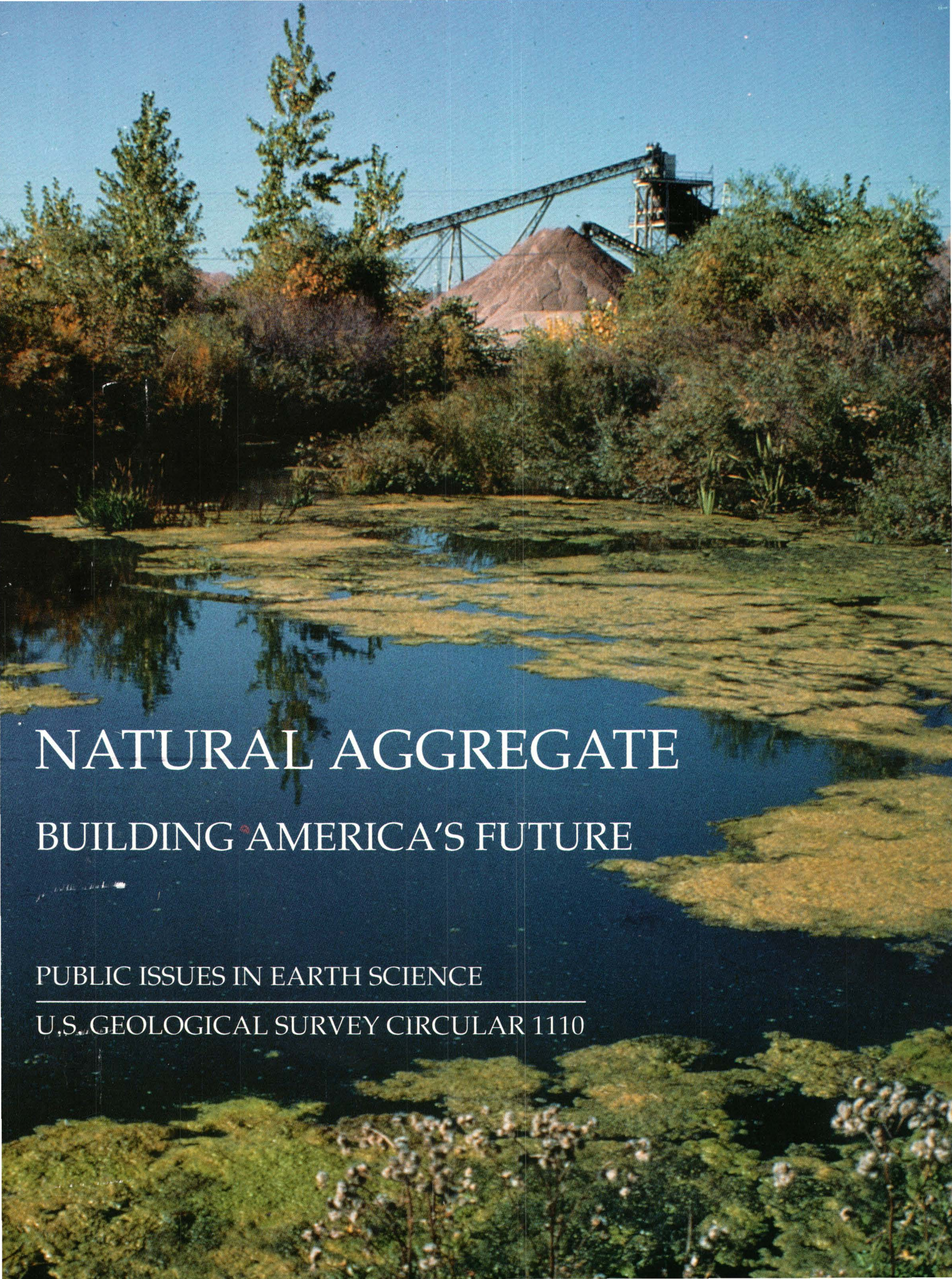

NATURAL AGGREGATE

BUILDING AMERICA'S FUTURE

PUBLIC ISSUES IN EARTH SCIENCE

U.S. GEOLOGICAL SURVEY CIRCULAR 1110

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By WILLIAM H. LANGER
and V. M. GLANZMAN

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FOREWORD

The United States produces nearly 2 billion tons of aggregate per year, which represents approximately one half of the non-energy mining volume in the country. Yet natural aggregate is one of the Nation's poorly understood resources. In this book, the authors discuss issues related to the geologic distribution and characteristics of aggregate and some implications of those factors for our Nation's economy. The two primary sources of aggregate are crushed stone and sand and gravel. Although potential aggregate is widely distributed throughout the United States in a variety of geologic environments, it is not evenly distributed geographically. Some areas are devoid of sand and gravel; potential sources of crushed stone may be lacking or covered by an overburden so thick that surface mining is uneconomical. In other areas, aggregate does not meet the physical or chemical property requirements for specialized uses. Furthermore, zoning, government regulations, or competing land uses may restrict or preclude the production of aggregate. Transportation to the user is an important factor in providing lower costs in construction projects.

In the next decade, the restoration and rehabilitation of an aging infrastructure will require the mining of enormous amounts of aggregate. Earth scientists provide input critical to the identification, protection, and extraction of suitable aggregate and equally important to reclamation efforts that return the land to beneficial uses. This information will be used into the next century to provide economical supplies of aggregate while providing protection from the impacts of mining to both citizens and environment alike.

Dallas L. Peck
Director

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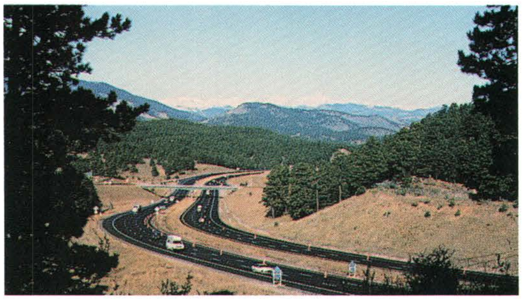
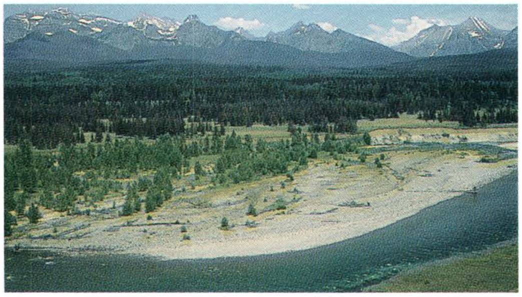
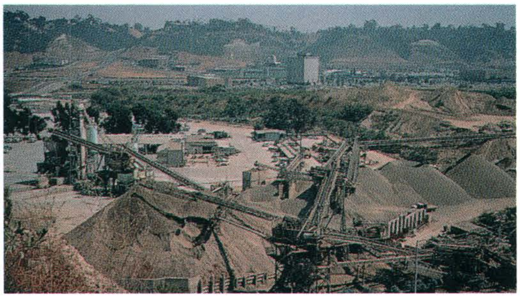






INTRODUCTION

Crushed stone and sand and gravel are the main types of natural aggregate used in the United States. Aggregate is used in nearly all residential, commercial, and industrial building construction and in most public-works projects such as roads and highways, bridges, railroad beds, dams, airports, water and sewer systems, and tunnels. The widespread use of aggregate results not only from its general availability but also from economic considerations. Aggregate of good quality commonly is available near the site of use at relatively low cost. This aggregate can essentially be obtained and used with a minimum of processing. However, even though crushable stone and sand and gravel resources are widely distributed throughout the United States, availability is not universal. Some areas are devoid of sand and gravel, and some potential sources of crushed stone may be lacking or covered by overburden that is too thick to allow economical surface mining. In some areas, moreover, aggregate does not meet the physical-property requirements for certain uses, or it contains mineral constituents that react adversely when used in cement concrete. Furthermore, citizens commonly prefer that stone and sand and gravel not be mined nearby. Many citizens do not support mining, in part because they do not recognize the dependence of society on aggregate. Personal use is very little, if any, and individuals may not recognize aggregate mining as a necessary land use, even though the need for the commodity is constant. Thus, zoning, regulations, and competing land uses may restrict or preclude aggregate mining.

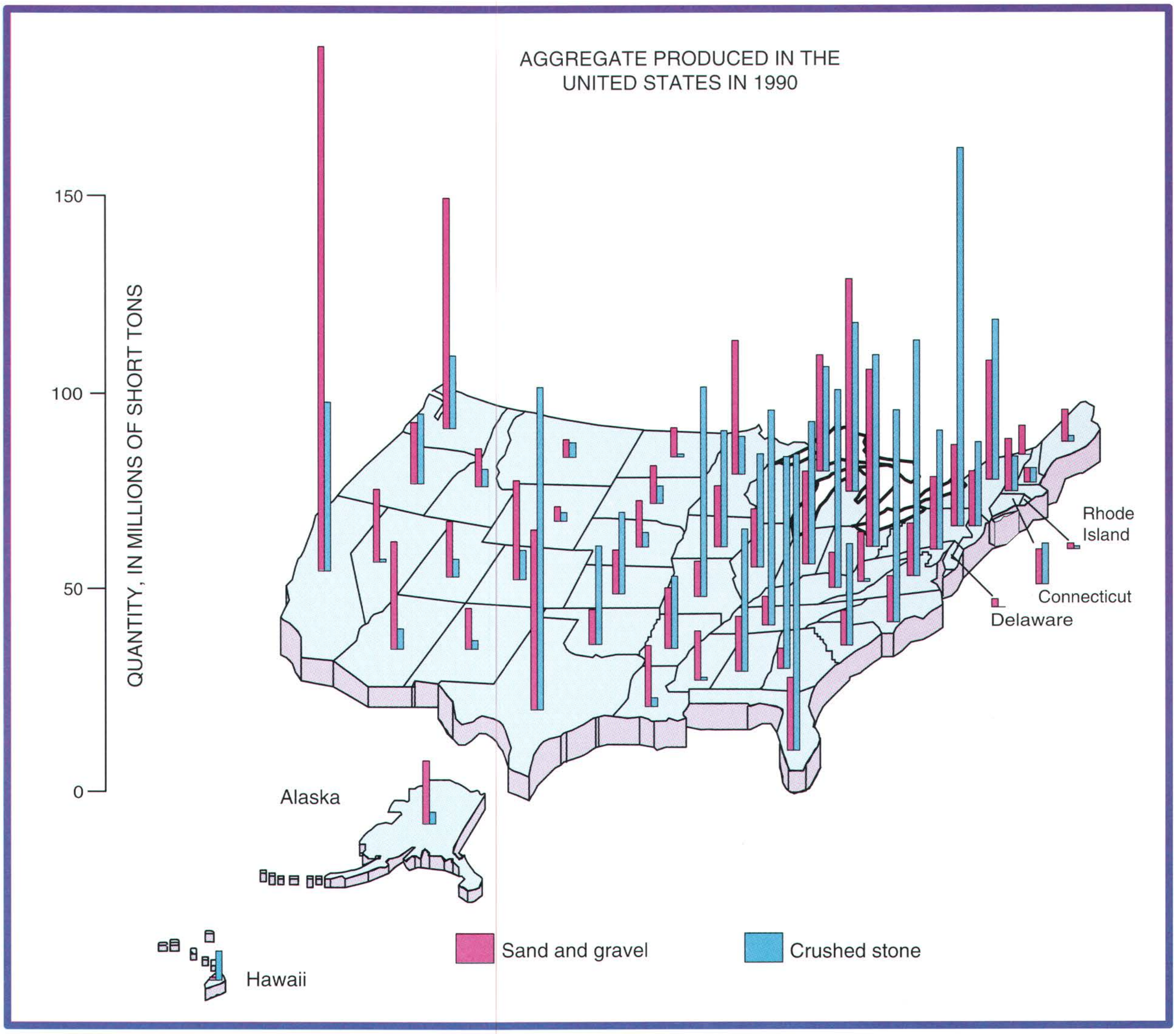
Aggregate production accounts for about half of the nonfuel-mining volume in the United States.

Between 1970 and 1990, aggregate use averaged 1.84 billion short tons per year, reaching a maximum of 2.17 billion tons during 1988. In the future, the rebuilding of deteriorated roads, highways, bridges, airports, seaports, waste disposal and treatment facilities, water and sewer systems, and private and public buildings will require that enormous quantities of aggregate be mined or quarried. Long-range planning is necessary to help ensure adequate economical supplies of high-quality aggregate in the future, while simultaneously protecting the public from unwanted effects of mining. This report provides an overview of the aggregate industry and of the availability of natural aggregate as an aid to those involved in protecting, conserving, and developing the Nation's resources.

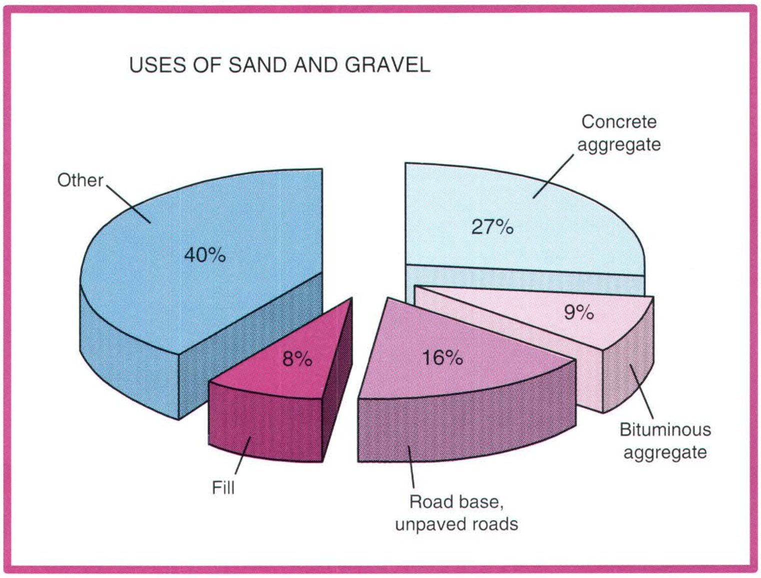
PRODUCTION AND USES OF AGGREGATE

Sand and gravel are produced commercially in every State in the United States, and crushed stone is produced in every State except Delaware. Aggregate production accounts for about half of the nonfuel-mining volume in the United States; during 1990, production yielded a gross value of about $9.1 billion. The 1990 gross value far exceeded that of iron ($1.8 billion), copper ($4.2 billion), or the combined value of precious metals including gold, silver, and the platinum-group metals ($4.7 billion).

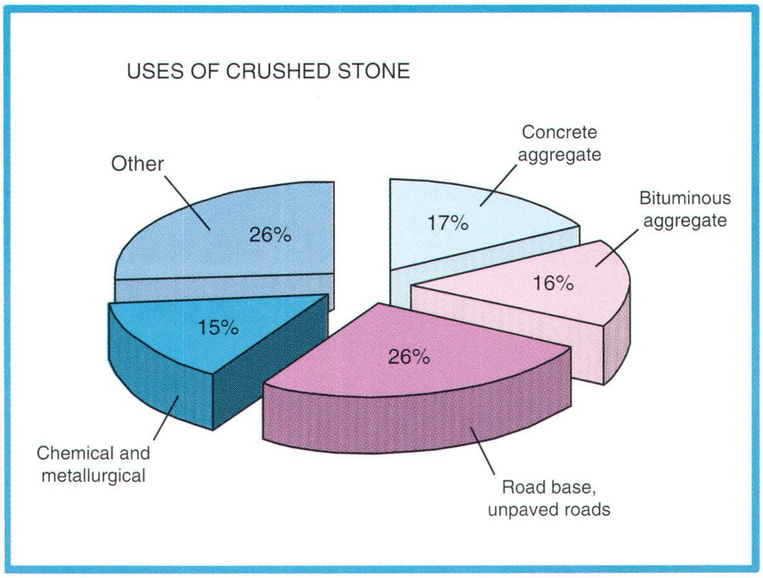
In 1989 (the last year for which a complete survey of crushed-stone production was taken), 1,716 companies produced 1.2 billion short tons of crushed stone from 3,416 active quarries. Individual crushed-stone quarries range in size from small operations reporting production of less than 50,000 short tons annually to those with production of more than 10 million tons. For a variety of reasons, including the large investment in capital equipment, crushed-stone operations tend to be very large. For example, in 1989, 10 companies operating 477 quarries produced 27.8 percent of the total output of crushed stone in the United States.



In 1990, about 4,200 companies produced 911 million short tons of sand and gravel from about 5,700 operations. Individual sand and gravel operations range in size from those reporting production of less than 25,000 short tons annually to those with production of more than 2.5 million tons. In contrast to crushed-stone operations, many sand and gravel operations are relatively small. In 1990, 3,564 operations, representing 63 percent of the total, each produced less than 100,000 short tons of sand and gravel.



Production of crushed stone and sand and gravel is necessary to many industries in the United States. Sand and gravel (or sand alone) is used for sand casting in foundry operations, glass manufacturing, abrasives, and filtration beds of water-treatment facilities. Crushed stone is used as a source of calcium for fertilizers, in metallurgy, and as the major component in the manufacture of cement and lime. Crushed stone may also be used in filtration systems and in the manufacture of glass.



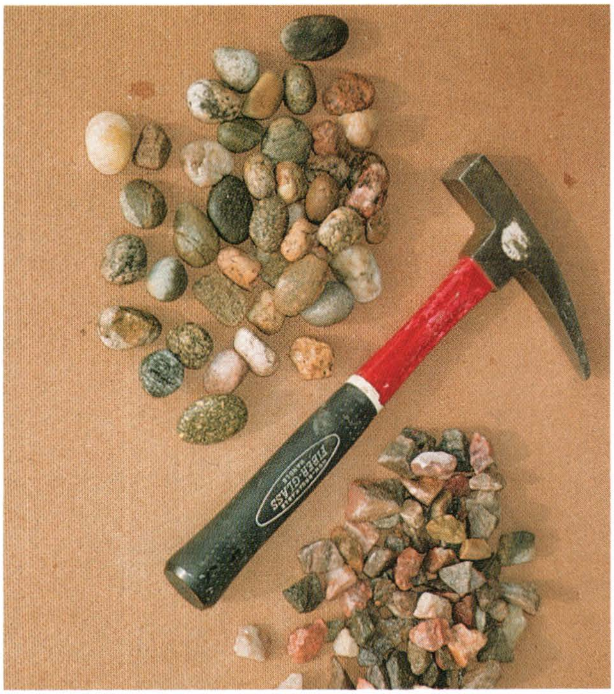
Crushed stone and sand and gravel are primarily used for aggregate in the construction industry, especially in cement concrete for residential and commercial buildings, bridges, and airports, and as cement concrete or bituminous mixes (asphalt) for highway construction. A large percentage of aggregate is used without a binder as road base, for road surfacing, and as railroad ballast. Aggregate is also used to provide drainage around house foundations, for septic-system leach fields, for snow and ice control, and as fill in wet or swampy land.

The view of any four-lane interstate highway with interchanges and bridges, international airports, or a great dam such as the Grand Coulee instantly conjures a picture of huge volumes of aggregate or concrete. Indeed, construction of 1 mile of four-lane interstate highway requires 85,000 tons of aggregate; the Denver International Airport, Colorado (pictured below), required 5 million tons; and the Grand Coulee Dam required 17 million tons. However, few homeowners realize that construction of an average six-room house requires 90 tons of aggregate or that construction of one average-size hospital or school requires 15,000 tons.

BASIC CONCEPTS AND TERMINOLOGY

Natural aggregate consists of rock fragments that are used in their natural state or are used after mechanical processing such as crushing, washing, and sizing. Quarry stone is crushed and processed to produce aggregate. In this report, the term natural aggregate (or aggregate) includes mined or quarried stone that has been crushed, washed, and sized, as well as sand and gravel.

Gravel generally is considered to be material whose particles are 3/16 inch to 3 inches in diameter and tend to be rounded with smooth edges. Sand and gravel aggregate is a mixture (aggregation) of sand and gravel in which gravel constitutes about 25 percent or more of the mixture. Gravel may be the predominant material in a natural deposit, but typically it occurs in layers or lenses with sand.



Crushed stone, as its name implies, is artificially crushed rock, boulders, or large cobbles. Crushed stone tends to be angular with sharp edges. Most or all of the surfaces on the clasts or particles are produced by the crushing operation. Most crushed stone is quarried from bedrock that is blasted, mined, crushed, and processed into aggregate. Selection of the bedrock to be used for crushed stone depends primarily on the physical and chemical properties of the rock.

PHYSICAL AND CHEMICAL REQUIREMENTS OF NATURAL AGGREGATE

Most people probably assume that natural aggregate is used chiefly in cement concrete. Much natural aggregate, however, is unsuited for such use. We all have seen crumbling driveways and bridges or cracks in sidewalks and patios. Concrete deterioration has many causes, but unsuitable aggregate, containing deleterious ingredients, can be a primary or secondary cause of the problem.

Natural aggregate varies widely in quality, depending on the source. To ensure that aggregate is suited for particular uses, testing laboratories compare aggregate properties with predetermined standards. The most generally used national guidelines for specifications and testing procedures are those of the American Society for Testing and Materials (ASTM). National specifications must be broad, and at best they serve as general guidelines. Local specifications need to reflect specific uses, availability and quality of local aggregates, and local climatic conditions.

Suitable aggregate consists of clean, uncoated particles of proper size and gradation, shape, physical soundness, hardness and strength, and chemical properties. The final use of the aggregate determines the specific properties sought. Generally, specifications for aggregate used in cement concrete or bituminous mixes are more stringent than are those for other construction-related uses.

Mechanical sieving or screening is used to grade, or sort to size, aggregate. In general, aggregate for cement concrete should be well graded throughout the sand and gravel range of particle sizes, although gap grading (aggregate with specific particle sizes missing) may be used and may be necessary for some products. Specifications for bituminous mixes are dependent on the pavement design, and therefore no general statement can be made regarding the sizes of aggregate used.

Particle shape affects both the grading limits of aggregate used in cement concrete and the workability of the concrete. The presence of excessive amounts of angular particles can require addition of a greater percentage of sand to the mixture, which in turn requires more water and cement. In contrast, because intergranular contact provides strength in bituminous mixes, angular particles generally are desirable. Smooth particle surfaces offer little assistance in holding the aggregate in place in bituminous mixes. In both cement concrete and bituminous mixes, too many flat or long particles may be harmful.

Physical soundness is the ability of aggregate to resist weathering, particularly freezing-thawing and wetting-drying cycles. Generally, aggregate that contains weak, easily broken, absorptive, or swelling particles is not suitable. Specifications for physical soundness are similar for use in cement concrete and bituminous mixes.

Hardness and strength of aggregate affect the ability of the final product to resist mechanical breakdown. The breakdown of soft or weak particles during handling or mixing is deleterious in both cement concrete and bituminous mixes. Such breakdown affects the grading of the aggregate, and it can be aggravated by weathering or traffic. Specifications for hardness and strength of aggregate are similar for use in cement concrete and bituminous mixes.

Ideally the aggregate is an inert filler, and it should not change chemically once in place. However, some aggregate contains minerals that chemically react with or otherwise adversely affect the concrete or bituminous mixes. In cement concrete, these chemical processes are reactions between the aggregate and the cement, solution of soluble materials, or oxidation of constituents. In bituminous mixes, chemical factors may influence oxidation of the asphalt or strip the bituminous film from the aggregate.

When aggregate does not meet the required specifications, a number of corrective alternatives exist. These include (1) blending high-quality aggregate with the unsuitable aggregate to achieve an acceptable overall quality; (2) removing deleterious materials from the aggregate by processing techniques; (3) making adjustments during processing, such as recrushing to change particle shape; or (4) adding chemicals or making other adjustments to cement mixtures or bituminous mixes.

GEOLOGY

Sources of aggregate, such as sand and gravel and rock for crushed stone, were formed by geologic processes. Volcanoes, glaciers, wind, rivers, and seas formed the shape and character of rock materials over millions of years. The gravel used today may have been deposited thousands of years ago—just yesterday geologically. Hard, dense limestone may have been deposited as a limy ooze hundreds of millions of years ago. When an aggregate supply is required, geological investigations can determine the location, distribution, and nature of potential aggregate in an area.

SAND AND GRAVEL

Sand and gravel deposits are products of erosion of bedrock and surficial materials and the subsequent transport, abrasion, and deposition of the particles. The principal geologic agent that affects the distribution of deposits of sand and gravel is water. Consequently, gravel is widely distributed and abundant in glaciated areas, in alluvial basins, and in, adjacent to, or near rivers and streams. Windblown deposits generally are fine grained and rarely are used for aggregate.

STREAM-CHANNEL AND TERRACE DEPOSITS

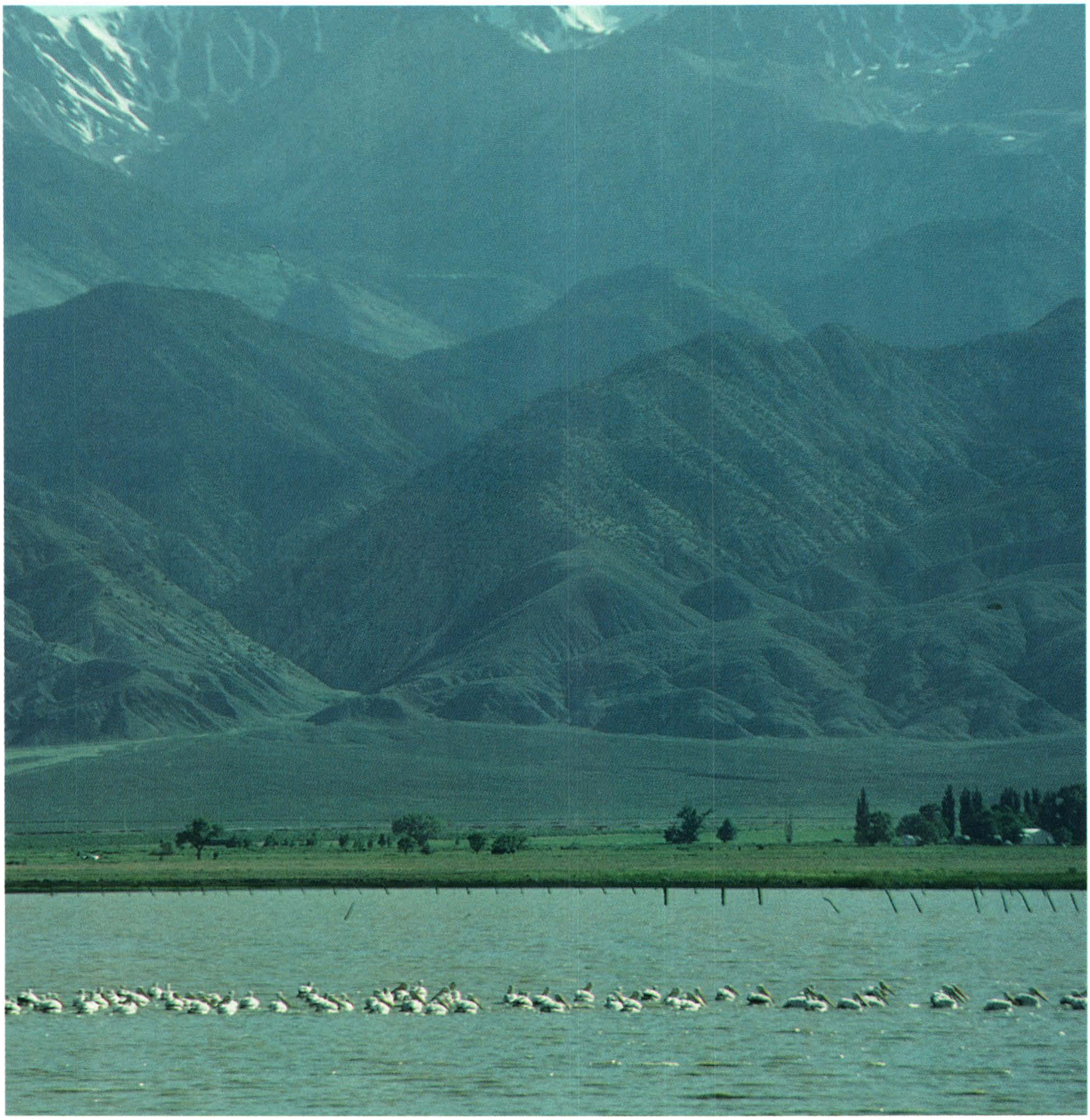
Sand and gravel deposited by rivers or streams is widely distributed throughout the United States as stream-channel or terrace deposits. In hilly or mountainous areas, bedrock is chemically and physically weathered and is progressively broken into smaller and smaller particles. Chemically less resistant minerals are dissolved or altered into clay minerals; the more resistant minerals remain as rock fragments. Depending on the composition and structure of the bedrock and on the climate, land cover, and topography, the remaining soils may range in thickness from almost nothing to many tens of feet, and may range in composition from nearly all clay, through mixtures of clay, silt, sand, and gravel, to nearly all sand and gravel, to rubble. Gravity and sheetwash move some of this material downslope, where it forms a deposit called colluvium. Eventually the colluvium is moved into valleys of relatively high gradient streams. In the stream channels, rock fragments are subjected to abrasion, rounding, and sorting. The stream-transported material is deposited in channels and on floodplains and consists of sand and gravel in some areas and silt and clay in others.

Aggregate occurs where nature placed it, not where people need it.

Erosion can alter an already-established floodplain. If the river or stream incises its channel, the older channel and floodplain deposits are preserved as terraces. Repeated downcutting can result in the formation of a series of terraces or terrace remnants.

GLACIAL DEPOSITS

Many of the extensive sand and gravel deposits in the northern parts and higher elevations of the United States are products of either continental or alpine glaciation. As a glacier advances over the land surface, it erodes the surficial materials and underlying bedrock, depositing till, which is a nonsorted or poorly sorted mixture of clay-size to boulder-size particles. As the ice melts, rock particles that had been crushed and abraded by the ice are transported by meltwater. As these particles are carried along, they are further abraded and sorted. Angular fragments are rounded, and weak particles are broken into smaller pieces. Finer materials are carried away and deposited in lakes and ponds (glaciolacustrine deposits), while the coarser sand and gravel is deposited in and along the stream channels (glaciofluvial deposits). Glacial erosion and deposition are complex dynamic processes. Hourly, daily, and seasonal temperature changes and longer term climatic changes affect the rate of melting and the volume of meltwater. The particle size of glaciofluvial deposits, therefore, varies greatly, both areally and with depth, and the deposits accumulate in diverse topographic settings.



ALLUVIAL-FAN DEPOSITS

In the arid and semiarid Western United States, many valley basins contain thick deposits of unconsolidated alluvium. Alluvium (detrital material consisting of clay, silt, sand, or gravel) is eroded in the adjacent mountains and is transported to the basins during infrequent but torrential floods (typical of desert environments) down steep-gradient streams. On reaching the basins, the water spreads out of the channel and infiltrates into the ground. The sudden change in gradient and reduced transporting capacity causes deposition of sediment, producing alluvial fans. Generally, the coarsest detrital material is deposited adjacent to the mountains. Deposition becomes progressively finer in the alluvial valleys toward the center of the basins. In time, the fans formed in adjacent valleys coalesce to form continuous thick deposits of alluvium.

CRUSHED STONE

Bedrock is classified in three main groups, based on its origin: sedimentary, igneous, and metamorphic. The sedimentary rocks limestone and dolomite make up about 71 percent of current crushed-stone production. Igneous rocks, generally referred to in the aggregate industry as "granite" or "traprock" (basalt or diabase), compose 14 percent and 8 percent of crushed stone, respectively. Metamorphic rocks, such as gneiss, marble, or quartzite also are used and, together with other miscellaneous stone, account for the remaining 7 percent.

Sedimentary rocks were formed by consolidation of loose sediment by chemical, biochemical, or mechanical processes or by direct chemical precipitation. Chemically or biochemically deposited sedimentary rocks, such as, hard, dense limestones and dolomites (calcium or calcium-magnesium carbonates), generally are good sources of crushed stone. Some limestone and dolomite, however, is too soft, absorptive, or friable to yield high-quality aggregate.

Chert and flint are silicate rocks that were precipitated in water by organisms such as sponges. These rocks may be crushed for aggregate, but they may cause adverse reactions, such as cracking and scaling, in cement concrete.

Clastic (mechanically deposited) sedimentary rocks are classified according to the sizes of individual particles. Rock that consists mostly of pebbles and larger size fragments is conglomerate; rock that consists mostly of sand-sized particles is sandstone; and rock that consists primarily of silt- or clay-sized particles is siltstone or shale, respectively. Of these rocks, hard, dense sandstone is the only type that generally is a source of crushed stone. In areas where no other material is available, it is a major source of aggregate, but it constitutes less than 3 percent of the total U.S. aggregate production.

Igneous rocks solidify from a molten or partly molten state and are classified further by their origin. Intrusive igneous rocks solidify at depth within the earth and have coarse mineral crystals, owing to the slow cooling associated with deep burial. Light-colored intrusive igneous rocks commonly are referred to as "granite" in the aggregate industry. Extrusive igneous rocks solidify at or near the earth's surface and generally are composed of small or microscopic crystals that were formed by rapid cooling. Such rocks frequently are referred to as "traprock" in the aggregate industry. Igneous rocks that are hard, tough, and dense commonly are excellent sources of crushed stone. However, some are very friable and others are very

porous. Some siliceous igneous rocks react deleteriously when used as aggregate in cement concrete.

Metamorphic rocks form when existing rocks are subjected to heat and pressure within the earth. Common metamorphic rocks are slate, schist, gneiss, marble, and quartzite. Of these, only gneiss, marble, and quartzite commonly are used as aggregate.

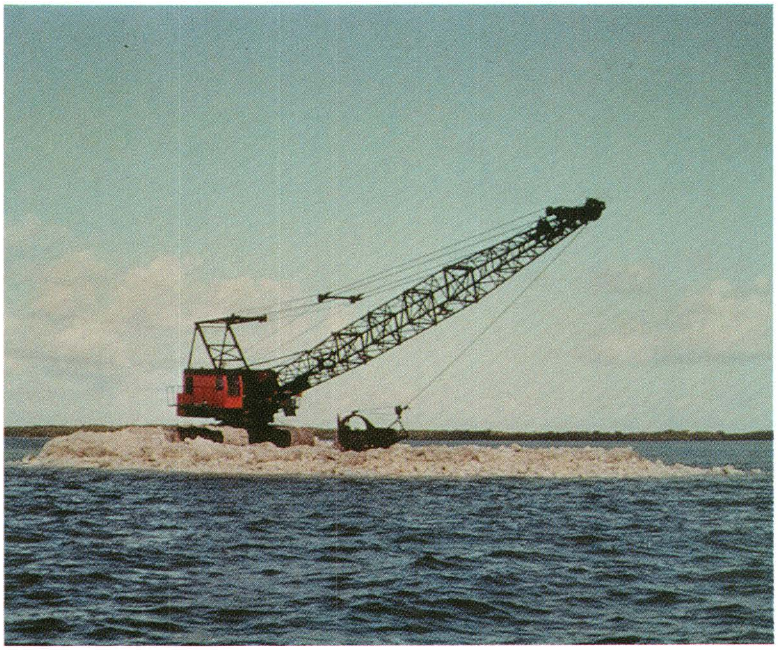
coal refuse, mine tailings, waste glass, and shredded rubber tires.

Recycling cement concrete (shown in photograph and inset below) and asphalt (bituminous mix) currently is a viable alternative for natural aggregate, and can be both economically and environmentally beneficial. In some States, recycling is either encouraged or required.

ALTERNATE SOURCES OF AGGREGATE

In areas where natural aggregate is not economically available, does not meet physical or chemical specifications, or is preempted by land use or regulations, various other materials may be used as aggregate to avoid excessive transportation costs.

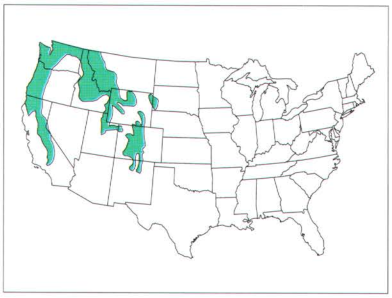
Natural materials such as shells (as shown at the upper right), "clinker" (bedrock that was baked or melted by underground coal fires), and caliche (calcium salts) have all been substituted for crushed stone or sand and gravel. Aggregate can be manufactured from clay and shale expanded by firing. In addition, certain types of waste have even been used, including blast furnace slag, steel slag, ash,



AGGREGATE REGIONS OF THE UNITED STATES

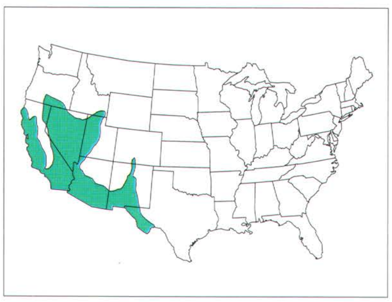
Natural aggregate occurs where nature placed it, not where people need it. To concisely describe aggregate availability and quality in the United States, this report divides the country into 12 regions. In general, each region has similar occurrences of aggregate within its boundaries but is fairly distinct from other regions. Those regions where natural aggregate is abundant are shown in green. Regions shown in blue are where

TOPOGRAPHY



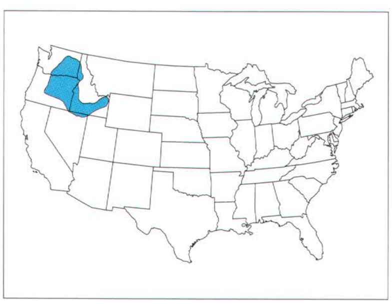
Western Mountain Ranges

Tall, massive mountains alternating with relatively narrow, steep-sided valleys. Larger valleys may have higher terraces.



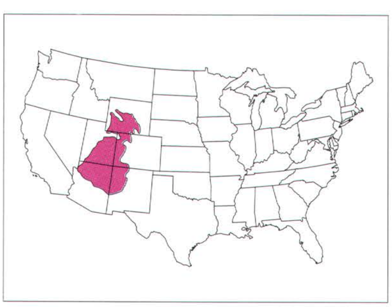
Basin and Range

Alternating basins or valleys and mountain ranges.



Columbia Plateau

Gently sloping plateau underlain by a thick sequence of extensive lava flows separated by soil zones and interbedded sediments.

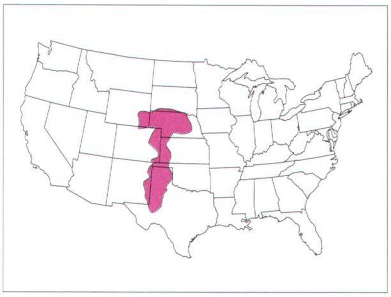


Colorado Plateau and Wyoming Basin

High plateaus with deeply incised canyons, mountains, deserts, and badlands. Erosion has produced extensive, prominent cliffs.

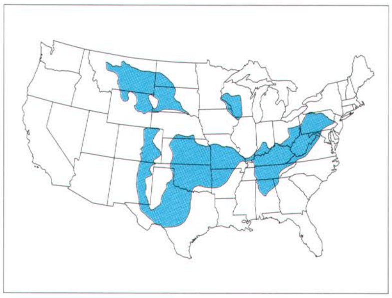
natural aggregate occurs in limited, but generally adequate, quantities; some areas may be devoid of aggregate. Regions shown in purple are where aggregate occurs in very limited quantities; large areas may be devoid of aggregate. In any region, quality problems can limit the use of aggregate, and conflicting land use, regulations, and other social and economic factors can restrict aggregate development. It should also be noted that these regional divisions are extremely simplified, and are intended only for general reference.

CRUSHED STONE RESOURCES	SAND AND GRAVEL RESOURCES
Mountains are underlain by igneous and metamorphic rocks, flanked by consolidated sedimentary rocks including some limestones. Potential sources of good-quality crushed stone are generally available	Stream-channel or terrace deposits and limited glaciofluvial deposits are present. Quality problems tend to be localized.
The mountain ranges are commonly underlain by igneous, metamorphic, and consolidated sedimentary rocks. Potential sources of good quality crushed stone are generally available.	Large alluvial basins commonly contain extensive deposits of poorly sorted sand and gravel deposits. In addition, terraces and beaches found on mountainsides consist of well-sorted sand and gravel. Some areas are deficient in sand and gravel. Quality problems tend to be localized.
The northern part of this region commonly is underlain by basalt that is generally a suitable potential sources of crushed stone. The southern part is underlain by basalt and other igneous rocks, some of which have physical or chemical properties that do not yield good aggregate.	Stream-channel, terrace, and glaciofluvial deposits are well distributed throughout the northern parts of the region. In the rest of the region, sand and gravel are rather limited, commonly being restricted to river and terrace deposits. Many gravel deposits have chemical and physical properties that do not yield good aggregate.
Generally underlain by poorly consolidated to consolidated sandstone, shale, and limestone, with the sandstone and shale being most prevalent and most extensive. In places the rock units contain significant amounts of gypsum or halite. The soft sandstone and shale tend to afford poor-quality crushed stone.	Stream-channel, terrace, and glaciofluvial deposits occur along parts of the valleys of major streams, especially adjacent to the mountain ranges in the northern and eastern parts of the region. In the remainder of the region sand and gravel is generally limited to alluvium and terraces. Gravel commonly is derived from the erosion of soft sandstone or shale, and tends to be of poor quality.



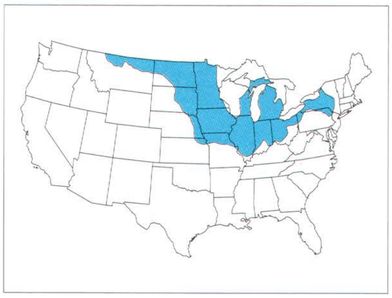
High Plains

Large, flat, gently eastward-sloping plain. Significant topographic features include sand dunes and wide valleys of braided streams that flow from the Rocky Mountains eastward across the plain.



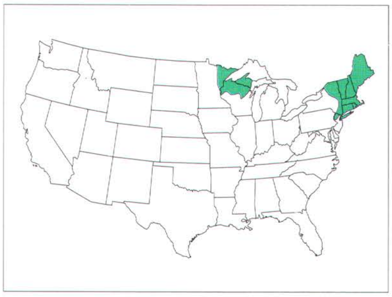
Nonglaciated Central Region

Topographically complex region including lowlands and plains as well as hilly and mountainous areas.



Glaciated Central Region

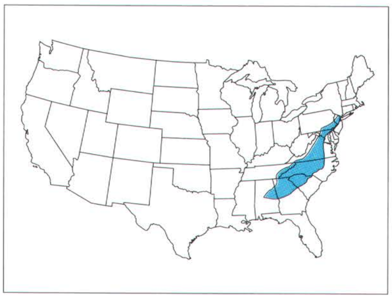
Flat plains, rolling hills and low rounded mountains.



Glaciated Northeastern and Superior Uplands

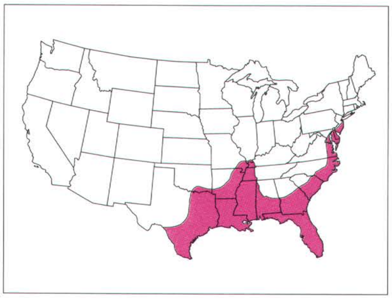
Rolling hills and low mountains.

CRUSHED STONE RESOURCES	SAND AND GRAVEL RESOURCES
Bedrock consists of soft semiconsolidated sediments, almost all of which is unsuitable for use as crushed stone.	Stream-channel and terrace deposits of the major rivers and their tributaries. Deposits generally are progressively finer downstream from the mountains and commonly are deficient in coarse sizes. Gravels frequently have chemical or physical properties that do not yield good aggregate.
Most of the northern part of the region and the part of the region flanking the Rocky Mountains is underlain by sedimentary rocks consisting mostly of sandstone, shale, and conglomerate. With the exception of scattered limestone, these rocks generally are poor sources of crushed stone. Most of the south-central region is underlain by limestone and dolomite. These rocks commonly yield suitable sources of crushed stone, although the presence of chert and other deleterious minerals may restrict certain uses.	The land surface in most of the region is overlain with a residual soil formed by the chemical and mechanical breakdown of the bedrock. The residual soils in the western part of the region are overlain with substantial thicknesses of windblown deposits. Stream-channel and terrace deposits are the source of sand and gravel throughout the region. The quality of sand and gravel is variable and depends on the type of parent material.
Bedrock consists of consolidated sedimentary rocks including sandstone, shale, limestone, and dolomite. These rocks are most prevalent in the central part of the area and are less prevalent in the east. The western parts of the region generally lack limestone or dolomite, and generally have inadequate sources of crushed stone. Throughout the region, even where suitable bedrock exists at depth, the thickness of overburden may be too great to extract the rock economically.	The major sources of sand and gravel aggregate are glaciofluvial, stream-channel, and terrace deposits. Sand and gravel deposits are generally abundant throughout the region. In the northern part of the region, much of the aggregate is buried by fine-grained deposits. Aggregate is almost completely absent in the Illinois Coal Basin. Aggregate from the Missouri River tends to be contaminated with deleterious material from the underlying soft sandstone and shale bedrock. In the Great Lakes area and scattered throughout the region, aggregate may contain minerals with chemical properties undesirable for certain uses.
Bedrock consists primarily of granite, syenite, anorthosite, and other intrusive igneous rocks and metamorphosed sedimentary rocks consisting of gneiss, schist, quartzite, slate, and marble. Most igneous rocks make suitable sources of crushed stone. The characteristics of metamorphic rocks vary widely, with the schists and slates commonly lacking the strength and shape characteristics for desirable crushed stone.	Most of the valleys and other low areas commonly contain stream-channel, terrace, and glaciofluvial sand and gravel. In several areas, the unconsolidated deposits consist of clay and silt deposited in lakes that formed during the melting of the ice sheets. The major sources of good-quality sand and gravel aggregate are glaciofluvial, stream-channel, and terrace deposits.



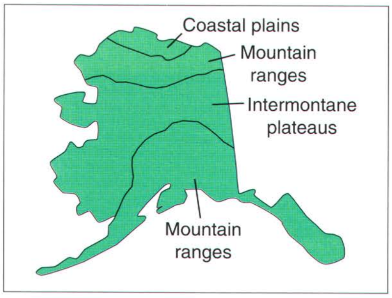
Piedmont Blue Ridge Region

The topography of this region is varied and consists of low, rounded hills, long rolling ridges, and mountains, and contains the highest peaks east of the Mississippi River.



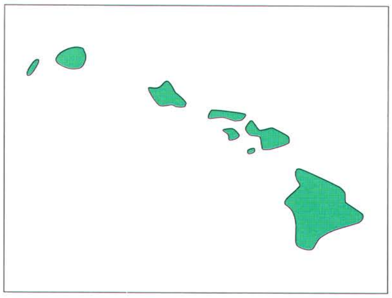
Atlantic and Gulf Coastal Plain

The topography ranges from extensive, flat, coastal swamps and marshes occurring near sea level, to rolling uplands occurring near the inner margin of the region.



Alaska

A complex area consisting of coastal plains, mountain ranges, and intermontane plateaus.



Hawaiian Islands

Islands formed by lava that issued from one or more volcanic eruption centers. The islands have a hilly appearance resulting from erosion that has carved valleys into the volcanoes and built relatively narrow plains along parts of the coastal areas.

CRUSHED STONE RESOURCES	SAND AND GRAVEL RESOURCES
Bedrock consists of igneous and metamorphosed sedimentary and igneous rocks including granite, gneiss, schist, quartzite, slate, marble, and phyllite. Granite and gneiss are commonly used as crushed stone, whereas schist, slate, and phyllite are commonly avoided. Potential sources of good-quality crushed stone are generally available.	The mountains are bordered by low-gradient streams flowing in relatively narrow valleys. The land surface is underlain by saprolite, which is clay-rich, unconsolidated material developed in place primarily from the chemical weathering of the underlying bedrock. The valleys are underlain by relatively thin, moderately sorted alluvium. Stream-channel and terrace deposits are the source of sand and gravel throughout the region. Quality problems tend to be localized.
Consolidated bedrock generally is inaccessible in the Coastal Plain region, except near the inner margin, and in southeastern Florida, which is underlain by semiconsolidated limestones that are of marginal use as aggregate.	The region is underlain with extensive deposits of semiconsolidated sand, silt, clay, and gravel, with sand being the predominant surficial material. Most gravel deposits occur near the inner edge of the Coastal Plain and occur as stream-channel and terrace deposits. These deposits are limited in occurrence and are the primary source of natural aggregate in the region. Isolated deposits of beach and terrace gravels are scattered throughout the area. The quality of the gravels depends on the parent material. The gravels in the Atlantic coastal area tend to be high in quartz and other silica minerals, whereas those in the Gulf coastal area are calcareous. Coarse materials are so limited in this region that shells are commonly substituted for gravel. Sand and gravel occur in parts of the Mississippi embayment as isolated terraces. Sand and gravel also occurs at depth under the alluvial clays of the Mississippi River floodplain.
Underlain by a diverse assemblage of rocks. The principal mountain ranges have cores of igneous and metamorphic rocks. These are overlain and flanked by sedimentary and igneous rocks. The sedimentary rocks include carbonate rocks, sandstone, and shale.	Approximately half of the region, including the mountain ranges and adjacent parts of the lowlands, was covered by glaciers. Glaciofluvial deposits in these areas commonly contain sand and gravel. In the intermontane plateaus, sand and gravel commonly is mined from stream channels, terrace deposits, and placer-mine tailings. The Arctic Coastal Plain consists of silt, sand, and gravel, with the northeastern part having moderate to high potential for sand and gravel. Much of the aggregate is frozen to some degree, and excavation requires drilling and blasting.
Each of the Hawaiian Islands is underlain by lava flows. Andesite and basalt flows are commonly used as a source of crushed stone. In addition, clinker from the tops of lava flows and cinders from cinder cones are also used as stone aggregate.	In some areas alluvium of older and modern terraces and alluvial fans contain poorly sorted sand and gravel of variable quality. In coastal areas a thin layer of coral and shell fragments, volcanic debris, and clay form discontinuous beach deposits, which may be used as aggregate if they meet the required specifications.

SUPPLY AND DEMAND

Each region has a baseline demand for aggregate that responds to a continuing need for highway, road, and street maintenance and construction. Superposed on this need are requirements of the cities and towns—requirements that are proportional to urban size and growth rates. Transecting all these requirements are special demands of major construction projects such as interstate highways and airports. Such projects often require large quantities of aggregate in relatively short periods of time.

The supply area is controlled by the geology of the area, ownership of the land, zoning, land use, and transportation.

Because aggregate is a high-bulk, low-cost commodity, the transportation cost to the site of use is a significant part of the total cost. Therefore, natural aggregate commonly is used within 30 to 50 miles of the place of extraction. Ultimately the supply area is controlled by the geology of the area, ownership of the land, zoning or other land-use restrictions, and transportation routes. Rural counties and their communities commonly attempt to obtain aggregates within their boundaries. In contrast, urban areas generally meet their needs from surrounding areas. These urban areas act as distinct markets, and the demand for aggregate may greatly exceed the availability of material in the surrounding areas. Major construction projects generally need aggregate for only certain phases of construction and therefore it may be necessary to transport aggregate great distances to guarantee its supply. All of the users of aggregate may compete for a supply from the same sources, and major construction projects may significantly disrupt an otherwise predictable market.

ESTIMATING SUPPLY

Potential sources of crushed stone and sand and gravel may be extremely large, but specific land-use considerations, socioeconomic considerations, or the physical or chemical properties of the materials may limit the utility of these sources. Unless the distribution, availability, and quality of aggregate are known, it is difficult to formulate a reasonable plan to set aside or develop aggregate. Therefore, in planning for future aggregate needs it is necessary to determine the reserves for the planning area.

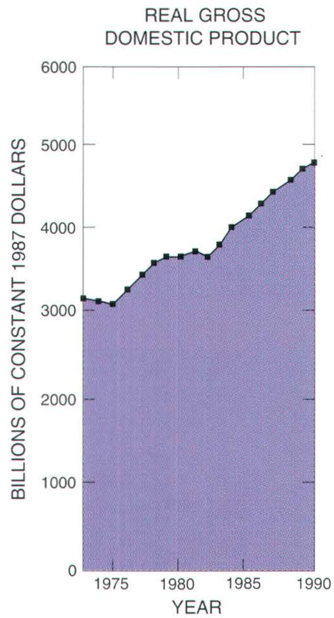
Even before field investigations begin, a geologist or an engineer with geologic experience commonly conducts a preliminary evaluation. In an urban area, the maximum economically feasible shipping distance from the market area commonly defines a crude target area. In areas where aggregate is in short supply, the target area obviously must be much larger. Geologic and topographic maps and geologic and engineering reports aid in targeting promising areas or, conversely, aid in ruling out areas for further study. State geological surveys and highway departments and the U.S. Geological Survey can provide much of this information.

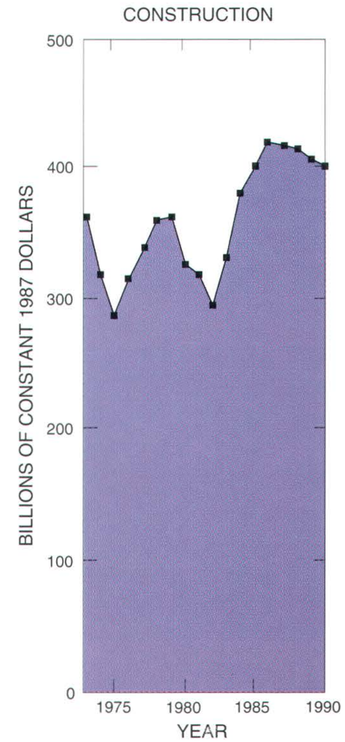
Preliminary investigations may be followed by detailed studies involving aerial photography, geophysical studies, and field reconnaissance studies (as shown in the photographs at right) of the target areas to more accurately define the limits of the potential sources of aggregate. These field studies focus on natural exposures such as stream cuts, cliffs, and other natural outcrops, and on artificial exposures such as highway and railroad cuts and abandoned or active pits and quarries. These studies commonly are augmented by the use of hand-sampling techniques and portable power-auger or coring equipment. Also important are rough estimates of the areal extent and volumes of the deposits, as well as specific physical or chemical properties of the materials. Laboratory analyses provide additional information about the physical and chemical properties of specific samples. Field observations should include information related to mineralogy and texture of the materials, thickness of overburden, water availability, and road access to the area.

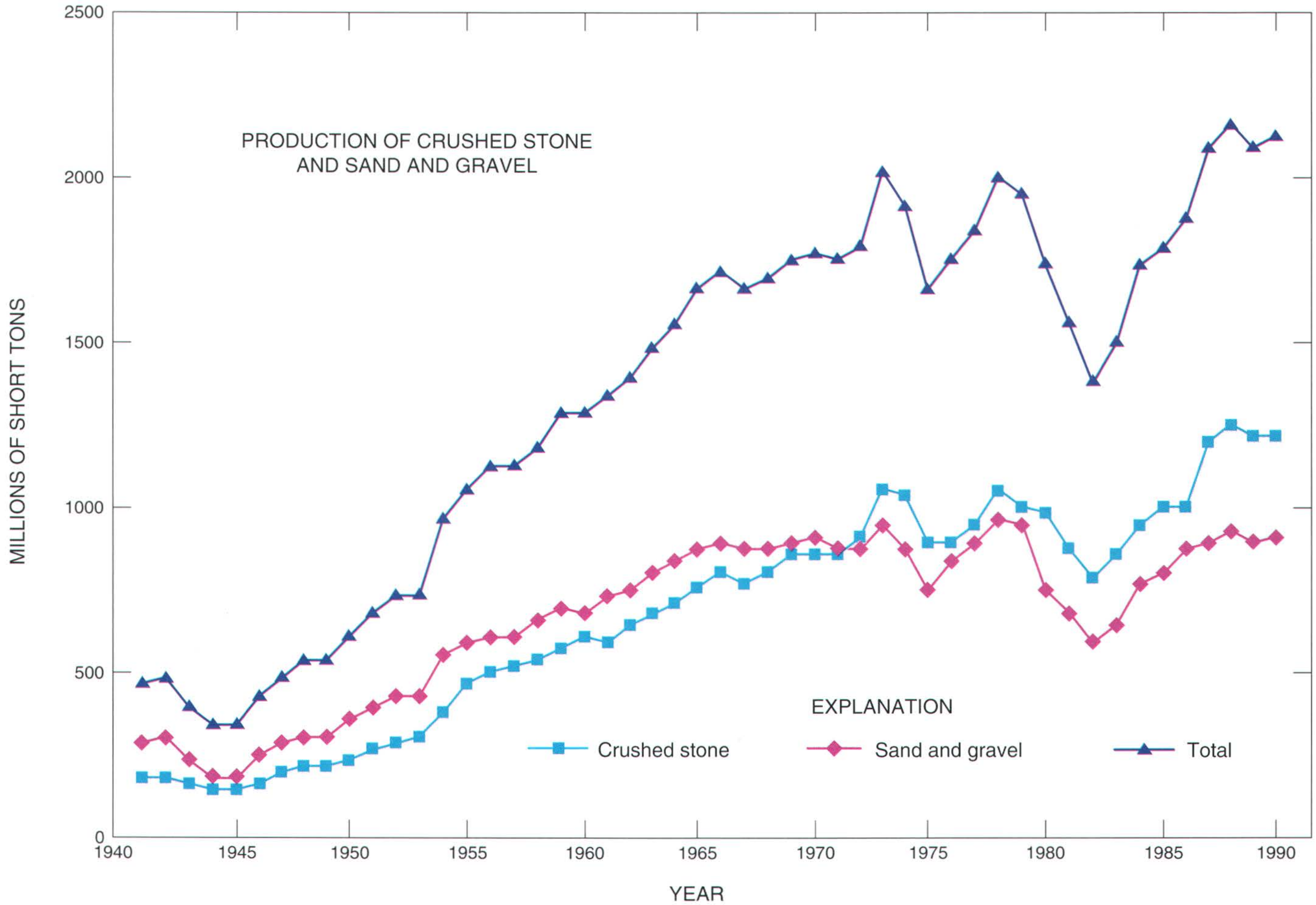
Detailed exploration of an identified source of aggregate may vary depending on the nature of and intended uses of the aggregate. Bulldozers, loaders, or backhoes are used to collect bulk samples; bulk sampling of bedrock may require drilling or blasting. Truck-mounted power augers or drill rigs can be used to collect deeper underground samples. In addition, seismic refraction may be used to determine the thickness of overburden and thickness of desired material, and electrical resistivity may be used to determine gross textural changes within the deposit, such as changes from gravel to sand or shale to sandstone.

ESTIMATING DEMAND

The U.S. Bureau of Mines and State and local agencies monitor the production of natural aggregate. One purpose of this monitoring is to provide data that can be used to project future needs. The production of aggregate, by itself, is relatively meaningless as a predictive tool. To improve forecasting techniques, a contingency analysis of the factors that could cause the demand to deviate from its current trend commonly is performed. Because crushed stone and sand and gravel are used mostly in the construction industry, reasonable estimates of the future demand for natural aggregate are based on predictions of future construction, such as the number of residential and nonresidential buildings, highway award contracts, and public construction products. Other factors commonly used to predict future aggregate production include population, employment, personal income, mortgage rates, and State or National gross domestic product. These factors can be compared, singly or in combination, to past and present aggregate production to determine if correlations exist. The objective is to find a socioeconomic factor that is predictable, and then to use it as a surrogate for predicting future aggregate production.







THE AGGREGATE INDUSTRY

Aggregate is produced from open pits in four major steps: site preparation, mining, processing, and reclamation. Site preparation consists of (1) clearing trees and vegetation; (2) stripping, transporting, and storing topsoil and overburden; (3) constructing fences, berms, buffer zones, roadways, and sediment traps; and (4) constructing or installing permanent or portable processing equipment.

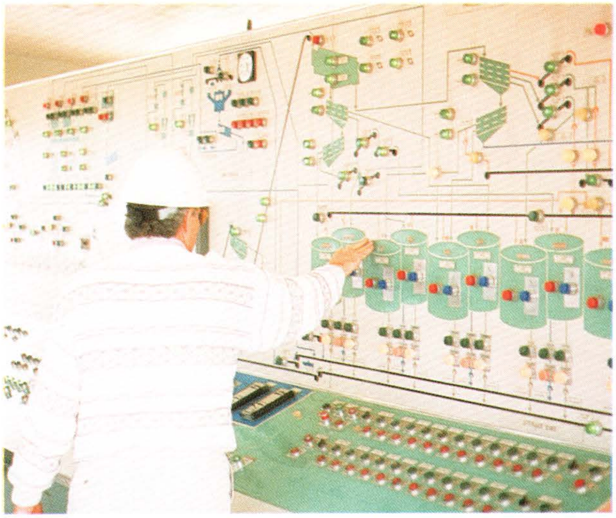
MINING AND PROCESSING

Mining of crushed stone or sand and gravel is dependent on the geologic characteristics and the areal extent and thickness of the deposit. Open-pit mining and quarrying commonly are used, although some stone is mined underground (as shown in the photograph on the following page). Sand and gravel deposits above the water table may be excavated with conventional earth-moving equipment such as bulldozers, front-end loaders, tractor scrapers, and draglines. Deposits below the water table, including stream and lakebed deposits, may be

The most acceptable method for the community and the producer is to plan mining and reclamation before the aggregate is extracted.

excavated with draglines or from barges using hydraulic or ladder dredges. Mining and quarrying stone generally requires drilling and blasting, after which the rock is extracted with power shovels, bulldozers, and draglines. The broken rock or the sand and gravel is then transported to a processing facility on trucks or conveyors.

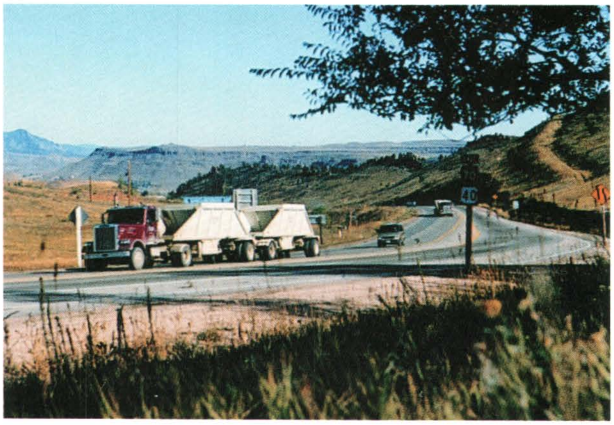
Processing plants are generally constructed on the site of extraction, but for some short-term projects the operator may utilize portable processing equipment. Processing of mined or quarried rock requires primary and possibly secondary crushing, depending on the sizes of aggregate needed. After crushing, crushed stone and sand and gravel usually are sorted to size. Silt and clay are removed by washing. At this stage, the coarser aggregate commonly is moved by conveyors (as shown at lower left) to bins or is stockpiled by size. Finally, aggregate is blended to the proportions of each particle size specified by the user (as shown at lower right). In some areas where the demand for aggregate is significant but production is impractical or uneconomical, producers set up distribution yards. Aggregate is moved to these yards by bulk transportation methods and subsequently is blended for final use and distribution.



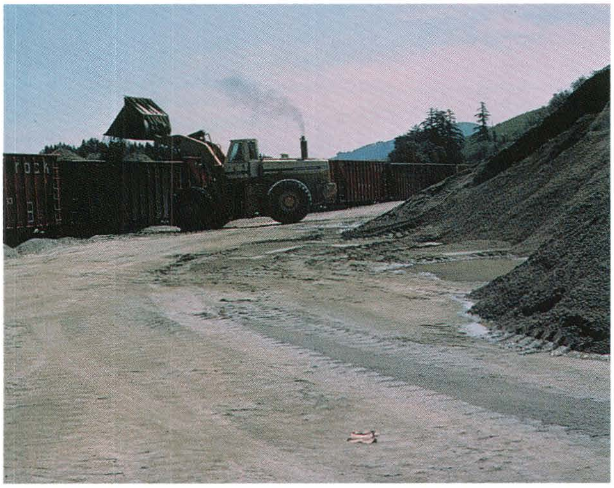
TRANSPORTATION

The three principal types of transportation are road, rail, or water. Aggregate is either used at the site of extraction (such as in cement concrete or bituminous mixes) or is transported to the point of use. The preferred mode of transportation depends on a variety of factors, including delivery-schedule requirements, the distance to be hauled, the volume of material, loading and unloading facilities, and the availability of transportation methods.

Transport by truck is by far the most common method. Trucks can quickly and simply be loaded at points of origin and can dump or drop their loads unassisted at the destination. They are not restricted to railways or waterways and can deliver practically anywhere there is a road. Trucks from small pickups to rigs that carry 28 tons can be matched to requirements and thus can make deliveries without great economic consequences.



If pits or quarries have access to railroads, rail delivery may be more economical than truck delivery. The choice depends on two principal variables—the tonnage of aggregate to be moved and the distance it must be hauled. Other factors to be considered are loading and unloading facilities and schedule requirements. If the aggregate shipped annually exceeds 20,000 short tons, or if the aggregate is to be hauled more than 45 miles, rail shipping may be more economical than truck transport. With greater tonnages and distances, the advantages of rail shipment are even greater. Aggregate can be loaded on either 100-ton bottom-dump hopper cars or gondolas and moved in single cars (the most expensive way to ship by rail), or can be joined and moved as multiple cars, by trainloads, or by unit trains (the least expensive way).



The midcontinent of the United States has many navigable rivers that have been modified to permit movement of freight by water. Moving aggregate by hopper or flat deck barges may be economical. Because the movement of aggregate by water is not regulated by government agencies, the rates are established by agreements between the user and the barge line. As with rail transport, economic advantages of shipping by barge increase as the tonnages and

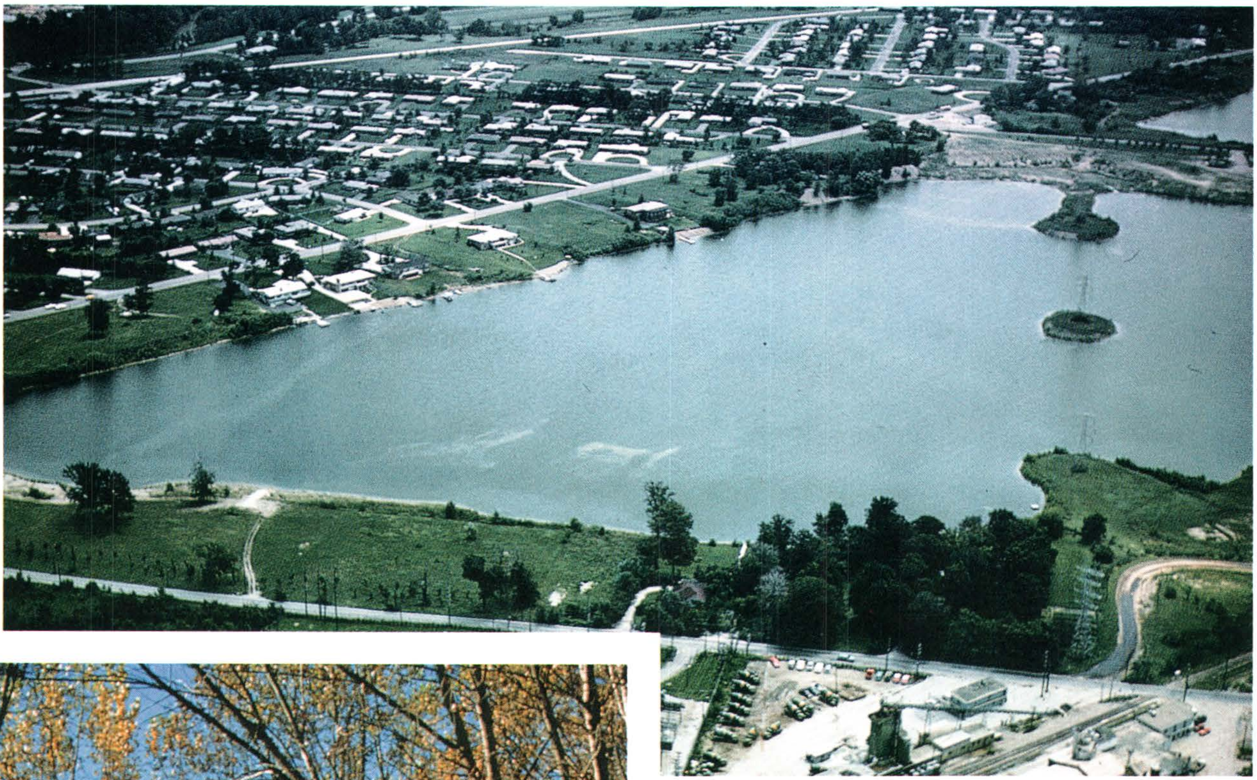
distances of transport increase. Hopper barges commonly hold 1,500 tons of aggregate and can be grouped into tows of 30 to 40 barges, depending on the width and depth of the river to be traveled and the size and horsepower of the tow boat.

Lake or ocean freighters only recently have become an efficient means to transport aggregate. Along the Atlantic and Gulf Coasts of the United States, where local supplies of good quality aggregate are in short supply, aggregates are imported from Mexico, Scotland, Canada, and other foreign countries. Transportation by ship is possible in part because of back-haul pricing. A commodity other than aggregate moves one way, and pays most of the cost of round-trip shipping. After unloading the initial commodity, the ship is loaded with aggregate for the return voyage. Transporting the aggregate on the return voyage at a low price prevents the vessel from returning to the point of origin with an empty hold.

RECLAMATION

Reclamation of a mined-out area is highly important to communities near aggregate operations because residents do not want a scarred landscape near their property. The most acceptable method for the community, and commonly the most economical for the producer, is to plan reclamation before the aggregate is extracted. Aggregate can be mined with the final land-surface contours in mind, equipment can be used for both mining and reclamation, and mined-out areas can be reclaimed concurrent with extraction in other parts of the operation.

The primary goal of reclamation is to return the land to a beneficial use. Residential developments are a popular use for reclaimed sites. The natural setting provided by rock outcrops and water fulfill a demand for scenic, lake-front property. Reclaimed pits or quarries have also been converted to industrial and commercial properties or to office parks, golf courses, parks and recreation areas, storm-water management, farmland, and landfills.



Reclamation procedures depend on the configuration and character of the mined-out area. Progressive reclamation typically involves the following steps: (1) terracing the pit or face walls during or after extraction, (2) final shaping of the worked out area by replacing and recontouring the overburden, and (3) landscaping. Reclamation plans are most effective if operators and planners select a strategy that satisfies the land use needs of the community and at the same time provides an economic incentive for the operator.

PLANNING AND REGULATION

DEVELOPMENT

Although nature dictates the location of natural aggregates, other factors influence the development of the resource. Prime aggregate sources are lost if parking lots, houses, or other buildings are constructed over the resources. Aggregate operations that were initially established in rural areas commonly are terminated when residential land use encroaches on the operations. Valuable lessons can be learned from areas in which development has engulfed aggregate sources that originally were distant from communities.

Citizens frequently consider aggregate operations to be a nuisance, and they wish to be protected from aggregate development near their communities. Aggregate development may create temporary environmental impacts such as increased airborne particulates, increased sediment yield to streams, and increased noise levels. Permanent impacts may result from major changes to the landscape. Increased truck traffic is both an environmental concern (dust and noise) and a safety concern (traffic congestion and hazards). For these and other reasons, many levels of government may impose regulations that must be accommodated before development can begin.

Cooperative planning by developers, government, and citizens is the key to successful protection and utilization of aggregate resources.

However, a continuing and uninterrupted supply of aggregate is an indisputable need. In meeting that need, aggregate operators must address other factors in addition to the societal and regulatory factors. For economic reasons, aggregate operations must be within reasonable distances of the market area. Zoning that permits extraction of the aggregate is necessary. Other land uses that preclude extraction of aggregate must be evaluated, and in some cases revision of zoning may be necessary.

When natural aggregates are mined, they probably will not be used exclusively in the community that produces them. The benefits of development are likely to be dispersed throughout a market area of many hundreds of square miles, but most, if not all, of the problems associated with extraction will be concentrated within a few miles of the aggregate operation. The local community may enjoy few of the benefits while enduring most, if not all, of the undesirable side effects. On the other side of the issue, however, if extraction is denied in favor of local interests, the consumers within the market area may be denied the resource at a reasonable cost, and the region may sustain greater, more widely dispersed environmental and economic costs. For example, the denial of a local operation on the basis of truck traffic may actually increase truck traffic because of longer haul routes from distant aggregate sources. Furthermore, increased traffic consumes more energy, increases emissions, increases wear-and-tear on equipment and highways, and increases exposure to the risk of traffic accidents.

Planning for and developing adequate supplies of aggregate thus is a complicated process, balancing the needs of a region for aggregate resources with the needs of the local community, and requires enlightened planning, resource protection, and regulation. Basic data related to aggregate resources provide a basis for decisions related to the locations, volume, and quality of potential aggregate in the planning area, and possibly an estimate of future needs. Plans then can contain provisions that balance the regional needs for aggregate with the protection of the environment and the right of the public to minimize operational nuisances.

RESOURCE PROTECTION

One step to ensure a continuing and uninterrupted supply of aggregate is to identify and protect existing aggregate resources. This is particularly important not only where supply is limited but also in high-demand areas, even where sources of aggregate are abundant. Some short-term and long-term techniques can be used to preserve aggregates.

All sites of potential aggregates cannot be protected. Protection of several separate sites 10 miles or so apart, instead of one very large site, minimizes future hauling costs, stimulates competition among industry operators, and hedges against the possibility of successful local resistance to development of any specific site.

Aggregate resources commonly are protected by zoning regulations. Potential areas of aggregate development are included in existing use districts that are compatible with mining, such as agricultural, industrial, or open space. However, zoning commonly permits a variety of land uses and can be changed at any time in the future. Other permitted uses that exclude aggregate development can be implemented in a specific zone and can exclude an area from further consideration for mining. Therefore, zoning tends to be effective only for sites that are likely to be developed in the near future.

Longer term techniques to protect aggregate resources involve actions that clearly identify the land for aggregate extraction.

- Operators can purchase or lease the land and a surrounding buffer area.
- Local governments can directly reimburse land owners or offer tax incentives in return for an agreement to delay development for other purposes until after aggregate is removed.
- Local governments can buy resources for later resale to operators, a plan called "land banking."
- Local governments can regulate land use by designating "resource conservation areas" or "extractive-use districts" whereby only aggregate extraction is permitted and all other uses are controlled through conditional use or special exception.
- When aggregate sources to be protected are identified, they are placed in an overlay zone. The land is then subject to both the original zoning requirements and regulations that protect the extractive overlay zone.

Planning can include efforts to make aggregate extraction more beneficial to the local residents. A sequential-use process can dedicate mined-out land to the community after extraction and reclamation have been completed. Extraction can be made more beneficial to the local area if a severance tax is returned to the local area or if development of recreational or other public facilities follow extraction. Other means are available to protect local communities from nuisance of extraction. Development rights can be transferred to permit higher density development in residential areas away from aggregate extraction in exchange for forgoing residential development near extraction sites. In essence, this expands the buffer zone with no net loss in residential development.

Extraction precluded by development

Site of previous extraction

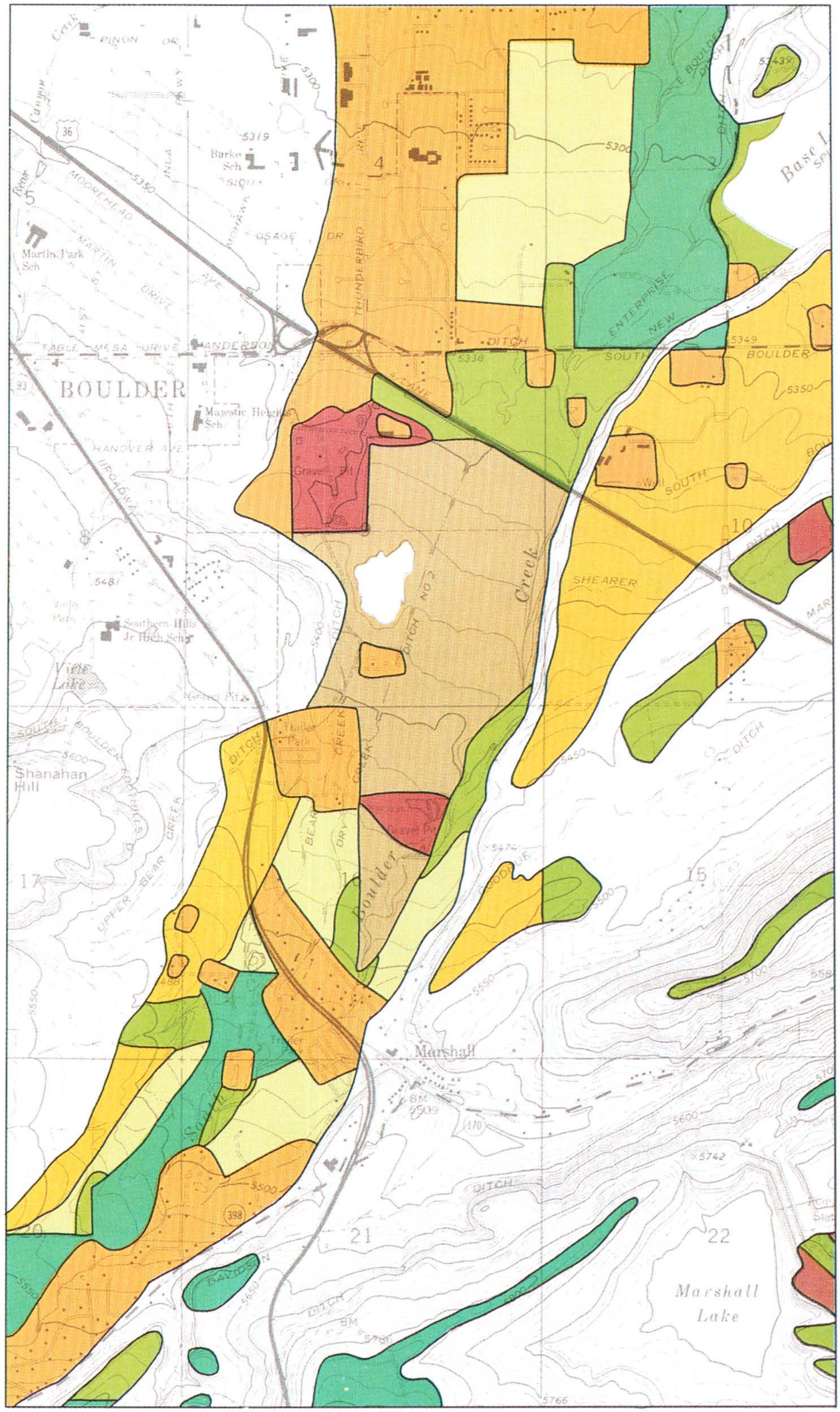
Current extraction permit

Owned open space

Designated open space

Potentially first-class sand and gravel deposit

Potentially extractable lower class sand and gravel deposit



From J. A. Pendleton, city geologist, Boulder, Colorado (mapping scale 1:12,000)

Sand and gravel planning map for part of the Boulder, Colorado, urban area

LIVING WITH AGGREGATE OPERATIONS

To design guidelines or regulations for crushed stone or sand and gravel operations, it is necessary to predict what effects such operations may have on the surrounding communities and environment. Regulations should set minimum operational standards to control impacts such as noise, traffic, dust, pollution of streams and water supplies, and erosion. The task for planners is to balance the needs of the operators with the public's right to minimum nuisance resulting from the extraction. Aggregate operators generally wish to be good neighbors and are willing to cooperate if cooperative efforts lead to a more smoothly operating facility. In fact, many innovative actions taken to decrease environmental impacts have been conceived and voluntarily implemented by aggregate operators.

Planning efforts such as those described above help to limit public exposure to the impacts of aggregate mining and processing. Buffer zones, in particular, help mitigate impacts. Regulations or permits should set minimum standards for buffer-zone widths. Buffer zones shield adjacent residents and land owners from mining operations and at the same time protect mining operations from intrusion or adjacent land-use conflicts. Berms, fences, screens, dense tree plantings, or other barriers contribute to public safety and provide aesthetic controls that help to screen objectionable views. Newly exposed rock faces can be treated to match adjoining naturally weathered surfaces.

Excavation of sand and gravel below the water table can affect aquifers. Regulations may prohibit penetration of the aquifer or may allow penetration of the aquifer only if operations will not adversely affect water supplies. If such excavations are to be refilled, the filling should meet water-pollution-control standards.

The impact of noise depends on adjacent land use; noise can be mitigated through the use of buffer zones, berms, and muffling

equipment. Noise-generating equipment (such as the primary crusher shown in the photograph to the right) can be placed near the middle of the site, in pits below grade, in sound-insulated buildings, or away from residential areas. Haul roads can be kept away from property lines, and the use of conveyor belts can minimize traffic within the site.

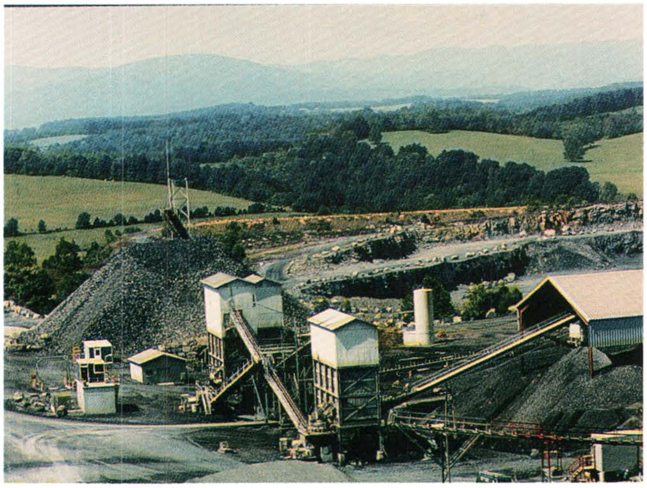
Truck traffic is one of the most serious problems associated with aggregate development. Some traffic can be mitigated at the site. Operators can be required to provide acceleration and deceleration strips on both sides of all entrances and exits to the operations. Paving and limiting the number

of entrances and exits and wheel washing procedures can minimize the amount of dirt deposited by trucks on adjacent highways. The most serious problems associated with truck traffic—noise and safety problems—are on public rights-of-way. Conveyors constructed to carry aggregate under highways, reduced speed limits, restriction of routes for truck traffic, and restriction of hours of operation all can help minimize traffic problems.

Dust can be reduced by minimizing the amount of area mined at any time, by planting vegetation or constructing other wind breaks, by using wet or chemical dust suppression systems, and by enclosing dust-generating equipment in vacuum-equipped buildings (such as those shown in the photograph below). Erosion can be controlled through techniques such as settling ponds and revegetation.

Reclamation plans can require the land to be left as originally contoured, or they can provide for acceptable final uses of the land. Performance bonds can be required to ensure that reclamation takes place according to plan. Contemporaneous mining and reclamation can reduce the impact of mining, accelerate revegetation, and allow incremental bond release to the operator.

Cooperative planning by developers, government, and citizens is the key to successful protection and utilization of aggregate resources.



SUMMARY

Present annual aggregate use in the United States is about 9 short tons for every person. This tonnage will increase as the aging infrastructure requires repair or replacement. Coupled with the demand for the resource, there also is an increasing demand for increased economy in large construction projects and for decreased cost in housing development.

Provisions for uninterrupted future supplies of aggregate should be made. Even though potential aggregate sources are widely distributed throughout the United States, some areas lack quality aggregate, or potential aggregate may be covered by overburden so thick that surface mining is impractical. Economic factors require that pits and quarries be near population centers. However, citizens and regulatory agencies in residential communities commonly desire that mining operations be conducted far from their boundaries. Furthermore, citizens commonly do not support mining because they do not recognize the community dependence on natural aggregate. They purchase little, if any, aggregate and do not recognize that aggregate mining is a necessary land use.

Proper long-range planning can help assure adequate supplies of aggregate, while simultaneously protecting the public from the unwanted effects of mining. Long-range plans should incorporate a multiple land-use program that includes identification and protection of natural resources, strategies that will permit development of resources in relation to future market needs and environmental considerations, and a beneficial use of mined-out areas.

Geologic maps and surveys provide useful information about potential aggregate sources. Judicious use of these sources is critical in areas where reserves are small or where urban pressures preempt their use. By using geologic information to identify resources near the sites of use, operators can provide the most economical resource for the consumer. Advance planning of haulage routes and conveyor distribution can minimize undesired impacts of transportation of aggregate, and application of advanced technology can alleviate many other inconveniences of aggregate mining.

A projected mine plan can diagram stages of an operation over a period of time. Adequately planned reclamation can be accomplished concurrent with mining. Predetermined uses for the reclaimed land can be mandated so that the final use will be beneficial to the community. As land is backfilled and recontoured, it can be converted to office parks, public parks, or wildlife habitats for the benefit of people living in the area. If land for housing is scarce or expensive, reclamation can provide additional home sites, some with lakefront access.

Mining operators, public officials, consumers, and community residents no longer can remain independent of one another. All groups and individuals must work together to ensure adequate community and environmental protection from the nuisances of mining, while at the same time ensuring low-cost construction and maintenance of the infrastructure.

As we progress into the 21st century, the view of aggregate production must be changed from one of a scarred landscape to one of protection of a valuable resource. Although natural processes move gravel from one section of a river to another, new detrital material is added at an imperceptible rate. Bedrock being formed by geologic processes today will not be available for use as aggregate for thousands of years. Aggregate mining must be seen as an interim use of the land, not the final use.

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