that contains lime, clay, sand, and carbonaceous material.

Because of its availability, limerock is used extensively in the construction of road surfaces and base courses in the southeastern Gulf Coast and Mississippi Valley states. Figure 2 shows the distribution of limerock aggregates in the United States.

Figure 2. Distribution of limerock and caliche deposits.



Material Characteristics and Evaluation

Limerock aggregate is generally soft; however, due to the cementing character of calcium carbonate in the material, the compacted layers of limerock increase in stiffness with age. A typical oolite limerock has 35 percent of the material passing a No. 200 sieve and a PI of 0-4, which places it in either the A-2-4 or A-2-5 soil group. Similarly, coquinoid limerock has a PI in the range of 0 to a maximum of 4 and may have 12-30 percent passing a No. 200 sieve. Shell limerock has 6 percent passing a No. 200 sieve and is generally nonplastic. Marl limerock is soft, and its color varies from grayish white to dark, depending on the amount of impurities it contains.

Limerock, which has no plasticity and does not shrink appreciably on drying, will generally provide a stable base course under practically all conditions. Highly plastic limerocks, although moisture susceptible, may still provide satisfactory service when good construction methods are used. Adequate compaction and proper drainage include some of those special provisions. Limerocks with PIs greater than 8 will seldom give satisfactory performances as base-course materials.

Shell is generally nonplastic. In thin layers, a minimum of 40 percent of calcium carbonate content in shell is required for satisfactory performance in low-volume roads.

Marl to be used in low-volume roads should have a PI of less than 10. Blending with granular material is necessary if the PI of marl is greater than 10.

Case Histories of Limerock Aggregates

Oolite, a good limerock aggregate, has been used successfully in Florida to construct high-volume roads (6). Limerock of the coquina or fossiliferous type has been used as base course of low-volume roads that carry an ADT of 100-500 vehicles in the eastern part of South Carolina. Low-volume-road bases were also built in Florida by using low-quality shell limerock. Shell has been used in road construction in the southern part of Mississippi. For example, in the six-mile road between Long Beach and Pass Christian, the shell base course surfaced with asphalt has been in service for more than 20 years. In a few other cases, shell was blended with sand (60:40) for use in the base course or in maintenance (7). In Virginia, the use of shell has also permitted the use of otherwise locally unsuitable sandy soils.

Marl limerock has been used on an experimental basis in South Carolina (8). Although it did not ravel or pothole under traffic when used with surface course, thin material did wear away due to aggregate loss. Extensive alligator cracking resulted when marl was used as a base course. Marl is being used for subbases of experimental high-volume roads by using appropriate compaction and drainage methods.

Caliche

Caliche refers to caprocks, soil hardpans, and earth or porous materials of a calcareous nature that occur at the surface or at shallow depths formed by cementation and replacement of soils. Generally, there is a layer of medium-hard caprock close to the surface, which varies in thickness from 1 to 4 ft. Below this lies a layer of soft chalky material that has a variable depth. Caliche is found in the semi-arid regions of the Southwest, especially in Arizona, Nevada, Oklahoma, and New Mexico (Figure 2).

Material Characteristics and Evaluation

The outstanding characteristics of caliche pits are that no two will be alike. Depending on its hard-

ness, caliche is classified into three groups: soft, semihard, and hard. Hard and semihard caliche possess properties that generally meet the standard specifications and can be recommended for both primary and low-volume roads. Soft caliche consists of fine calcareous sand loosely cemented with a fine powder, semihard caliche consists of cemented caliche interspersed with soft and hard caliche, and hard caliche is a cemented strata or conglomerate caliche. A typical gradation analysis shows that soft caliche has 25-70 percent passing a No. 4 sieve, 20-55 percent passing a No. 10 sieve, and 0-12 percent passing a No. 200 sieve (9). Based on its engineering properties, caliche has been identified as a soil similar to those exhibited by A-2-4, A-4, and A-2-6 groups of the AASHTO classification system. The PI ranges from 5 to 20 (with lower values for good caliche), and its liquid limit ranges from 20 to 40 percent. Because of its high PI, soft caliche is objectionable in bituminous mix.

The consistency of caliche varies from hard rock to firm soil. On average, the caliche cap will show a hardness of about 50 by the Los Angeles Abrasion test.

Hard and semihard caliche has been used successfully as a base with and without bituminous treatment. Soft caliche, although high in plasticity, has also given adequate performance as a base course without surfacing in the extreme southern part of Texas, since surface evaporation helps the material to set hard. If used under a bituminous surfacing, however, soft caliche should be treated with bitumen, fly ash, or lime for best results; otherwise, salt migration from the calcrete material will cause the road to fail. A soft caliche wearing course should have a PI of 12 or less and a liquid limit of 40 or less for adequate performance.

Case Histories of Caliche Aggregates

Hard and semihard caliche has been used for base courses in the southern parts of Texas. Generally, the caliche is retained on a No. 10 sieve with minor amounts of low PI binder material. The performance of these roads under low-volume traffic has been excellent, and life expectancy is approximately 15 years. Eight miles of NM-176 in Lea County in New Mexico were built with a hard caliche base course overlain by a hard caliche asphalt wearing surface. The life expectancy of NM-176 is 20 years for an ADT of 1000 vehicles, 80 percent of which is oil-field traffic. In the extreme southern part of Texas, where it is very hot and dry, soft caliche has been successful as a base course. When caliche was used in base course without surfacing, it gave adequate performance, since surface evaporation helped the material to remain firm. However, when a soft caliche base was overlain by an asphalt surface, it failed completely in less than a year and had to be removed.

In the southern part of New Mexico, hard caliche has been used in the subgrade of railroad tracks for many years. The subgrade was topped with ballast, and it was noted that the tracks did not have any unusual maintenance problems.

Decomposed Sandstone

Decomposed or disintegrated sandstone refers to the sedimentary deposit that results from the rapid weathering of moderately hard sandstone. Two categories of decomposed sandstone are recognized in low-volume-road construction: partly weathered colluvial sandstone gravel and highly weathered sandy aggregate. Marginal sandstones are available in the states of Iowa, Montana, Nebraska, New Mexico, Oregon, Pennsylvania, and Wisconsin.

Material Characteristics and Evaluation

Decomposed sandstone typically consists of angular to moderately rounded particles that contain a large percentage of quartz and variable amounts of clay. They are often poorly graded and porous. The type, grain size, and amount of clay minerals determine the plasticity and swell characteristics. Decomposed sandstone typically has 20 percent material passing a No. 200 sieve and generally is nonplastic, which places it in the A-2-4 classification. However, decomposed sandstone contains enough fines to impart cohesive strength to the aggregate.

Decomposed sandstone is considered a marginal material because of its susceptibility to continued weathering. Frost action is the primary contributing factor for the continued disintegration of the sandstone rock.

Case Histories of Decomposed Sandstone

A 1.35-mile low-volume road was built in 1963 on PA-179 on the Allegheny National Forest in Pennsylvania (10). The 8-in-thick road base was constructed with soft decomposed sandstone stabilized with 9 percent cement. The traffic included approximately 10 trucks/day, especially oil, gas, and mineral transport vehicles. Although the road developed some rutting and required minor reconstruction in 1971, it has provided a smooth riding surface for several years with little required maintenance.

In Montana, decomposed soft sand-sized sandstone has been used in several instances as a subbase course and as a surfacing on low-traffic county roads. Results have varied from fair to good, depending on the quality of sand, the underlying material, and especially on moisture conditions. A 70-mile experimental road was built in eastern Montana. Decomposed sandstone was used both as base (untreated) and as a sand-asphalt mat. Untreated sand was barely adequate for a base under low-traffic, low-volume roads. The prevalence of intensive mat cracking and displacement indicated serious strength deficiencies in both the base and the bituminous mat (11).

GENERAL GUIDELINES FOR AGGREGATE PROPERTIES

The properties of aggregates govern its suitability for use in roadways. These properties serve as a yardstick in assessing the anticipated performance of the roads under varying environmental and loading conditions. Specifications for aggregate properties were originally developed to control the quality of the materials required to ensure that adequate strength, resistance to environmental forces, and compaction characteristics were obtained. However, specifications originally developed for high-volume paved roads cannot be used for low-volume roads. This section, therefore, reviews the significant aggregate properties and their desired range, which are particularly important for the design and construction of low-volume roads.

Environmental factors, particularly those related to climate, can have a significant effect on the performance of roadways, and hence should influence material requirements for low-volume roads. Moisture and temperature are perhaps the most important climatic factors. Temperature has little influence on the performance of aggregate roads; however, most pavement engineers agree that the presence of excess moisture in a pavement system is usually detrimental to the pavement structure. The moisture available

is influenced by the amount of rainfall, and then by the amount of evaporation. Accordingly, it is conjectured that the environment can be characterized by rainfall. Therefore, two climatic zones are recognized: a wet zone where the annual rainfall exceeds 35 in, as opposed to a dry zone where the rainfall is no more than 35 in.

The following discussion presents the limiting material property desired for each climatic zone, with summary data appearing in Table 1. Much of the investigative work for this data has been previously conducted by Meyer and others (2); their data, however, have been reviewed and summarized. For comparison, the specifications proposed by AASHTO (12) and ASTM (13) are also included in the table. Note that the latter limiting values by and large pertain to conventional aggregate, whereas the proposed values exercise limitations on marginal materials in low-volume roads.

Gradation

The stability of a soil-aggregate mix depends on particle-size distribution, particle shape, relative density, and the activity of clay-sized particles. A well-graded aggregate owes its stability to a good distribution of particle sizes, which provides grain-to-grain contact that maximizes natural grain-to-grain contact. An aggregate that contains few fine sizes usually has a lower density and is less stable but more pervious. However, an aggregate that contains sufficient fines to fill nearly all the voids between the aggregate grains will attain high density and low permeability, sometimes at the expense of increased frost susceptibility. Another aggregate property that is of equal concern is the maximum particle size. Generally, it can be said that strength increases with maximum particle size. Desirable levels of the percentage of fines and maximum particle size of aggregates, which pertain to both dry and wet zones, are listed in Table 1.

Plasticity

The behavior of fine-grained soils in roads is related to the plasticity as measured by the liquid limit and plastic limit tests. A mixture in which the PI of the binder fraction is too high tends to soften in wet weather. A pavement constructed of such material develops ruts under traffic and may shift and shove (i.e., develop a washboard surface). On the other hand, if the mixture is nonplastic in character, it will become friable in dry weather, ravel at the edges, and abrade severely under traffic. Such a pavement becomes dusty in service, and much of the binder soil may gradually be blown away in dry seasons of the year. Guidelines for plasticity and for the soil-aggregate used for surfacing are suggested to minimize those undesirable behaviors (see Table 1).

Resistance to Wear

Wear resistance of aggregates is important when they are incorporated in an untreated surface course. Based on the specifications of several highway departments and results of Everitt (14) for local roads and collector roads that have small traffic volumes, an acceptable maximum Los Angeles Abrasion loss of 50 percent is proposed (see Table 1).

Guidelines for Marginal Materials

Based on these limiting values of aggregate properties, material-specific guidelines are assembled for marginal igneous and sedimentary materials in Tables 2 and 3, respectively. It is important to note that, depending on the properties of each material, the limiting values are shifted slightly up or down in relation to those suggested in Table 1. Limiting values for index properties, design parameters, and construction-control requirements compiled in the tables would serve as general guidelines in developing low-volume-road designs.

Judging from the case histories cited in this paper, it is concluded that the proposed guidelines would satisfy the requirements of class 2 low-volume roads. Roads that carry an ADT of 50-400 belong to this class. The traffic axle-load distribution is seldom specified in the design of low-volume roads; accordingly, the suggested ADT is comprised of a normal traffic mix--light axles of all type and heavy axles primarily of buses and single-unit trucks.

SUMMARY AND CONCLUSIONS

As a result of the literature search, questionnaires, and interviews with selected engineers working on low-volume roads, a list of marginal materials that have shown potential in constructing and maintaining low-volume roads is assembled in this FHWA-sponsored paper (1). Out of 15 aggregates identified, only 8 unconventional aggregates are reported here. The aggregates included in the present study, based on their geologic origin, are classified into two groups:

1. Igneous: extrusive volcanics--cinder, pumice, and rhyolite; and intrusives--disintegrated granite; and
2. Sedimentary: limerock, coquina, caliche, and disintegrated sandstone.

Material characteristics, their performance histories in various climatic regions, and guidelines for potential use are stressed in this paper. The results of the study show that

1. Volcanic aggregates, although soft and porous, may be used as an untreated gravel base and surface with proper admixtures;
2. Disintegrated granite becomes slippery and mudlike when wet; therefore, a well-drained subgrade is mandatory;
3. Marginal limerock aggregates would normally require sand or coarse aggregate as an admixture;
4. Soft caliche, depending on its texture, would warrant admixtures such as fly ash; and
5. Partly decomposed sandstone can be used in a low-volume-road base without treatment; however, decomposed sand should be stabilized with cementing agents such as portland cement or self-hardening fly ash.

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The opinions, findings, and conclusions expressed in this paper are ours and not necessarily those of FHWA. This report does not constitute a standard, specification, or regulation.

Table 2. User guide for igneous materials—material properties, design, and construction-control requirements.

Material Type	Specific Use	Suggested Index Properties: Maximum Aggregate Size (in)	Percent Fines Passing No. 200 Sieve	Liquid Limit (%)	PI	Suggested Design Parameters: Thickness (in)	Recommended Wearing Surface	Admixture
Igneous extrusive								
Cinder	Untreated base and surface	1.5 for base; 1 if no surfacing provided	≤12[a]	≤35	2-10[b]	5-6	Asphalt overlay[c]	Clay binder for hard variety
	Road-mixed bituminous mixture	1				>4	NA	8-10 bitumen
	Seal coat	0.375	≤5	≤35				Emulsified asphalt
Pumice	Treated or untreated base	NA[d]	6-12	NA	NP	6	Chip seal wearing course of asphalt overlay mandatory	Lime, cement, or cinder clay
Ryholite	Untreated base and surface	2	NA	NA	NP	6	Double or single chip seal[c]	Clay binder
Igneous intrusive, disintegrated granite	Untreated base and surface	NA	20	35	≥10	6	Single chip seal[c]	Foamed asphalt cement or stone screening

Note: NA = not applicable, NP = nonplastic.
[a]Coarse gradation desired.
[b]Or sand equivalent of 50-30.
[c]Optional.
[d]Not applicable as fine textured (silt and sand sized).
[e]From personal communication to authors by D. Logan, Forest Service, Albuquerque, New Mexico, 1980.
[f]From Forest Service at Geotechnical Workshop during Second International Conference on Low-Volume Roads, Ames, Iowa, 1979.

Table 3. User guide for sedimentary materials—material properties, design, and construction-control requirements.

Material Type	Specific Use	Desired Index Properties: Maximum Aggregate Size (in)	Percent Fines Passing No. 200 Sieve	Liquid Limit (%)	PI	Design Parameters: Thickness (in)	Wearing Surface	Admixture
Limerock								
Oolite	Base course of high-volume roads							
Coquina	Untreated bases	2	≤15	NA	NP[a]	4[b]		Normally not required
Shell	Untreated base or surface	2	-[c]	NA	NP	4	Chip seal (optional)	40 percent sand
Marl	Untreated base	NA	≤15	≤35	≤8	8	Not recommended	Coarse aggregate or sand
Caliche								
Hard or semi-hard	Untreated base course	2	≤15	≤35	≤12	6	Single chip seal	Untreated
Soft	Untreated base or surface	NA	Base ≤2 Surface 6-12	≤40	≤12	6	Not recommended	Fly ash optional
Decomposed sandstone	Untreated base	NA	≤20	NA	NP[a]	6	Chip seal	Untreated but cement preferred

Note: NA = not applicable, NP = nonplastic.
[a]Generally.
[b]Four-inch cold asphalt wearing course or chip seal (optional).
[c]Crushed to specification.
[d]From personal communication by D. Logan, Forest Service, Albuquerque, New Mexico, 1980.

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Construction-Control Requirement or Compaction Equipment	Limitations and Special Precautions	Key Reference
No less than 100 percent AASHTO T-99; vibratory rollers preferred, second choice pneumatic roller	Lack of fines a problem Bituminous penetration-type surface not satisfactory Overlay should not be placed over new base Unsatisfactory from economic consideration	Henderickson and Lund (3)
Vibratory roller satisfactory	Unsatisfactory as aggregate for bituminous mixture Bituminous penetration surface unsatisfactory	Lund (4)
90 percent AASHTO T-99; at near optimum moisture using grid rollers	Moderately moisture susceptible	Logan[e]
Vibratory roller	Drainage of layer extremely important	Huddleston and Vinson (5), Forest Service[f]

Construction-Control Requirement or Compaction Equipment	Limitations or Special Precautions	Key Reference
	Good quality aggregates can be produced from oolite	Potts and others (6)
Standard compaction equipment	Moderately moisture susceptible Gains in strength due to cementation	
Standard compaction equipment	Soft shell breaks down under traffic Hard shell lacks fines	Newlon (7)
90 percent of AASHTO T-99	Moisture susceptible; adequate drainage necessary Bituminous wearing surface unsatisfactory Aggregate loss high in unsurfaced roads	Jones and Tarwater (8)
90-95 percent of AASHTO T-99	Lack of fines is a problem Bituminous surface not recommended for untreated soft caliche base	Logan[d]
Compacted by hauling equipment	Sand-asphalt mat is not satisfactory	Coghlan (10)

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