

# **Natural Aggregates of the Conterminous United States**

**By William H. Langer**

The geologic occurrence of potential  
sources of crushed stone and sand and gravel  
for use as natural aggregate and a summary  
of the natural aggregate industry

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# Natural Aggregates of the Conterminous United States

By William H. Langer

## Abstract

Crushed stone and sand and gravel are the two main sources of natural aggregates. These materials are commonly used construction materials and frequently can be interchanged with one another. They are widely used throughout the United States, with every State except two producing crushed stone. Together they amount to about half the mining volume in the United States. Approximately 96 percent of sand and gravel and 77 percent of the crushed stone produced in the United States are used in the construction industry.

Natural aggregates are widely distributed throughout the United States in a variety of geologic environments. Sand and gravel deposits commonly are the results of the weathering of bedrock and subsequent transportation and deposition of the material by water or ice (glaciers). As such, they commonly occur as river or stream deposits or in glaciated areas as glaciofluvial and other deposits. Crushed stone aggregates are derived from a wide variety of parent bedrock materials. Limestone and other carbonates account for approximately three quarters of the rocks used for crushed stone, with granite and other igneous rocks making up the bulk of the remainder. Limestone deposits are widespread throughout the Central and Eastern United States and are scattered in the West. Granites are widely distributed in the Eastern and Western United States, with few exposures in the Midwest. Igneous rocks (excluding granites) are largely concentrated in the Western United States and in a few isolated localities in the East.

Even though natural aggregates are widely distributed throughout the United States, they are not universally available for consumptive use. Some areas are devoid of sand and gravel, and potential sources of crushed stone may be covered with sufficient unconsolidated material to make surface mining impractical. In some areas many aggregates do not meet the physical property requirements for certain uses, or they may contain mineral constituents that react adversely when used as concrete aggregate.

In areas where suitable natural aggregate is not available or accessible, it may become necessary to improve the quality of existing aggregate, to import aggregate from outside the area, or to substitute artificial aggregate for natural aggregate. In most cases, all of

these alternatives add substantially to the cost of the final product. Even though an area may be blessed with an abundance of aggregate suitable for the intended purpose, existing land uses, zoning, or regulations may preclude commercial exploitation of the aggregate.

This report also discusses the aggregate industry in general terms, including exploration, mining, and processing, as well as aggregate production rates. Proper long-range planning based on an understanding of the aggregate industry can help assure adequate supplies of aggregate.

## INTRODUCTION

### Purpose and Scope

This report provides an overview of the availability of natural aggregates and the aggregate industry. The maps show the relative abundance of natural aggregates and the major areas where aggregate is likely to occur. They can be used for national or regional planning projects or to compare local with regional conditions. Due to the small map scale and the general nature of the maps, they are not to be used for prospecting or for site investigations. The report is also designed to assist local users in understanding the production and use of natural aggregates in order to minimize the problems associated with its production.

Crushed stone and sand and gravel are the two main sources of natural aggregates. These materials are widely distributed throughout the United States; however, they are not universally available for consumptive use. Sand and gravel does not occur in some areas, and some areas may be covered with sufficient material to make mining of stone impractical. In some areas, many aggregates do not meet the toughness, strength, durability, or other physical-property requirements for certain uses, or they contain mineral constituents that react adversely when used as concrete aggregate.

Together, crushed stone and sand and gravel amount to approximately half the mining volume in the United States. Crushed stone and sand and gravel are among the top nonfuel mineral commodities in annual U.S. production with a combined value during 1981 of more than \$5.4 billion. This by far exceeds iron ore (\$3.0 billion), copper (\$2 billion), or the precious metals such as gold, silver, and platinum group metals (\$983 million) (production figures from U.S. Bureau of Mines, 1982). However, the average citizen is not aware of his dependency on aggregate. The noise, traffic, dust, and unsightly appearance associated with mining operations make them unattractive neighbors. To prevent mining from encroaching upon residential developments, zoning or regulations are commonly enacted. Therefore, even if an area has an adequate supply of natural aggregates, regulations, as well as existing land use, may preclude its commercial exploitation.

The U.S. Bureau of Mines predicts an annual demand of nearly 2.5 billion short tons of natural aggregate by the year 2000. Because aggregate will continue to be in demand, provisions for uninterrupted economic supplies must be made. Proper long-range planning and zoning techniques based on an understanding of the aggregate industry can help assure adequate supplies of aggregate, while simultaneously protecting the public from the unwanted effects of mining operations.

## Acknowledgments

The author wishes to acknowledge the helpful cooperation of Donna L. Belval, U.S. Geological Survey, who, in addition to coauthoring plate 1 of this report, provided valuable assistance in collecting and interpreting data for this report and plate 2. Special thanks are also given to the National Sand and Gravel Association, in particular Richard C. Meininger, Director of the Engineering Branch, and the National Crushed Stone Association, in particular Frederick A. Renninger, Senior Vice President, for their review and comments on the manuscript and plates. The author also acknowledges the helpful review and comments on the plates from the many State highway department and State geological survey staffs. And finally the author acknowledges the efforts of coworkers in the U.S. Geological Survey, in particular Jerry C. Stephens, former Chief, Earth Sciences Assistance Office.

## AGGREGATE TYPES AND DEFINITIONS

Some terms associated with aggregates have different meanings to different users. In addition, some

terms have different meanings in different geographic locations. Commonly these terms have descriptive characteristics that are dependent on local conditions and as such serve an important function. The terms used in this report that relate to the aggregate industry generally conform to industry usage and to definitions accepted by the American Society for Testing and Materials.

*Aggregate*.—The term “aggregate” has a number of definitions depending primarily on the use of the material. The American Society for Testing and Materials (ASTM) defines aggregate in a number of ways. The definition given in ASTM Designation C 125-79a, Standard Definitions of Forms Relating to Concrete and Concrete Aggregate, is “a granular material such as sand, gravel, crushed stone, or iron blast-furnace slag, used with a cementing medium to form hydraulic-cement concrete or mortar.” The definition given in ASTM Designation D 8-79a, Standard Definitions of Terms Relating to Materials for Roads and Pavements, is “a granular material of mineral composition such as sand, gravel, shell, slag, or crushed stone, used with a cementing medium to form mortars or concrete, or alone as in base courses, railroad ballasts, and so forth.” Aggregate therefore encompasses a wide variety of naturally occurring and manmade materials of a wide range of sizes and physical properties.

More common definitions of the term “aggregate” seldom restrict it to use with a binder to form a conglomerated mass. Woods (1948, p. 1) defined the mineral aggregate as “an aggregation of sand, gravel, crushed stone, slag, or other material of mineral composition, used in combination with a binding medium to form bituminous and portland cement concrete, macadam, mastic, mortar, plaster, etc., or alone as in railroad ballast, filter beds, and various manufacturing processes such as fluxing, etc.” Woods left out reference to the term “inert material” since some aggregates, when bound into concrete by cement, are highly reactive. Woods’ definition has been referred to and used by McLaughlin and others (1960). It is used in this report and is consistent with most of the references used in the preparation of this report.

*Natural aggregate*.—McLaughlin and others (1960, p. 16-4) defined natural aggregate as “materials composed of rock fragments which are used in their natural state except for such operations as crushing, washing, and sizing.” This definition adequately describes the use of the term “natural aggregate” in this report with the exception that natural aggregate contains approximately 25 percent or more coarse fragments (those fragments retained on the No. 4 (4.75-mm) sieve).

*Rocks*\*.—Any hard, consolidated materials derived from the earth and usually of relatively small size.

*Bedrock*\*.—A general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.

*Gravel.*—Granular material predominantly retained on the No. 4 (4.75-mm) sieve that results from natural disintegration and abrasion of rock or processing of weakly bound conglomerates.

*Crushed gravel*\*\*.—The product resulting from the artificial crushing of gravel or small cobblestones with substantially all fragments having at least one face resulting from fracture.

*Crushed stone*\*\*.—The product resulting from the artificial crushing of rock, boulders, or large cobblestones, substantially all faces of which have resulted from the crushing operation.

*Sand.*—Granular material passing the 3/8-inch (9.5-mm) sieve, almost entirely passing the No. 4 (4.75-mm) sieve, and predominantly retained on the No. 200 (75- $\mu$ m) sieve that results from natural disintegration and abrasion of rock or processing of completely friable sandstone.

*Coarse aggregate*\*\*.—Aggregate predominantly retained on the No. 4 (4.75-mm) sieve (composed mainly of gravel-size particles).

*Fine aggregate*\*\*.—Aggregate passing the 3/8-inch (9.5-mm) sieve, almost entirely passing the No. 4 (4.75-mm) sieve, and predominantly of sand-size particles).

*Sand and gravel aggregate.*—A mixture (aggregation) of sand and gravel in which gravel makes up approximately 25 percent or more of the mixture.

*Artificial aggregates.*—Byproduct aggregates such as blast-furnace slag and cinders or manufactured aggregates such as lightweight aggregates including expanded clay or shale, processed diatomaceous earth, processed volcanic glasses, and expanded slag (McLaughlin and others, 1960).

\*The definitions marked by single asterisks have been taken, or paraphrased from, the American Geological Institute Glossary of Geology (Bates and Jackson, 1980).

\*\*The definitions marked by double asterisks have been taken, or paraphrased from, American Society for Testing and Materials (1980), ASTM Designation C 125-79a, Standard Definitions of Terms Relating to Concrete and Concrete Aggregates.

## MAP PREPARATION

Plate 1 is a map of the conterminous United States showing the major potential sources of sand and gravel aggregate. The map is subdivided into regions based on various natural processes that affected the formation of these deposits.

Plate 2 shows the distribution of selected types of bedrock normally considered for use as crushed stone.

The maps have been prepared at a scale of 1:5,000,000, or 1 inch equals approximately 79 miles. At

this scale, the distribution of natural aggregates cannot be shown in detail. Instead, these maps are intended to be an overview; they show the relative abundance of natural aggregates and the distribution of major areas where natural aggregate is likely to occur. These maps are not to be used for prospecting or for site investigations. For more detailed information, the reader should see the references cited or should contact State geological surveys or State highway departments at the addresses shown in a section at the end of the report.

Drafts of plates 1 and 2 were sent to the directors of each of the State highway departments and State geological surveys of the conterminous United States for their comments and review. More than 80 percent of the agencies responded. These maps reflect the State reviews wherever possible. The comments of the State agencies are greatly appreciated; however, their comments do not necessarily represent an endorsement of this report. Furthermore, the State agencies that responded to the review request did not officially approve the maps, and they have no official responsibility for the data shown on the maps or discussed in the report. This responsibility rests solely with the author. State agencies that responded to the review request are listed in the section "Sources of Data."

The information used to produce plate 1 was obtained, in general, on a state-by-state basis. Some regional and national maps were used when little or no information was available for a State or to resolve conflicts between data sources.

Each State has published some information concerning the availability of sand and gravel within the State; that information has been produced in many forms. Some States give written descriptions of where sand and gravel are most available; other States have produced maps that delineate areas likely to contain sand and gravel deposits; still others have maps that divide the entire State into regions and show the likelihood of finding sand and gravel throughout the State. Plate 1 combines all of this information onto one map showing the distribution of potential sand and gravel deposits on a national basis.

The actual compilation of the map involved transferring the information from the State publications to a 1:5,000,000-scale base map. When written descriptions were given of where sand and gravel could most likely be found, the approximate areas were plotted on the base map. State map publications that specify the areas where sand and gravel deposits are likely to occur were reduced and plotted on the base map. The publications that divided States into regions based on availability of aggregate were used as guides to the distribution of aggregate, but they were not directly used in preparation of the map since they did not provide enough detail.

As the source-map information was drafted onto the base map, two obvious problems surfaced: first, there were conflicts at the borderlines between States as to the boundaries of the sand and gravel units; second, some States were shown in greater detail than others because of map scale or mapping techniques. To solve discrepancies

at borders, national maps or regional maps were used as a supplemental sources of data. These included the Geologic Map of the United States (King and Beikman, 1974), the Surficial Geologic Map of the United States (Hunt, 1977), and the Glacial Map of the United States East of the Rocky Mountains (National Research Council, 1959).

Because some State maps had more detail than others, changes were made to provide for equal overall accuracy of the national map, rather than for extensive detail in only a few States. This was accomplished by compiling all maps at the 1:5,000,000 scale, then smoothing some contacts, enlarging some units to emphasize their existence, and deleting some units.

Plate 2 was produced largely from national or regional scale maps. Thus, many of the problems of differing scale, detail, and interpretations between States were avoided.

Information on the distribution of igneous and metamorphic rocks was obtained from the Geologic Map of the United States (King and Beikman, 1974). In reducing the map to the 1:5,000,000 scale, some of the smaller units had to be combined, enlarged, or deleted. Decisions were made based on an attempt to reflect the general distribution of rock types in an area.

The distribution of limestone and dolomite was obtained from Davies and others (1977), Ericksen and Cox (1968), French (1967), and Hubbard and Ericksen (1973). Because of differing scales and mapping techniques, adjustments to mapped units, commonly to conform to the King and Beikman map, were necessary.

## POTENTIAL SOURCES OF SAND AND GRAVEL

Sand and gravel deposits are the result of the erosion of bedrock and the subsequent transport, abrasion, and deposition of the particles by ice, water, gravity, and wind. The principal geologic agents that affect the distribution of deposits of aggregate are ice and water. Gravity has a minor influence on the formation of sand and gravel deposits through downslope movement of materials. (See "Regions of Bedrock and Residual Soils Resulting from the Weathering of Bedrock in Place.") Windblown deposits are generally confined to fine-grained materials and are therefore of little importance as natural aggregates except possibly as blending sands.

For the purposes of this report, in plate 1, the conterminous United States has been divided into five geographic regions. The origin and occurrence of sand and gravel deposits throughout a region reflects, in general, the geologic history and physiography of that region. Therefore, the mode of distribution of sand and gravel is similar within a region and fairly distinct from that of the other regions.

Within each of these geographic regions, major areas of sand and gravel have been delineated. Note, however, in regions III and IV, areas mapped as sand and gravel may actually be sand with only small local sand and gravel deposits.

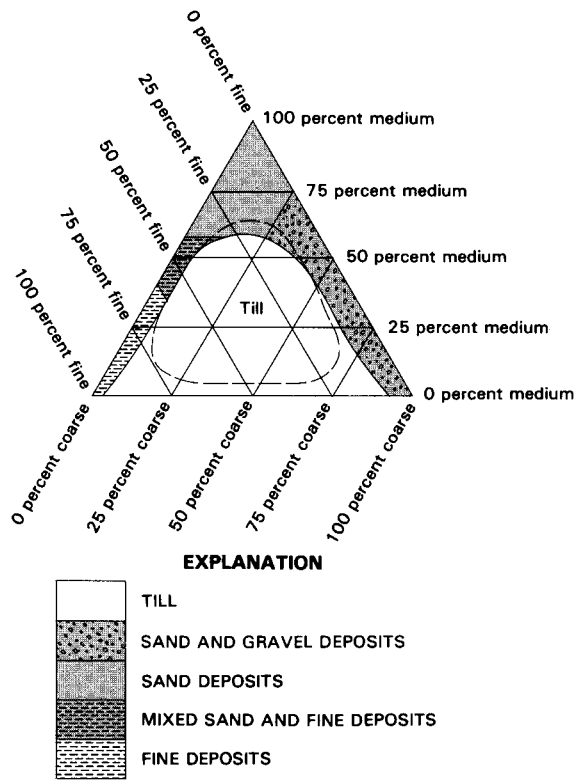
## Major Regions Covered with Glacial Materials (Plate 1, Region 1)

Glacial materials are the products of either continental or alpine glaciation, and in the United States, they are restricted to northern latitudes or high altitudes. Glacial materials are strongly influenced by the type of bedrock over which the glacier passed. They occur as two principal types of deposits: true glacial deposits and glaciofluvial deposits. In geologic terms, true glacial deposits are classified as till. This is material deposited directly by the ice, either at the base of the overriding ice (lodgement till) or as the ice melts (ablation till). Both types of till are poorly sorted mixtures of clay-size to boulder-size particles. Lodgement till commonly is very dense due to the presence of fine material and due to compaction from the weight of the overriding ice. Ablation till commonly is sandier and less dense. During the melting (ablation) process, much of the fine material is washed out of the ablation till, and in some cases, it is clean enough to be used as a source of natural aggregate.

As a glacier recedes by melting, meltwater flows from on top of, within, and under the ice. Glaciofluvial deposits consist of glacial material that has been transported and redeposited by this meltwater. As the material is transported, it is subjected to the abrasion and sorting action streams. Angular fragments are rounded, and weak materials are broken into smaller size particles. Fine materials are carried away and deposited in quiet waters (glaciolacustrine deposits), whereas the coarser sands and gravels are deposited in and along the stream channels. Because of this abrading and sorting process, coarse-grained glaciofluvial deposits generally yield satisfactory deposits of natural aggregate, although the presence of impurities may require washing. Figure 1 shows generalized grain size for typical glacial and glaciofluvial deposits.

Glaciofluvial deposits occur in a wide variety of topographic situations. Streams flowing within or on top of the ice may deposit the materials as sinuous ridges called eskers or ice channel fillings, respectively. Where the materials are deposited as conical mounds or terraces adjacent to the ice, they are called kames and kame terraces, respectively. Eskers, ice channel fillings, kames, and kame terraces all tend to contain a high percentage of coarse material. The materials that get carried farther away from the ice before they are deposited commonly are called outwash. They tend to have fewer very coarse particles and also tend to be better sorted.

The processes involved with glacial erosion and



**Figure 1.** Distribution of three particle-size groups for stratified deposits and till (from Langer and Recny, 1978).

deposition are extremely complex and dynamic. Hourly, daily, seasonal, and longer term temperature and climatic changes affect the generation of meltwater. Because of this, the characteristics of glaciofluvial deposits vary greatly, both areally and with depth. Figure 2 is a generalized block diagram (modified from Stone and others, 1979) which demonstrates the changes in texture encountered in glacial deposits.

Major deposits of sand and gravel aggregates, as shown on plate 1, are widespread throughout much of region I. In addition to those areas shown on the map, numerous, smaller deposits are found throughout much of the region. However, substantial parts of region I are practically devoid of sand and gravel aggregate. Areas in the Midwest that were once large glacial lakes are covered largely by materials too fine to be used as natural aggregate. Such lacustrine regions include glacial Lake Maumee, extending from Toledo, Ohio, to Fort Wayne, Ind.; glacial Lake Agassiz, extending from south of Fargo, N. Dak., north into Canada; glacial Lake Souris in northern North Dakota; Lake Wisconsin in Wisconsin; and others. The areal extent of these glacial lakes is shown in figure 3 and in more detail on some State geological maps as well as on the Glacial Map of the United States East of the

Rocky Mountains (National Research Council, 1959). In addition to these glacial lakes, large parts of the glaciated section of the Missouri Plateau (Fenneman, 1946) are lacking in deposits of sand and gravel aggregate.

### Major Regions of Large Alluvial Valleys (Plate 1, Region II)

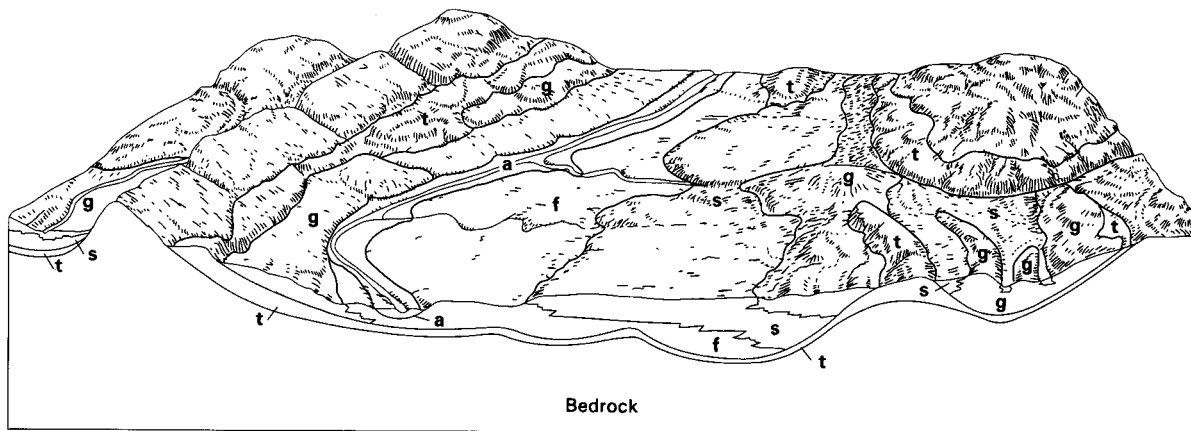
Climatic conditions associated with the continental glaciation of the northern part of the United States had a pronounced effect on large areas in the Western United States. The affected areas shown on plate 1 as region II consist primarily of much of the Basin and Range province and the California trough section of the Pacific Border province (Fenneman, 1946). Today the entire region is desertlike in character. However, during glacial times, rainfall was more abundant and mountain streams and meltwater from mountain glaciers sustained numerous freshwater lakes. These are sources of large deposits of sand and gravel aggregate.

Alluvial fans are another type of deposit typical of this region. Fan deposits are characteristic of arid and semiarid regions and are formed by repeated torrential floods. When flooded mountain streams reach the flat valleys, the sudden change in gradient and loss of carrying power cause the streams to deposit the materials they were carrying as fan-shaped deposits. These materials are quite different from those deposited by normal streams and rivers in that they are commonly angular and poorly sorted and require significant processing prior to use as sand and gravel aggregate.

Plate 1 indicates that sand and gravel aggregates are widely spread throughout region II. The mapped deposits include most of the alluvial valleys. The quality, physical properties, and grading of aggregates in these areas vary widely.

### Coastal Plain Province (Plate 1, Region III)

The Atlantic Coast from Long Island south and the Gulf Coast from Florida to Texas make up an area geographically known as the Coastal Plain province (Fenneman, 1946). This province is covered with extensive deposits of sand, silt, clay, and gravel that vary in thickness from a featheredge along the Fall Line in the east and along the Balcones escarpment and the Interior Low Plateaus in the south to hundreds of feet along the coast. Depending on location, they are either of marine or fluvial origin. The predominant surficial material of the Coastal Plain is sand. However, clays occur at the surface in the northern portion of the province, in central Alabama and western Tennessee, in a band approximately 800



**EXPLANATION**

t	TILL DEPOSITS	f	SILT AND CLAY
g	SAND AND GRAVEL DEPOSITS	a	SAND, SILT, AND CLAY
s	SAND DEPOSITS		

**Figure 2.** Generalized block diagram showing areal and vertical changes in textures of glacial deposits (from Stone and others, 1979).

miles long paralleling the boundary of the Coastal Plain in central Texas, along much of the Gulf Coast in Texas, and in the Mississippi embayment and its tributaries (Woods and Lovell, 1960).

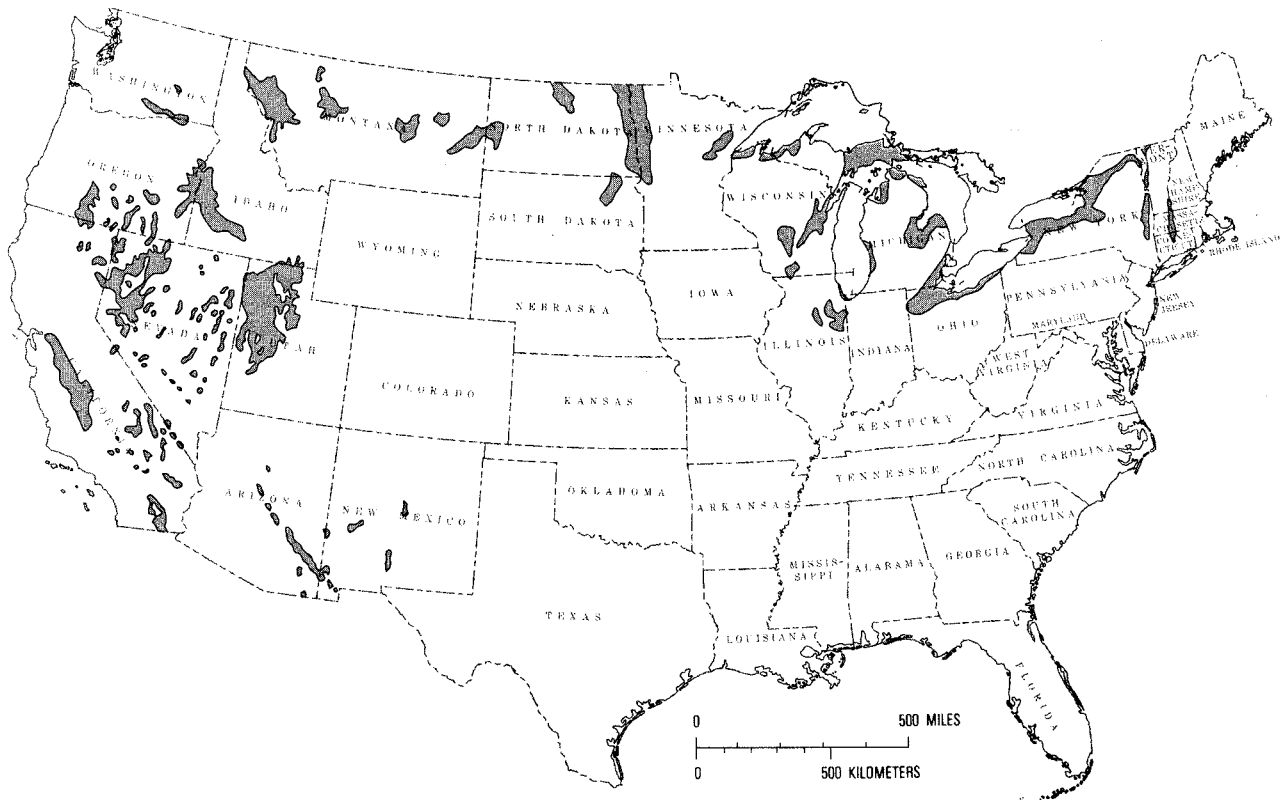
Near the inner edge of the Coastal Plain are deposits of sands and gravels. Present-day streams cutting through these deposits transport gravels downstream as much as 50 miles. These terrace and fluvial gravels are the primary sources of natural aggregate in the Coastal Plain, although small, isolated deposits of beach and terrace gravels are scattered throughout the area. The quality of the gravels varies in accordance with the types of rock from which they originated. The gravels associated with the Piedmont tend to be siliceous, whereas those occurring in contact with the limestones of the Interior Low Plateaus are calcareous (Woods and Lovell, 1960). Sand and gravel occur in parts of the Mississippi embayment as isolated terraces, the largest of which is Crowleys Ridge in southeastern Missouri and northeastern Arkansas. Sand and gravel also occur at depth under the alluvial clays of the Mississippi River. These sands and gravels are buried by clays ranging in thickness from 5 feet in the northern part of the embayment near Cairo, Ill., to more than 100 feet near New Orleans (Fisk, 1944).

As shown on plate 1, occurrences of sand and gravel are relatively restricted in region III. In contrast to regions I and II, much of region III mapped as sand and gravel may include only small deposits.

### Regions of the Midwest Covered Primarily with Soft Sedimentary Rocks (Plate 1, Region IV)

Large portions of the Midwestern United States are covered with soft (semiconsolidated) sedimentary rocks. This area includes most of the High Plains, the unglaciated Missouri Plateau, the Wyoming Basin, and the Uinta Basin (Fenneman, 1946). By far the largest section is that made up of the combination of the High Plains and the unglaciated Missouri Plateau. This area extends from the southern limit of the continental ice sheet south almost to the Rio Grande. In the northern sections the region is approximately 400 miles wide. From Oklahoma south it is generally less than 200 miles wide.

Soft (semiconsolidated) sedimentary rocks crop out throughout most of the region. Surface exposures range from silt to sand and gravel, with sand being most abundant, and clay occurs only in a few areas. Sand covers large areas of north-central Nebraska (Nebraska Sand Hills); an area in northwestern Kansas, northeastern Colorado, and southwestern Nebraska; and the area along the Texas-New Mexico border. Gravels occur haphazardly throughout the region, usually in small deposits (Woods and Lovell, 1960). The principal sources of gravel are terraces on mountain flanks and channel and terrace deposits of major rivers and streams. Gravels become progressively more scarce along the rivers and streams downstream from the mountains.



**Figure 3.** Areas of extinct glacial lakes in the conterminous United States.

Plate 1 indicates most areas where potential sources of sand and gravel aggregate are likely to occur in region IV. Except near the mountains along the western margin, very few sand and gravel deposits occur in the areas between river deposits. Also, in contrast to regions I and II, and similar to region III, much of region IV mapped as sand and gravel includes only small deposits. Deposits vary greatly in size as well as in physical properties.

### **Regions of Bedrock and Residual Soils Resulting from the Weathering of Bedrock in Place (Plate 1, Region V)**

Large portions of the conterminous United States have surface exposures of bedrock or residual soils resulting from the in-place weathering of bedrock. As bedrock is chemically and physically weathered, it is progressively broken down into smaller particles. Less resistant minerals are dissolved or altered into clays; the more resistant minerals remain as sands and gravels. Depending on the properties of the parent remaining residual soils range in composition from nearly all clay minerals through mixtures of clay, silt, and sand, and gravel to nearly pure sand or sand and gravel. The material remaining in place is more angular than water-transported material. Gravity, sheetwash, and small tribu-

tary streams move some of this material downslope into valleys where it is picked up, transported, and redeposited by streams and rivers. During this process, it is subjected to the abrading, rounding, and sorting processes of the stream or river. These stream-channel or terrace deposits are the primary source of sand and gravel aggregate in areas of bedrock and residual soils.

Deposits mapped in region V are areas of major deposits along major rivers. Numerous smaller deposits occur elsewhere along small rivers and streams. However, potential sources of sand and gravel aggregate are almost entirely restricted to alluvial and channel deposits. The distribution of sand and gravel aggregate in region V depends on a number of factors including type of parent bedrock, characteristics of the stream or river, and climatic conditions.

### **Marine Sand and Gravel**

Marine deposits on the continental shelves are large potential sources of sand and gravel that have been exploited very little. The surface materials on the continental shelves commonly are sand-size and finer. Important exceptions to this are large deposits of sand and gravel that occur off the coasts of New England and New Jersey, as well as those scattered along both the Atlantic and Pacific coasts. The mineralogy of these deposits

varies depending on the source of the material, and they may contain impurities of shells and salts. In addition, they are more difficult to prospect for and to mine than onshore deposits. However, as onshore deposits become more scarce in certain regions, offshore deposits may become economically feasible.

### **Areas Where Sand and Gravel Aggregate Generally Is Lacking**

Plate 1 and the preceding text indicate a number of areas in the conterminous United States where sand and gravel aggregate generally is lacking.

In the High Plains, coarse aggregate is largely restricted to river channels and terraces. However, much of this alluvium lacks coarse fractions. Large areas of glaciolacustrine deposits in Michigan and the Dakotas lack significant deposits of sand and gravel. The seaward sections of the Coastal Plain are primarily sand and lack significant deposits of gravel. Much of the Mississippi alluvial plain is covered with fine alluvium and lacks significant deposits of sand and gravel.

Residual areas (region V) are difficult to characterize as far as sand and gravel are concerned. Deposits are restricted to alluvium and are dependent on the characteristics of the river and the parent bedrock type. Some types of bedrock produce suitable coarse fragments; others do not.

In addition to these areas, Witczak (1972) has identified other areas where sand and gravel aggregates are generally lacking, including the Salton Trough (Fenneman, 1946) in southern California, which is an area primarily of fine-grained alluvial and lacustrine deposits, and the Mississippi loessial upland (Witczak, 1972), which is covered with extensive deposits of windblown silts and lacks significant deposits of sand and gravel.

### **POTENTIAL BEDROCK SOURCES OF CRUSHED STONE**

Bedrock deposits are classified on the basis of their origins into three main groups: sedimentary, igneous, and metamorphic. The complex origins and detailed distributions of bedrock are beyond the scope of this report. However, table 1 shows, in abbreviated form, classifications of the three main categories of bedrock. Plate 2 shows, in a generalized format, the distribution of bedrock commonly used for crushed stone. In many areas of this map, bedrock is covered with overburden too thick to make surface quarrying economical. This is particularly true in the glaciated parts of the country. In some of these

areas, crushed stone aggregate is currently being mined using underground mining techniques.

### **Sedimentary Rocks**

Sedimentary rocks are rocks resulting from the consolidation of loose sediment. The principal types of sedimentary rocks are those that have been chemically or biochemically deposited and those that have been mechanically deposited (clastic rocks). Sedimentary rocks range from heavy to light, strong to weak, hard to soft, and dense to porous. Their suitability for use as crushed stone varies accordingly.

Chemically or biochemically deposited sedimentary rocks consist primarily of limestones, dolomites, chert, flint evaporates, and organics. Of these rocks, evaporates and organics are seldom, if ever, used as aggregate and will not be discussed in this report.

Limestone and dolomite are rocks composed essentially of carbonates; limestone is primarily calcium carbonate ( $\text{CaCO}_3$ ), and dolomite is primarily calcium-magnesium carbonate ( $\text{CaMg}(\text{CO}_3)_2$ ). Both limestone and dolomite are commonly called limestone by the aggregate industry.

Most limestones are lithified mixtures of sediments and lime mud. The sediments that form limestones and dolomites are the remains of organisms that extract carbonates from the water. They can be the shells of clams or snails, the skeletons of corals, or the ooze precipitated by bacteria. Dolomites form in some places where seawater evaporates or indirectly where magnesium partially replaces calcium in limestones.

Limestones and dolomites, when hard and dense, commonly make good sources of crushed stone. Of the total production of crushed stone in 1981, 74 percent was limestone (U.S. Bureau of Mines, 1982). However, limestones may be friable, soft, and absorptive when they contain significant amounts of clay.

Plate 2 shows that limestone and dolomite are widespread throughout the conterminous United States, and nearly every State has formations adequate to supply some aggregate for construction. Limestones and dolomites are most extensive in the mid-continent, especially in Kentucky, Tennessee, Missouri, and States adjacent to the Great Lakes. Rocks in parts of the Appalachians and the Rocky Mountains are folded and faulted, and the limestones and dolomites tend to crop out in linear bands paralleling the regional structures. As such, they are restricted in area (Hubbard and Ericksen, 1973).

Silicates that form chert and flint are precipitated from water by organisms such as sponges, radiolarians, and diatoms. Cherts are used as crushed stone; however, some types of chert may cause adverse reactions when used as concrete aggregate (See "Physical Properties of Aggregate").

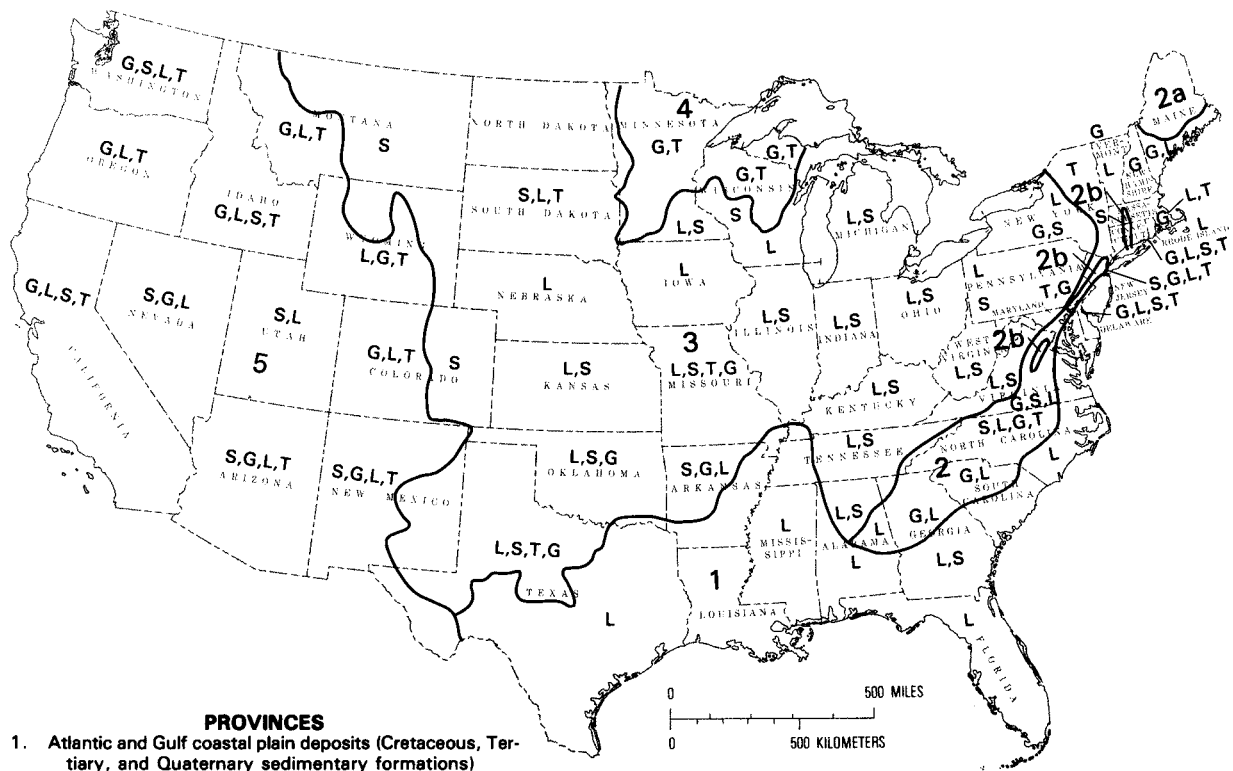


imperfect cementation of the constituent grains. They may also contain clay that renders the rock friable, soft, and absorptive. Siltstones and shales are generally poor aggregates, although they are used in some areas where other better quality aggregate is not available. They generally assume flat shapes when crushed, and they are soft, light, weak, and absorptive. Siltstones and shale may be fired to make lightweight aggregate. Conglomerates generally make aggregates because they are weak and frequently break down when handled (Water and Power Resources Service, 1981).

Sandstone differs from sand in that it is coherent instead of loose. The coherency is due to cementation

resulting from precipitation of carbonates or silicates in water circulating through the sediments. The individual grains of sandstones commonly are quartz, although other impurities may be present in significant amounts. The color of sandstones commonly is due to the cementing agent or to impurities. Red colors are attributed to hematite cements, brown colors to limonite cements. White sandstones commonly are cemented with silica and are frequently referred to as quartzites. Pink colors in sandstones commonly are caused by feldspar impurities in the rock.

Sedimentary rocks commonly occur in layers and may occur as any combination of conglomerates, sand-



**PROVINCES**

1. Atlantic and Gulf coastal plain deposits (Cretaceous, Tertiary, and Quaternary sedimentary formations)
2. Eastern crystalline (eastern Appalachian belt, Piedmont belt, Adirondack Mountains, and New England)
  - 2a. Northern Maine, area chiefly Paleozoic sedimentary rocks with scattered areas of intrusive crystalline rocks
  - 2b. Triassic sandstone areas
3. Great Plains-central interior-western Appalachian area of Paleozoic and Mesozoic sedimentary rocks, with a few scattered small areas of crystalline rocks
4. Lake Superior area of crystalline rocks
5. Cordilleran, Great Basin, and Pacific coastal belt of crystalline and sedimentary rocks, undifferentiated

Boundaries are generalized, and based on "Geologic Map of the United States," U.S. Geological Survey (1932)

**ROCK SYMBOLS**

Symbols denote States that reported production of major classes of crushed stone and placed within States and lithologic provinces, but they do not indicate locations of exploited deposits within States  
 G Granite and related metamorphic rocks  
 L Limestone (noncrystalline)  
 S Sandstone, including quartzite  
 T Trap rock

**Figure 4.** Lithologic provinces of the conterminous United States, 1969, as related to occurrence and production of principal kinds of crushed stone (modified from Currier, 1969, and Laurence, 1973).

stones, siltstones, shales, and carbonates or silicates. The thickness of the layers affects the density and hardness of the rocks as well as the ease of mining the desirable rock types and, consequently, the suitability of the rocks for use as crushed stone.

The only sedimentary rocks shown in plate 2 are carbonate rocks. Other sedimentary rocks such as conglomerates, sandstones, and siltstones are not shown on plate 2 because of their limited use on a national scale. However, in some localities, the use of these materials can make them an important resource.

Limestone and dolomite were plotted in plate 2 under one category, carbonate bedrock, because for most uses of crushed carbonate rocks, differences among properties of rock from specific individual sources are more important than whether the rock is classified as a limestone or a dolomite.

Figure 4 (modified from Currier, 1960, and Laurence, 1973) divides the conterminous United States into five lithologic provinces and indicates the types of crushed stone produced in each State. Sedimentary rocks cover province 3 (Great Plains, central interior, and western Appalachian area); much of province 5 (Cordilleran, Great Basin, and Pacific Coast belt); and parts of province 2b (Triassic basins within the eastern Crystalline section). Sedimentary rocks also occur in province 1 (Atlantic and Gulf Coastal Plain); however, few consolidated formations in these areas yield suitable crushed stone.

## Igneous Rocks

Igneous rocks that solidify from molten or partly molten material are commonly classified by origin and mineralogy.

Intrusive rocks are igneous rocks that formed within the Earth. They are generally coarse grained, due to the

slow cooling associated with being deeply buried, and include the general rock types of granite, diorite, and gabbro. Volcanic rocks (extrusive rocks) are igneous rocks that have been ejected onto the Earth's surface. They have been quickly cooled and therefore are fine grained. These include the general rock types of rhyolite, andesite, and basalt (trap rock).

Intrusive and volcanic rocks are further subdivided on the basis of mineralogy. Light-colored igneous rocks generally are high in silica and commonly are referred to as acidic or felsic rocks. These include the general rock types of granite, diorite, rhyolite, and andesite. Dark-colored igneous rocks generally are low in silica and are referred to as basic or mafic rocks. These include the general rock types of gabbro, diabase, and basalt, and they commonly are called trap rock. Ultramafic rocks, dark-colored composed almost entirely of mafic minerals, include the general rock types of serpentinite and dunite. Figure 5 demonstrates the relationships among origin, texture, and mineralogy of igneous rocks that are shown on plate 2.

Igneous rocks commonly are hard, tough, and dense; they make excellent sources of crushed stone. However, there are exceptions: tuffs and certain lavas are very porous due to the inclusion of gases, and some acidic rocks react when used as aggregate in concrete. About 12 percent of the crushed stone produced in 1981 was granite; about 8 percent was trap rock (U.S. Bureau of Mines, 1982).

The occurrences of igneous rocks and related metamorphic rocks are combined on figure 4 and are shown by the letter G. Igneous rocks are most common through province 5 of figure 4 (Cordilleran, Great Basin, and Pacific Coast belt) and province 2b (Triassic sandstone of the eastern Crystalline section).

## Metamorphic Rocks

Metamorphic rocks are derived from preexisting rocks through mineralogical, chemical, and structural changes. They are rocks that have been changed by heat and pressure and generally include slates, schists, gneisses, marbles, and quartzites. The physical characteristics of metamorphic rocks vary widely. Marbles (metamorphosed carbonates) and quartzites (metamorphosed quartz sandstones) are generally massive, dense, hard, and strong; and they generally are suitable sources of crushed stone. Schists and slates commonly are laminated and tend to assume slabby shapes when crushed. They often contain micaceous minerals and often lack the desired strength characteristics of crushed stone. However, some schists are suitable for use as crushed stone. Gneisses are usually massive, dense, hard, and strong; some gneisses may have the undesirable characteristics of schists.

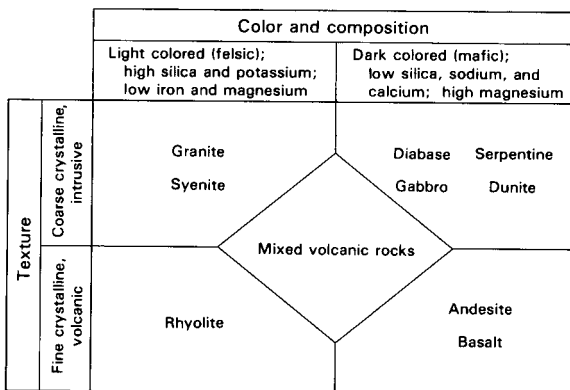


Figure 5. Diagram showing classification of igneous rocks shown on plate 2.

In figure 4, metamorphic rocks (which are included in the rocks depicted by the letter G) are common throughout province 2 (eastern Appalachian belt, Piedmont belt, Adirondacks, and New England) and province 4 (Lake Superior area), and are scattered through province 5 (Cordilleran, Great Basin, and Pacific Coast belt).

## PROPERTIES OF NATURAL AGGREGATES

The properties of natural aggregates vary greatly depending on the source of the material. The properties that one looks for depend primarily on the uses to which the aggregates will be put. In order to insure that aggregates will perform adequately under particular uses, their properties commonly are compared to predetermined specifications. The most generally used national guidelines for specifications and testing procedures for natural aggregates are those described by the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO). Some large construction agencies also develop their own specifications and tests. It must be pointed out, however, that national specifications must be broad, and that, at best, they are general guidelines. Local specifications must reflect specific uses, local aggregates, and local climatic conditions. For example, physical properties that may be innocuous in one area may be problems in another.

The largest single use of natural aggregates is in construction-related activities: 96 percent of the sand and gravel produced in the United States in 1981 was used in construction; 77 percent of crushed stone was used in construction. Of the construction uses, more than 57 percent of the sand and gravel was used as aggregate in portland-cement concrete or bituminous mixes. Nearly 25 percent of the crushed stone was used as aggregate for concrete or bituminous mixes.

Because of the use of natural aggregate in portland-cement concrete or bit mixes is generally more specific than for other construction-related uses, these specifications will be discussed. First, however, it is necessary to have a general understanding of what these products are and how they behave.

Portland-cement concrete is composed of sand, gravel, crushed stone, or other aggregates held together by a hardened paste of cement and water. When properly proportioned and thoroughly mixed, the materials make a plastic mass which can be cast or molded into a predetermined size and shape. In order for the concrete to set and cure, chemical reactions (hydration) must take place between water and compounds in the cement. When concrete sets, it becomes rigid and unworkable. Upon further hydration of the cement by the water, concrete becomes as hard and as strong as stone.

Bituminous mixes are composed of crushed stone, sand, gravel, or other aggregates held together by a flexible paste of bitumen. All, or nearly all, bituminous mixes are used for highway pavements and bases. The strength of the mixture comes from the intergranular contact between individual particles of the aggregate. The bitumen provides waterproofing and binds the aggregate particles in position; it is markedly different from the cement paste in concrete in that it can deform when loaded and rebound with the removal of the load (Goetz and Wood, 1960). Therefore, bituminous pavement is considered to be flexible, whereas concrete pavement is not.

Ideally, aggregate is an inert filler in concrete or bituminous mixes. However, owing to economic factors, the use of aggregate is usually limited to local deposits, which may or may not be completely inert. Therefore, adjustments in specifications of the aggregates and subsequently in the mixes of the final product must often be made. Generally speaking, factors that bear on the suitability of an aggregate to be used for concrete or bituminous mixes are gradation of grain sizes, particle shape, the presence or absence of contaminants, physical soundness, hardness and strength, skid resistance (only for pavement), chemical properties, volume-change characteristics, and specific gravity.

Gradation.—The grain-size distribution of particles in an aggregate as determined by mechanical sieving or screening is called gradation. Generally speaking, concrete aggregates should be well graded throughout the sand-and-gravel range of grain sizes, although gap grading (aggregates with particular grain sizes missing) can be used and may be necessary for some products. In most cases, grading in aggregates can be improved by processing to meet specifications.

Grading of concrete aggregate is most important in its effect on concrete proportions such as mixing-water requirements, cement content, and water-cement ratio, and in the subsequent handling characteristics and cost. Grading of sand has little or no material effect on the compressive strength of properly proportioned concrete, but it is important that the sand be uniform in character from batch to batch. In extremes, grading can affect the workability and finishing quality of concrete. In addition, either very fine or very coarse sand or coarse aggregate having either large deficiencies or excesses of any size fraction may be undesirable (Water and Power Resources Service, 1981).

The top size (maximum size) of the coarse fractions of concrete aggregate has an important effect on the water and cement requirements, with the necessary mixing-water content (and cement for lower strength concrete) decreasing as the maximum aggregate size increases. These reductions are possible because the coarser aggregate has less surface area and fewer surface voids, thus requiring less cement to make the concrete workable.

For high strength concrete, coarse aggregate with a maximum size in the ½-inch range may work best.

The grading of aggregates for bituminous mixes may be different from that of concrete aggregates. The grading commonly varies greatly, depending on the pavement design. Specific grading requirements are beyond the scope of this report.

Maximum particle size of aggregates for bituminous mixes may also differ greatly from that of concrete aggregate. It has been observed that using particles larger than 1 inch in graded mixtures often results in mixtures that are unworkable and that have surface voids which may lead to raveling (Goetz and Wood, 1960).

*Particle shape.*—Allowable grading limits of aggregates depend somewhat on particle shape and surface characteristics. In portland-cement-concrete aggregate, a sand composed of smooth, well-rounded surfaces normally can be more coarsely graded than a sand with sharp, angular edges and rough surfaces, due to the freedom of movement of the aggregate in fresh concrete. Round, smooth sands require less mixing water in concrete and thus produce better strength at the same cement content because a lower water-cement ratio can be used. Angular sands, in addition to requiring more mixing water, may not be workable enough for applications such as pumping of concrete.

Particle shape also affects the workability of concrete aggregate. Flat or angular particles, such as those obtained through crushing, have a detrimental effect on workability. In general, the presence of about 25 percent or less of flat or elongate particles in any size range has no important effect on workability; a higher percentage generally requires a greater percentage of sand in the mixture, which requires more water and cement (Water and Power Resources Service, 1981).

Because intergranular contact provides the strength in bituminous mixes, angular particles are generally desirable for these mixes. However, excess flat or elongate particles may be harmful. Therefore, as with concrete aggregate, aggregate for bituminous mixes should be reasonably free of flat or elongate particles. Smooth surfaces on aggregates may be easy to coat with bitumen, but they offer little assistance in holding the aggregate in place. ASTM specifications call for a specified minimum amount of particles with fractured faces to be used in bituminous mixes (Goetz and Wood, 1960).

*Contaminants.*—The presence of excessive amounts of contaminants, including silt, clay, mica, and organic materials, may (1) cause decreased strength and durability, (2) affect the quality of the bond between the cement and the aggregate, (3) cause an unsightly appearance, and (4) inhibit the hydration of the cement. These contaminants commonly can be reduced to acceptable levels during processing.

*Physical soundness.*—Physical soundness is usually considered to be the ability of an aggregate to resist

weathering, particularly freezing-thawing and wetting-drying cycles. Generally aggregates that contain weak, cleavable, absorptive, or swelling particles are not suitably sound. Examples are shales, clayey rocks, some very coarse crystalline rocks, and porous cherts (Neville, 1973). Specifications for soundness are similar for aggregates to be used in concrete or bituminous mixes.

The most important physical property of rock particles affecting weathering resistance (particularly freezing-thawing) is the size, abundance, and continuity of pores and channels (McLaughlin and others, 1960). These provide conduits for the passage of water, which in turn accelerate the weathering process.

*Hardness and strength.*—Hardness and strength characteristics of aggregates determine their ability to resist mechanical breakdown. These properties are generally controlled by the individual mineral constituents of rock particles, the strength with which these minerals are locked or cemented together, and the frequency of fractures. Particles consisting of minerals with a low degree of hardness are considered to be soft; those which are easily broken down, due to weak bonding or cementation or to fracturing, are considered to be weak (McLaughlin and others, 1960). Soft or weak particles are deleterious in aggregates because they break down during handling, thus affecting the grading of the aggregates, and because they perform poorly in use.

Mechanical breakdown of aggregates due to the action of mixers, mechanical equipment, and (or) traffic, or breakdown due to weathering is referred to as aggregate degradation. Mechanical breakdown can occur due to compressive failure of grains at points of contact, as well as to abrasive action of grains on each other. Mechanical breakdown is generally of greater significance in bituminous pavements than in concrete pavements.

*Skid resistance.*—Aggregates that are to be used in concrete or bituminous mixes for surface courses in highway construction should possess high polishing resistance. In general, the hardness of the minerals in an aggregate controls the polishing resistance of the aggregate. This polishing, in turn, determines the skid resistance of pavements. Although skidding can be a problem for both concrete and bituminous pavements, the significant factors may be different. Coarse-aggregate hardness is more important in bituminous pavements than in concrete pavements because there is greater exposure of individual pieces of coarse aggregate in the pavement generally is controlled by the fine aggregate portion of the mixture because the coarse aggregate will not be exposed at the surface until significant wear has taken place (Witczak, 1972; Renninger and Nichols, 1977).

*Chemical properties.*—Chemical properties of aggregate are important in the manufacture of concrete or bituminous mixes. Ideally, the aggregate is an inert filler and should not change chemically in place. However, some aggregates contain minerals that chemically react







































