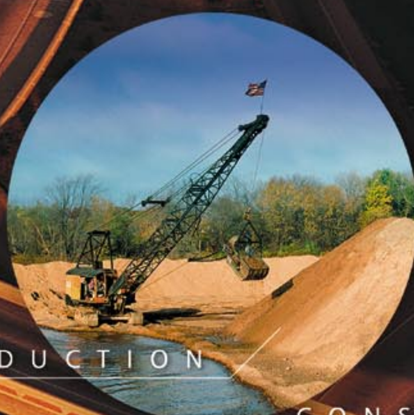
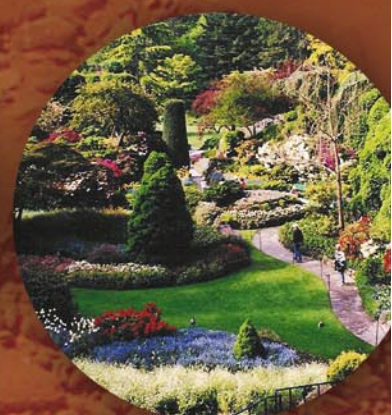
AGGREGATE and the Environment



PRODUCTION

CONSTRUCTION



RECLAMATION

AGI Environmental Awareness Series

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

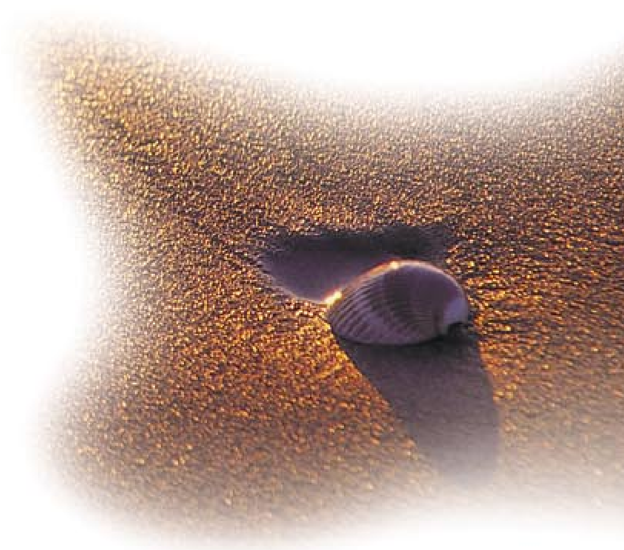
AGI gratefully acknowledges the **AGI Foundation** and the **U.S. Geological Survey** for their support of this book and of the Environmental Awareness Series. For more information about this Series please see the inside back cover.

AGGREGATE and the Environment

William H. Langer

Lawrence J. Drew

Janet S. Sachs



*With a Foreword by
Travis L. Hudson and
Philip E. LaMoreaux*

American Geological Institute
in cooperation with
U.S. Geological Survey

C O N T E N T S

About the Authors

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Lawrence J. Drew has nearly 40 years of experience working on mineral and petroleum assessment and environmental problems in private industry and with the federal government. Since joining the U.S. Geological Survey in 1972, he has worked on the development of assessment techniques for undiscovered mineral and petroleum resources. He is the author of many publications including a column for *Nonrenewable Resources* in which he explored ideas about the environment and the extraction and use of natural resources. Recently, he has written on the environmental concerns inherent with the production of natural aggregate.

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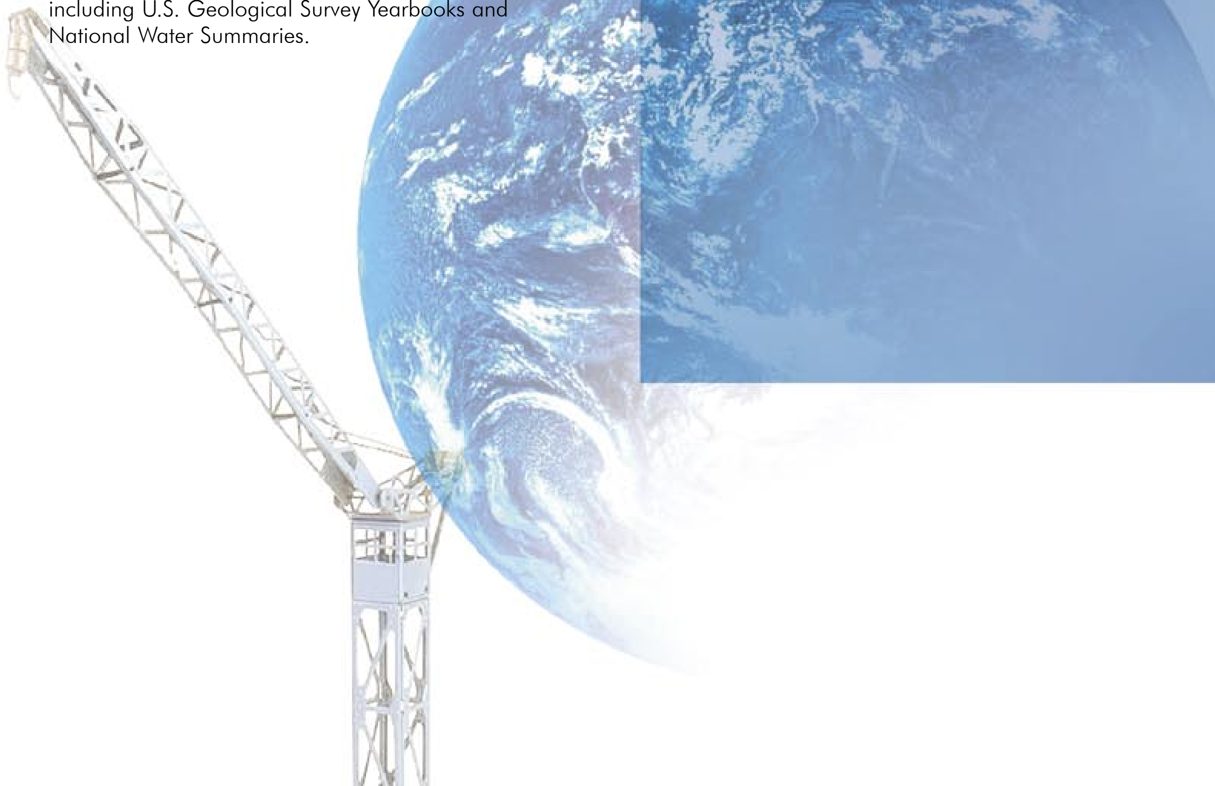

2

Producing and Transporting Aggregate

3

Protecting the Environment

4

Providing for the Future

The **American Geological Institute** (AGI) is a nonprofit federation of 43 scientific and professional associations that represent more than 120,000 geologists, geophysicists, and other earth scientists. Founded in 1948, AGI provides information services to geoscientists, serves as a voice of shared interests in our profession, plays a major role in strengthening geoscience education, and strives to increase public awareness of the vital role the geosciences play in mankind's use of resources and interaction with the environment. The Institute also provides a public-outreach web site, **www.earthscienceworld.org**.

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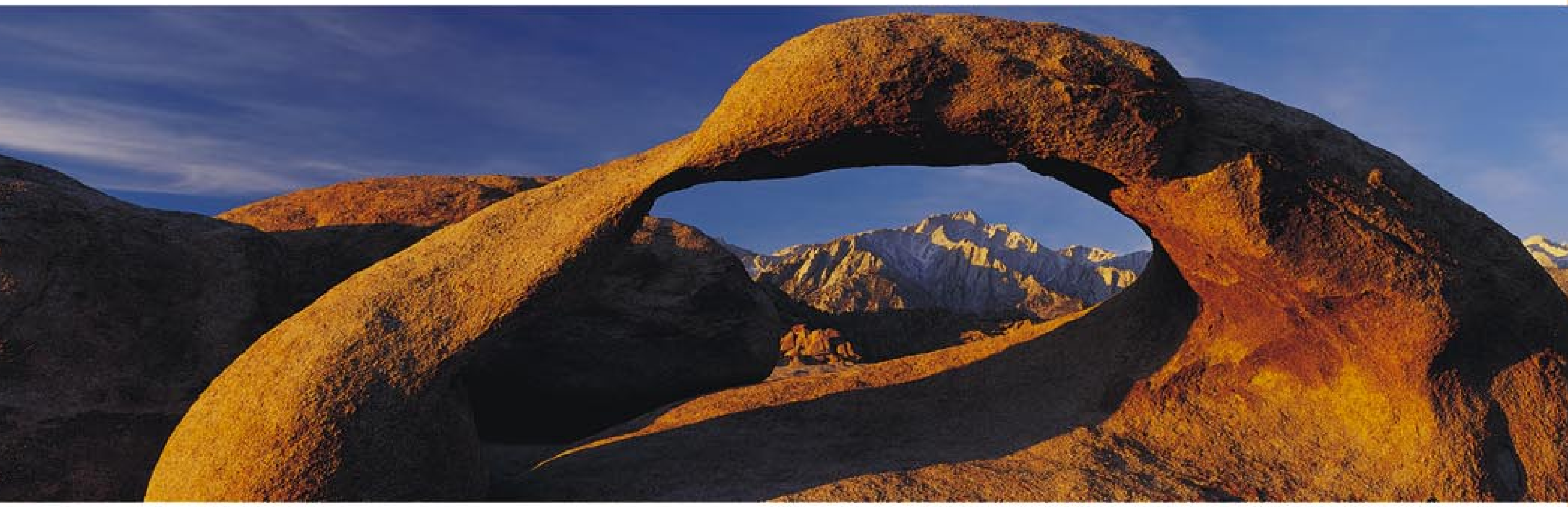


FOREWORD

Sand, gravel, and crushed stone — the main types of natural aggregate — are essential resources for use in construction. Today, aggregate production accounts for about half of the non-fuel-mining volume in the United States. 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 enormous quantities of aggregate to be mined.

An area's geology, land ownership, land use, and transportation infrastructure are factors that affect aggregate supply. Although potential sources of sand, gravel, and crushed stone are widespread and large, land-use choices, economic considerations, and environmental concerns may limit their availability.

Making aggregate resources available for our country's increasing needs will be an ongoing challenge. Understanding how sand, gravel, and crushed stone are produced and how the related environmental impacts are prevented or mitigated can help citizens, communities, and our nation meet this challenge.

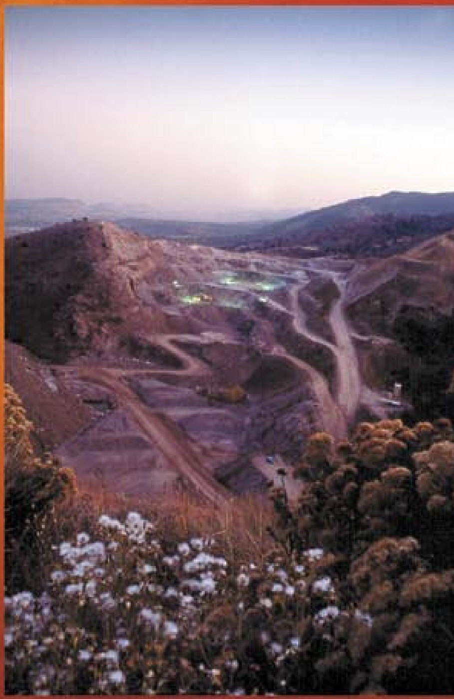
This Environmental Awareness Series publication has been prepared to give the general public, educators, and policy makers a better understanding of environmental concerns related to aggregate resources and supplies. The American Geological Institute produces this Series in cooperation with its 43 Member Societies and others to provide a non-technical geoscience framework considering environmental questions. *Aggregate and the Environment* was prepared under the sponsorship of the AGI Environmental Geoscience Advisory Committee with support from the U.S. Geological Survey and the AGI Foundation. Other titles in the AGI Environmental Awareness Series are listed on the inside back cover, and they are available from the American Geological Institute.

Travis L. Hudson, *AGI Director of Environmental Affairs*
Philip E. LaMoreaux, *Chair, AGI Environmental Geoscience Advisory Committee*

PREFACE

Many of us tend to take natural resources for granted, especially aggregate – sand, gravel, and crushed stone. On one hand, aggregate resources are vital to our way of life because they are the major raw materials used in construction of roads, rail lines, bridges, hospitals, schools, airports, factories, and homes. On the other hand, the mining and processing of natural resources such as aggregate commonly raises concerns about potential environmental impacts. Nevertheless, we must have access to a readily available supply of high quality aggregate if we wish to maintain our current lifestyle. Given the right information and access to suitable resources in appropriate geologic settings, aggregate producers can meet the nation's demand for aggregate without causing undue harm to the environment. We do not need to choose between aggregate development and the environment. The question is how to achieve a balance among the economic, social, and environmental aspects of aggregate resource development.

This book is designed to help you understand our aggregate resources — their importance, where they come from, how they are processed for our use, the environmental concerns related to their mining and processing, how those concerns are addressed, and the policies and regulations designed to safeguard workers, neighbors, and the environment from the negative impacts of aggregate mining. We hope this understanding will help prepare you to be involved in decisions that need to be made — individually and as a society — to be good stewards of our aggregate resources and our living planet.



We are grateful to the many individuals and organizations who provided illustrations and other forms of support for the project, and for the technical reviews provided by many colleagues in industry, academia, and state and federal agencies. Those colleagues included John Hayden, Travis Hudson, John Keith, Phil LaMoreaux, Marcus Milling, Steve Testa, and Jan van Sant. The authors thank the following individuals for their technical input to this document: Belinda Arbogast, Nicole Cline, Wallace Bolen, Daniel Knepper, David Lindsey, Michael Sheahan, Valentin Tepordei, and Bradley VanGosen. Our special thanks go to Julia A. Jackson, GeoWorks, for her editorial assistance, and to Julie DeAtley, DeAtley Design, for her superb graphic design. This document truly would not have come together without their hard work. Finally, we would like to acknowledge the American Geological Institute for the opportunity to produce this publication, and the U.S. Geological Survey for its support.

William H. Langer
Lawrence J. Drew
Janet S. Sachs
July, 2004


TAMPA, FLORIDA
Aggregate is the foundation of our nation.

IT HELPS TO KNOW

1

US COMMODITY VALUES

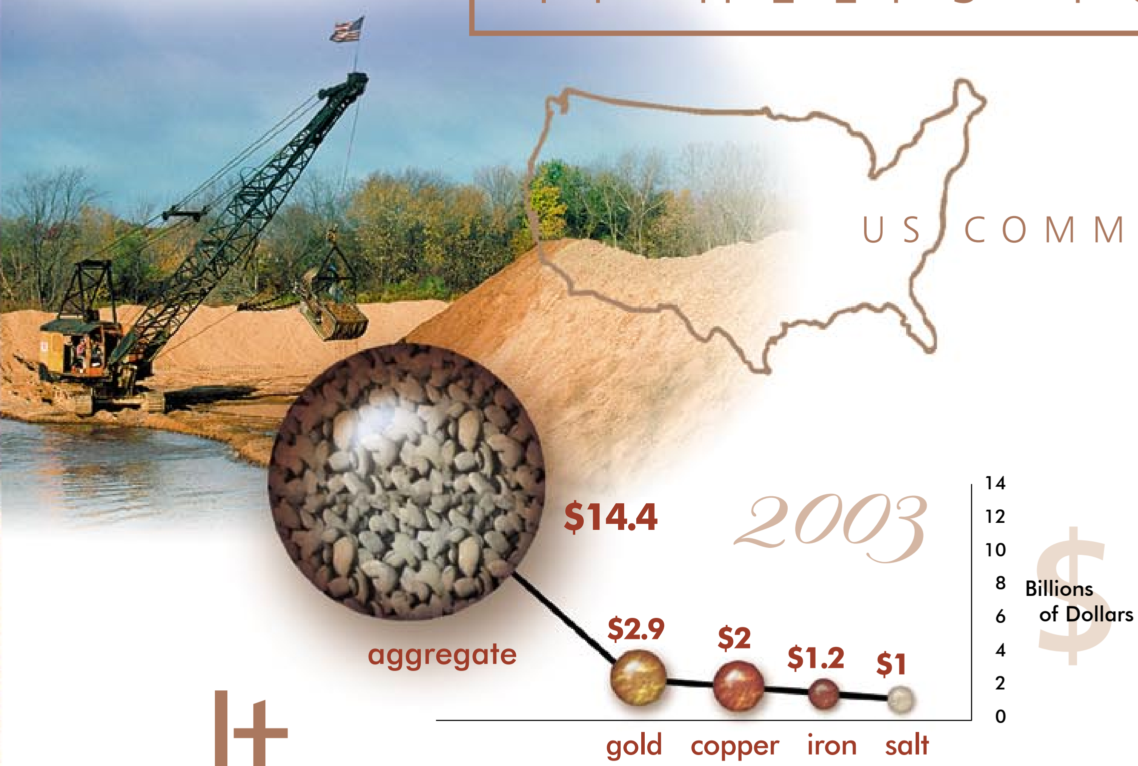


Fig. 1. At $14.4 billion, the value of aggregate dwarfs other nonfuel commodities. Commodities valued at less than $1 billion, such as zinc, lead, silver, and peat, are not shown.

It is impossible to construct a city without using natural aggregate — sand, gravel, and crushed stone. The amount of these essential construction materials we use each year is likely to surprise you. Annual production of aggregate worldwide totals about 16.5 billion tons (15 billion metric tons). This staggering volume valued at more than $70 billion makes aggregate production one of the most important mining industries in the world (Fig. 1). What becomes of these earth materials? Aggregate is used to build and maintain urban, suburban, and rural infrastructures including commercial and residential buildings; highways, bridges, sidewalks, and parking lots; factories and power generation facilities; water storage, filtration, and delivery systems; and wastewater collection and treatment systems. Developed countries cannot sustain their high level of productivity, and the economies of developing nations cannot be expanded, without the extensive use of aggregate.

Aggregate consists of grains or fragments of rock (Fig. 2). These materials are mined or quarried, and they are used either in their natural state or after crushing, washing,

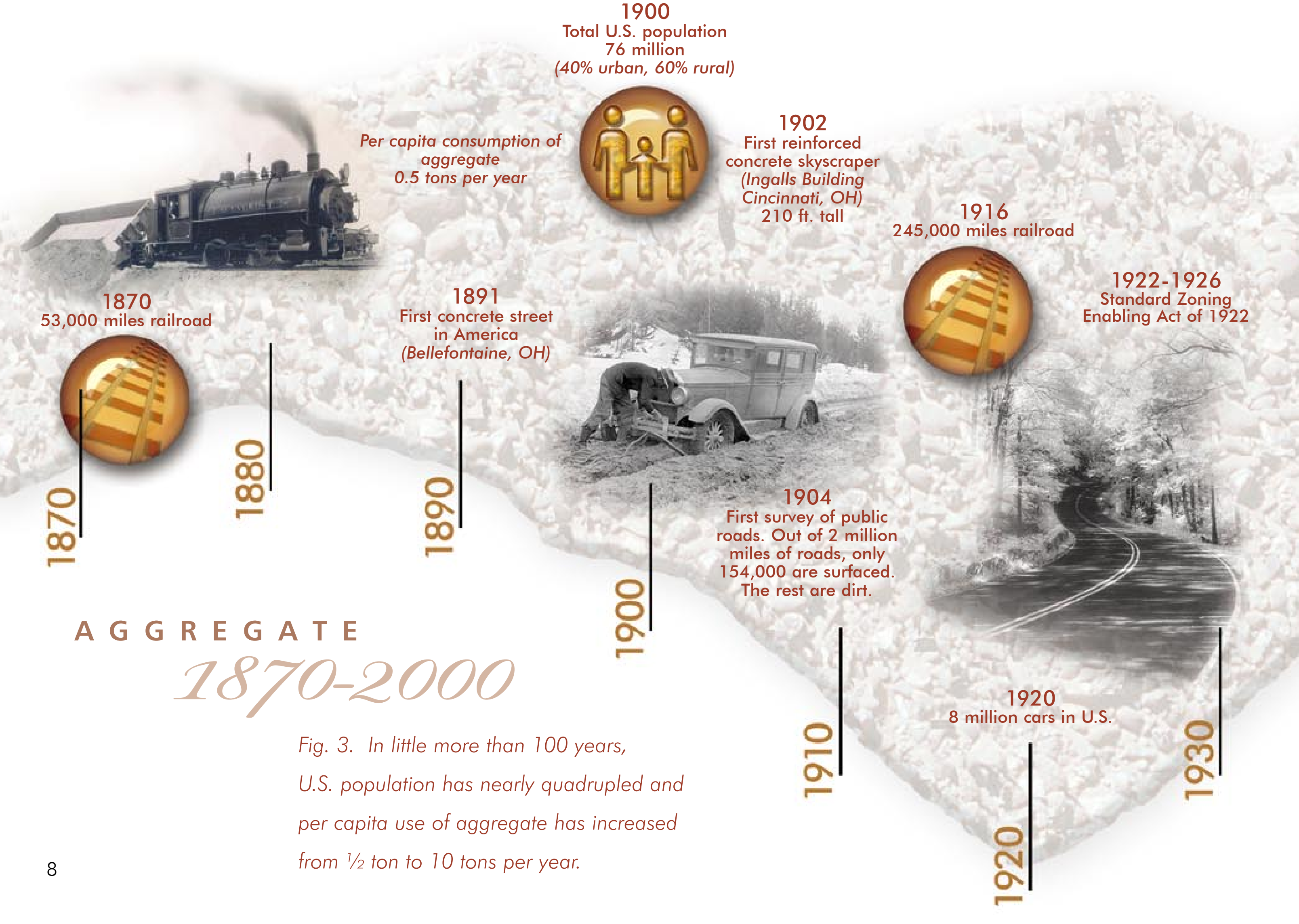
AGGREGATE

Fig. 2. Sand and gravel are rock fragments shaped and rounded by erosion. Machines make crushed stone by breaking rock into small angular pieces.

and sizing. Sand, gravel, and crushed stone are commonly combined with binding media to form concrete, mortar, and asphalt. They also provide the base that underlies paved roads, railroad ballast, surfaces on unpaved roads, and filtering material in water treatment.

Unlike metals, such as gold, that have a high "unit value" derived from their special properties and relatively low abundance, aggregate is a high-bulk, low unit value commodity. Aggregate derives much of its value from being located near the market and thus is said to have a high "place value." Transporting aggregate long distances can increase its price significantly and may render distant deposits uneconomical. Therefore, aggregate operations commonly are located near population centers and other market areas.

Even though natural aggregate is widely distributed throughout the world, it is not necessarily available for use. Some areas do not have sand and gravel, and potential sources of crushed stone may occur at depths that make extraction impractical. In other areas, natural aggregate does not meet the quality requirements for use, or it may react adversely when used in such applications as concrete or asphalt. Furthermore, an area may contain abundant aggregate suitable for the intended purpose, but conflicting land uses, zoning, regulations, or citizen opposition may preclude its development and production.



AGGREGATE

1870-2000

Fig. 3. In little more than 100 years, U.S. population has nearly quadrupled and per capita use of aggregate has increased from ½ ton to 10 tons per year.

All of these factors — high place value, the need to locate operations close to the market, the limited distribution of aggregate, and the limited access to aggregate — complicate the process of producing aggregate and increase the desirability of planning for future supplies.

Why Aggregate Is Important

The use of aggregate in the United States is tied closely to the history of road building. Until the early 1900s, railroads and canals were the primary means of transporting of goods, and roads were generally in poor condition (Fig. 3). As the nation's highway system grew throughout the 20th century, so did the demand for aggregate. Today, however, aggregates touch nearly every aspect of our lives, not just as highways (Fig. 4).

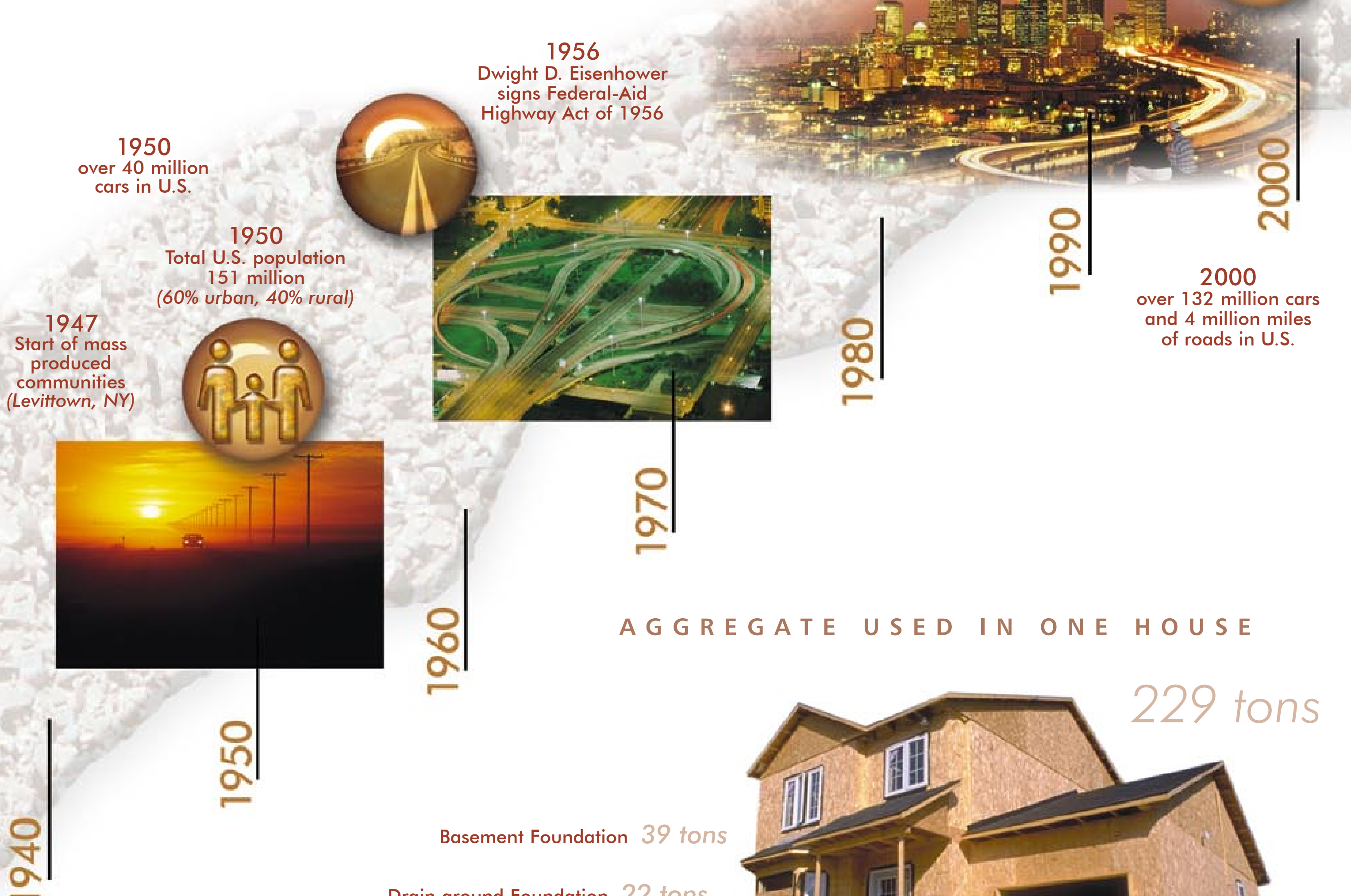


Fig. 4. It is estimated that 229 tons of aggregate is needed for a 1,000 square foot ranch house, (or a 2,000 square-foot two story house), with a full, unfinished basement.

Urban Uses

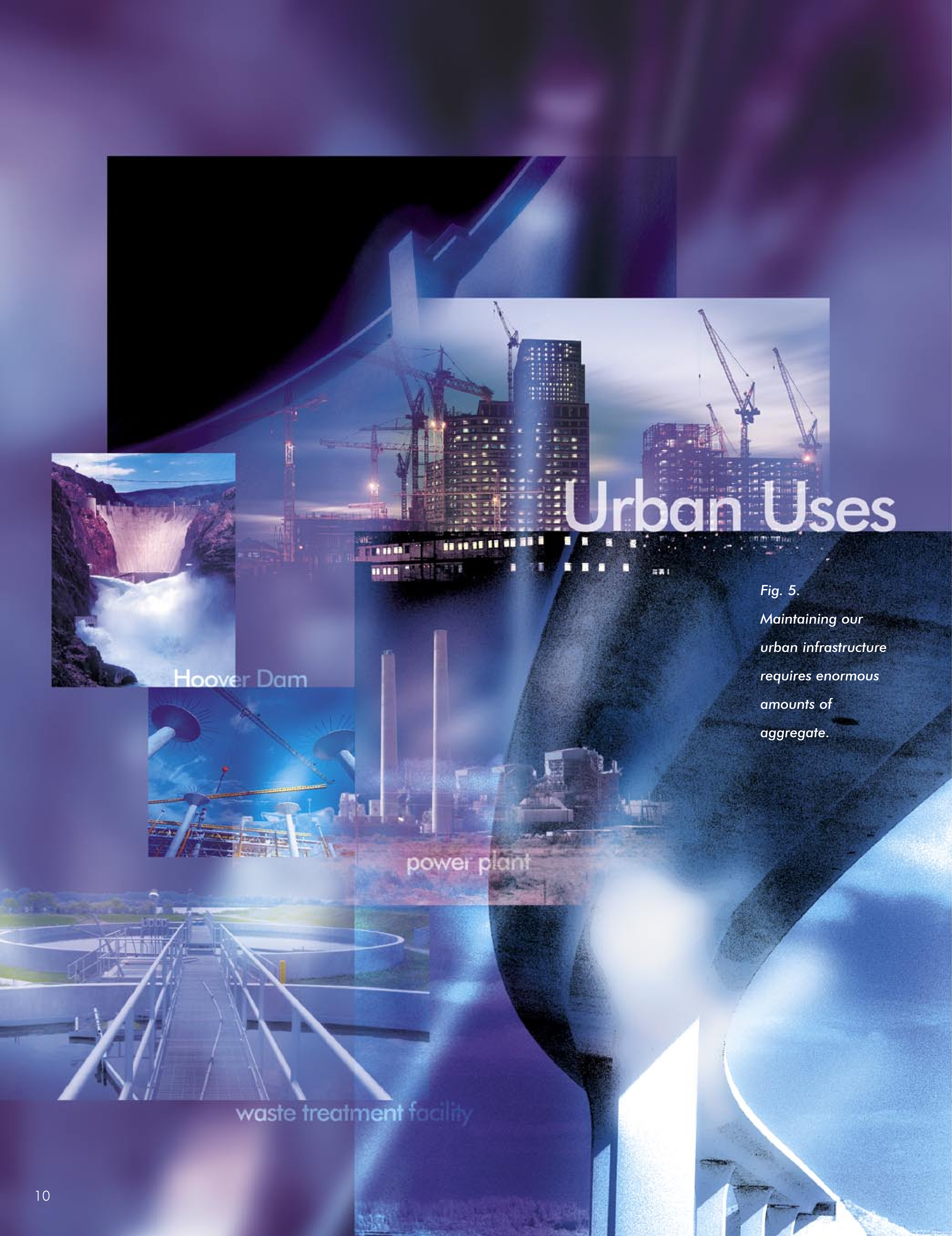


Fig. 5. Maintaining our urban infrastructure requires enormous amounts of aggregate.

We are born in hospitals constructed from natural aggregate. We live our lives dependent on an infrastructure created out of concrete and asphalt-bound natural aggregate (Fig. 5). And after we die, our remains are likely to be interred for eternity in a vault of concrete.

In general, employment in urban and suburban areas is defined by the workplace and transportation structures built with sand, gravel, and stone and tailored to our needs. Nearly all commercial activity is transacted in buildings and on highway, air, rail, and marine systems that require concrete and asphalt-bound structures comprised almost totally of aggregate. In volume, aggregate comprises about 85 percent of these structures; the binder (portland cement in concrete and bitumen in asphalt pavement) and the reinforcing skeletons made of structural steel comprise the remaining 15 percent.

Life in our urban and suburban worlds depends on supplies of water that are collected behind dams and transported through aqueducts and tunnels constructed or lined with aggregate in the form of concrete. The human waste generated in urban and suburban life requires a complex of transport and treatment facilities that are, in large part, built of concrete. Unbound natural aggregate is widely used in the waste-water filtration part of these systems. Hydroelectric power (10 percent of U.S. total electric power) is based on systems of dams, many of which are constructed from concrete. Coal-fired electric power plants are built of concrete and use unbound natural aggregate (crushed limestone) to scrub flue gases of pollutants. Aggregate makes it possible to construct and enhance all of the structures in our lives: our schools, offices, supermarkets and department stores; our homes, neighborhood streets, sidewalks, and curbs; our sports arenas, recreational centers, natural park facilities, and bike trails; and our places of worship.

Aggregate, or more properly crushed stone, also has numerous agriculture and industrial uses. Pulverized stone is used in fertilizers and insecticides to enhance the growth of plants (Fig. 6) and to process that food and fiber; in the manufacture of pharmaceuticals, from antacids to life-saving drugs; in the manufacture of sugar, glass, paper, plastics, floor coverings, rubber, leather, synthetic fabrics, glue, ink, crayons, shoe polish, cosmetics, chewing gum, and toothpaste, and the list goes on and on. Stone in one form or another is used in practically everything that we touch during the day.

Fig. 6. Minerals from crushed stone help ensure healthy crops.

Agricultural Uses

Our need for construction aggregate is increasing. Figure 7 shows the historical and estimated future use of construction aggregate in the Unites States until the year 2025. It is projected that in the United States we will use almost as much construction aggregate in the next 25 years as we used in the entire 20th century. Aggregate is needed to repair existing infrastructure, create new infrastructure for the nation's growing population, and to meet the demands of changing lifestyles for bigger and better houses and more, bigger, and better highways. Meeting these needs depends on the availability of large supplies of aggregate.

What the Environmental Concerns Are

Operations associated with aggregate extraction and processing are the principal causes of environmental concerns about sand, gravel, and crushed stone production, including

- Increased dust, noise, and vibrations;
- Increased truck traffic near aggregate operations;
- Visually and physically disturbed landscapes and habitats; or
- Affected surface or groundwater.

The geologic, hydrologic, vegetative, climatic, and man-made characteristics of an area largely determine the potential environmental impacts of aggregate production. Effects such as dust, noise, and vibrations are typical of nearly any construction project. These impacts commonly can be controlled, mitigated, or kept at tolerable levels and restricted to the immediate vicinity of an aggregate operation by using available technology.

In certain locations, for example in active stream channels, karst areas (landscapes formed primarily through the dissolving of rock), and some groundwater systems, the geologic characteristics of the site raise environmental concerns. Aggregate recovery may change the geologic conditions, and potentially alter the dynamic equilibrium of a given environment. Some ecosystems underlain with aggregate serve as habitat for rare or endangered species. Similarly, some geomorphic features are themselves rare examples of geologic phenomena or processes. Although aggregate extraction may be acceptable in such areas, it should be conducted only after careful consideration and only when properly managed to avoid potential undesirable environmental consequences.

How Science Can Help

Scientific and technological advances increase the understanding of the natural and engineering processes that lead to environmental problems and provide sound foundations for solving them. As our knowledge advances, so does our ability to prevent environmental impacts and to correct those that do occur or have occurred. Science and technology can help to

- Identify high-quality natural aggregate resources to meet society's growing demand for durable road surfaces, buildings, and other facilities;
- Provide sound, unbiased scientific information to the permitting process to allow better-informed decision-making;

HOW MUCH AGGREGATE IS USED ON YOUR BEHALF?

To visualize the 10 tons of aggregate used for each person in the United States each year, imagine stopping by your local home supply center to pick up a 50-pound bag of landscaping rock, every day of the week for 365 days. At the end of one year you'd still be 35 bags short.

Fig. 7

AGGREGATE USE PROJECTION

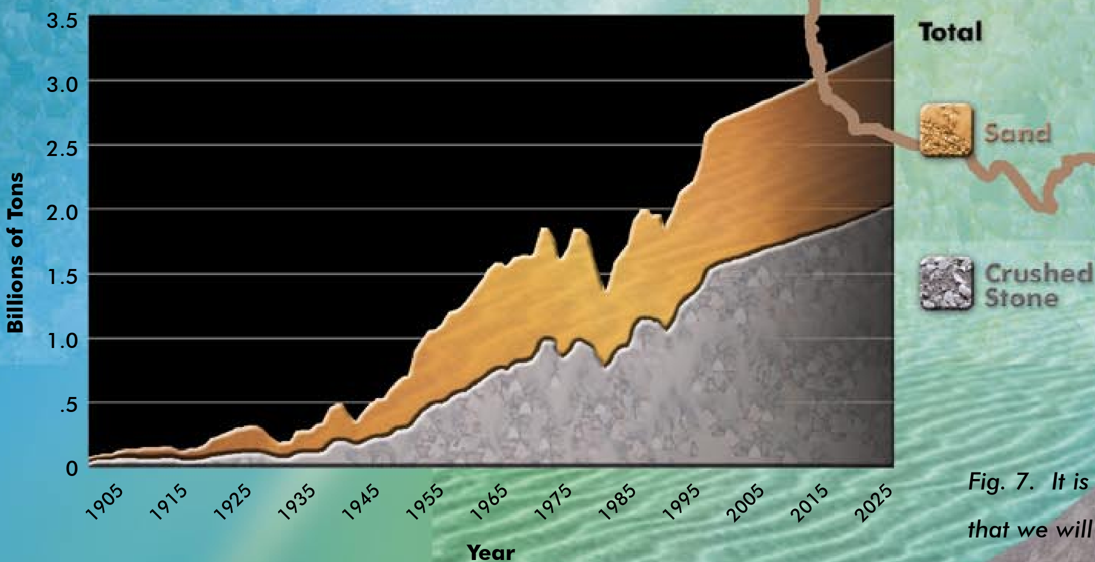


Fig. 7. It is projected that we will use as much aggregate in the next 25 years as we have used in the previous 100 years.

- Identify potential environmental impacts of extracting and transporting natural aggregate and determine methods to avoid or minimize impacts;
- Investigate the performance of recycled aggregates or other materials to determine if they can be substituted for natural aggregate, thus reducing the waste of concrete, stone, and asphalt from old structures, as well as conserving natural aggregate sources;
- Provide vital information for planning for the availability of aggregate; and
- Provide essential data for implementing the reclamation of mined-out areas.

The Hidden Costs and Benefits

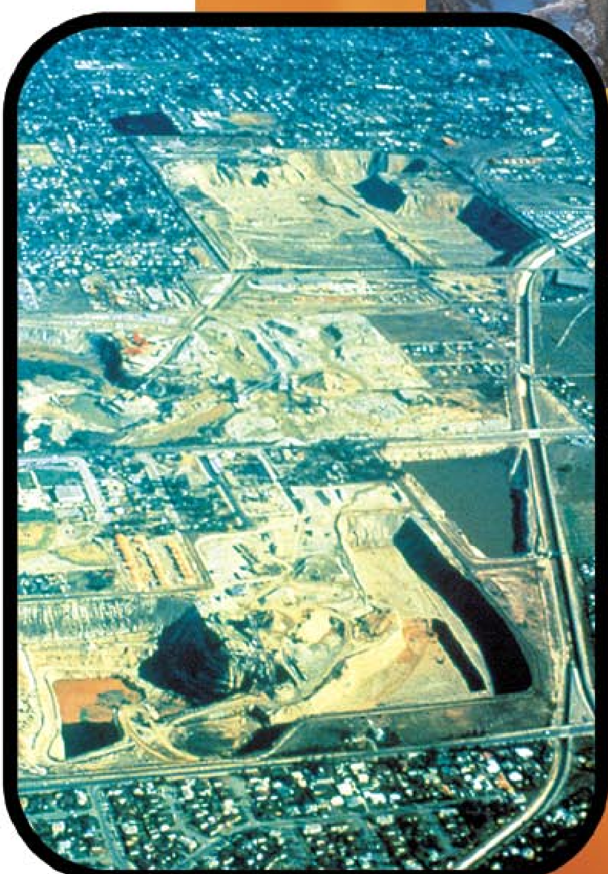
Many urban areas grow without any consideration of the presence of a resource or an analysis of the impact of its loss. In addition to covering valuable undeveloped aggregate resources, urban growth often encroaches upon established aggregate operations (Fig. 8). Some residents in the vicinity of pits and quarries object to the dust, noise, and truck traffic associated with an aggregate operation. Other citizens may object because they are not aware of the community's need for aggregate or because their personal need for aggregate materials is minor. This "not in my back yard" syndrome may restrict aggregate development. In addition, local regulations may prohibit mining.

Natural aggregate, especially sand and gravel, commonly occurs in areas that are also favorable for other land uses. Prime aggregate resources are precluded from development if permanent structures such as roads, parking lots, houses, or other buildings, are built over them. Once development has occurred, the value of the improvements probably will permanently prevent any further development of aggregate at that location.

As a result, new aggregate operations may be located long distances from the markets. The additional expense of the longer transport of resources must be passed on to consumers. For example, a city of 100,000 residents can expect to pay an additional $1.3 million every year for each 10 miles (16 kilometers) that the aggregate it uses must be hauled. Also, new deposits may be of inferior quality compared with the original source, yet they are used to avoid the expense of importing high-quality material from a more-distant source. Any savings for aggregate may be offset by decreased durability of the final product.

The benefits of aggregate development are dispersed over very large areas, but the community where extraction occurs experiences a combination of economic benefits and local disruptions. If regional benefits are not considered in a local permitting process, and if the resource operation is denied, regional costs, such as longer haul routes that result in more truck traffic, noise, accidents, and more hydrocarbons released to the atmosphere, generally increase. Any gain by a local community from stopping resource development is likely to be at the expense of the greater public, the greater environment, and the region where extraction ultimately takes place. A question to be considered when a political entity is evaluating whether or not to develop a resource is this: How can we be sure that the regional benefits of making a resource available are adequately weighed in the final decision?

Natural aggregate, especially sand and gravel, commonly occurs in areas that are also favorable for other land uses.



URBAN GROWTH AFFECTS AGGREGATE OPERATIONS

Fig. 8. As urban growth surrounds an aggregate operation, the risk of unwanted environmental impacts increases.

Aggregate occurs where nature places it.

PRODUCING AND TRANSPORTING AGGREGATE

2

Every state except Delaware produces crushed stone, and all 50 states produce sand and gravel. To keep up with the ever-increasing demand, the aggregate industry has evolved from a relatively inefficient, hand-power oriented process to a highly mechanized, efficient industry (Fig. 9). Aggregate production essentially turns big rocks into little rocks and carefully sorts them by size. Excavating crushed stone or sand and gravel is dependent on the geologic characteristics and the extent and thickness of the deposit. Open-pit mining and quarrying methods commonly are used, although some stone is mined underground. Quarrying and mining stone generally requires drilling and controlled blasting before the rock is extracted with power shovels, bulldozers, and draglines. Sand and gravel deposits

Fig. 9. Aggregate production continues to become more mechanized and efficient.

commonly are excavated with conventional earth-moving equipment such as bulldozers, front-end loaders, and tractor scrapers, but may be excavated from streams or water-filled pits with draglines or from barges that use hydraulic or ladder dredges.

Processing of quarried rock and large gravel may require crushing, depending on the requirements for the final product. After crushing, the aggregate is sorted to size. Silt and clay are removed by washing. At this stage, aggregate commonly is moved by conveyors to bins or is stockpiled by size. Finally, aggregate is loaded on trucks, railcars, barges, or freighters for shipment to the site of use.

Reclamation, returning the land to a beneficial use, is the final step of aggregate production. The rock outcrops and water in some quarries provide a natural setting that fulfills a demand for scenic, lake-front property. Reclaimed pits or quarries have been converted to many uses including residential developments, recreational areas, wildlife areas, botanical gardens, golf courses, farmland, industrial and commercial properties, storm-water management, office parks, and landfills. Reclamation commonly is planned before mining begins, allowing the pit or quarry to be developed in a manner that facilitates final reclamation.

Aggregate Deposits and Sources

Although the sources of natural aggregate are widespread, they are not universally available for use. Large areas have no gravel, and underlying bedrock that might be a source of crushed stone may be so deeply buried that mining is impractical. The sources of aggregate may not meet the strict chemical or physical quality requirements for current or future use. Communities lacking local aggregate sources generally face the costly alternatives of importing aggregate from outside the area or substituting another material for aggregate.

POTENTIAL SOURCE AREAS OF

Sand and Gravel

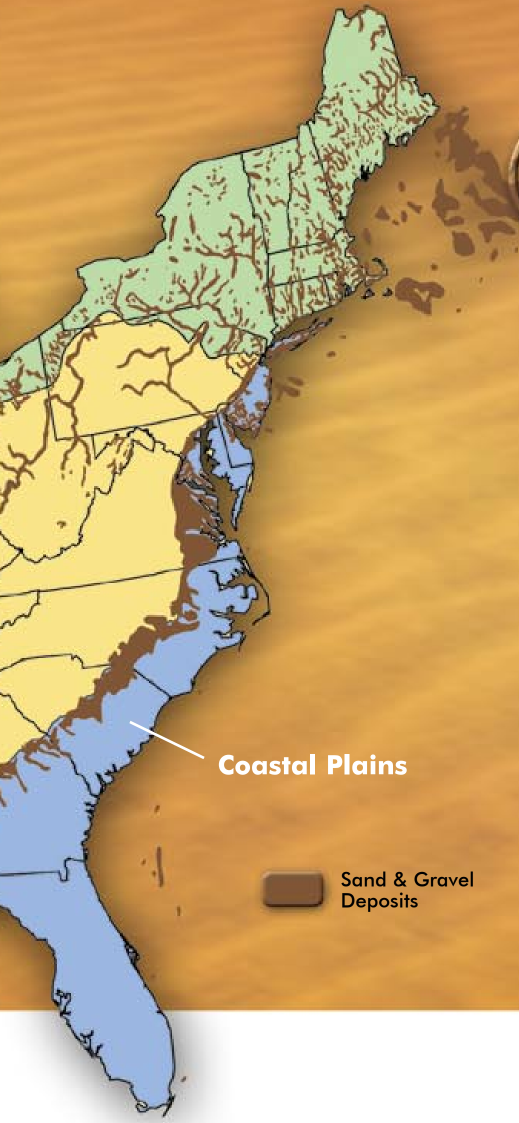
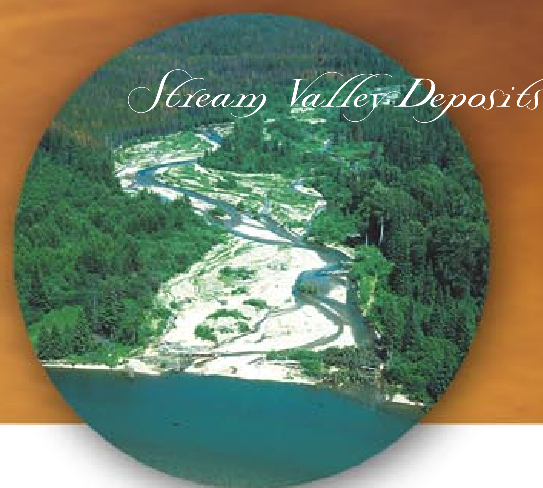


Fig. 10. Although every state contains potential sources of sand and gravel, it may not be economically or environmentally advisable to develop certain deposits.



Aggregate is produced from materials formed by geologic processes on and within the Earth's crust. Sand and gravel created by the process of erosion may have been deposited thousands of years ago — only an instant in geologic time. Granite may have formed over a billion years ago when molten magma deep within the Earth cooled and solidified. Limestone may have been deposited as coral in an ancient sea hundreds of millions of years ago. Basalt may have formed just yesterday as molten lava flowing from a volcano cooled and solidified. When an aggregate supply is required, geological investigations can determine the location, distribution, and nature of potential aggregate sources in an area.

Sand and Gravel

Sand and gravel deposits are products of erosion of bedrock and the subsequent transport, abrasion, and deposition of the particles. Water and glacial ice are the principal geologic agents that affect the distribution of deposits of sand and gravel. Consequently, gravel is widely distributed and abundant near present and past rivers and streams, in alluvial basins, and in previously glaciated areas (Fig. 10).

Sand & Gravel Deposits

Throughout the United States, sand and gravel are widely distributed as stream-channel and terrace deposits. Bedrock exposed near the surface of the Earth undergoes weathering and is progressively broken into smaller and smaller pieces. The harder, more-resistant minerals remain as fragments that combine with the silt and clay particles and organic materials to form soil.

Gravity — commonly with the aid of water — moves soil material down from the mountains or other high areas and it accumulates in stream valleys (Fig. 11). Streams pick up the particles and in the process of transporting them, subject the particles to abrasion and rounding. Eventually, stream-transported material is deposited on floodplains. Stream deposits consisting of sand and gravel may be suitable for aggregate, but deposits of silt and clay are not suitable.

As a river or stream cuts its channel deeper, older channel and floodplain deposits standing above the modern floodplain may be preserved as terraces (Fig. 11a). Some stream terraces can be sources of sand and gravel. Stream-transported material deposited in the oceans may be dredged for use as aggregate, if it is of the proper size and quality.

During the infrequent but torrential floods typical of desert environments, rock fragments are eroded from mountains and are transported down steep-gradient streams to the adjacent basins. When the flood water reaches a basin, it spreads out of the stream channel and deposits sediments in the shape of a fan (Fig. 11b). These fans, referred to as alluvial fans, contain thick deposits of unconsolidated material including large boulders, cobbles, pebbles, sand, silt, and clay. Some of this material provides useful sources of aggregate.

Many of the extensive sand and gravel deposits in the northern and higher-elevation regions of the United States are products of either continental or alpine glaciations. Glaciers leave deposits of till, an unsorted mix of clay, sand, gravel, and boulders. Although till is quite widespread in glaciated areas, it commonly contains a large amount of fine material. Thus, till generally is not suitable for use as aggregate.

As glacial ice melts, rock particles that had been crushed, abraded, and carried by the ice can be picked up and carried by water melting from the glaciers (Fig. 11c). The particles carried along in glacial meltwater streams, are abraded, rounded, and deposited much like particles carried by nonglacial streams. Much of the sand and gravel deposited by glacial meltwater streams can be used as aggregate.

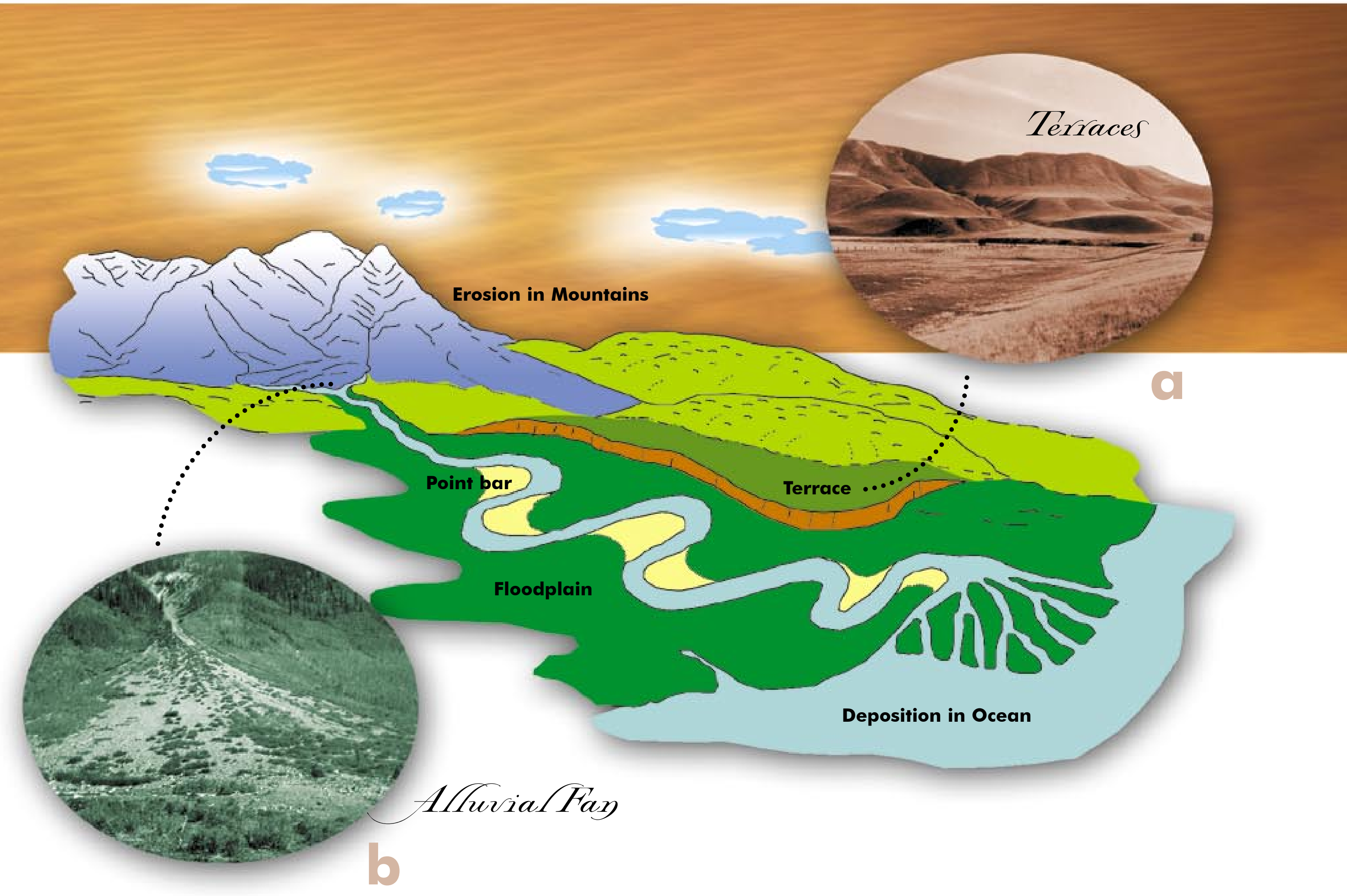
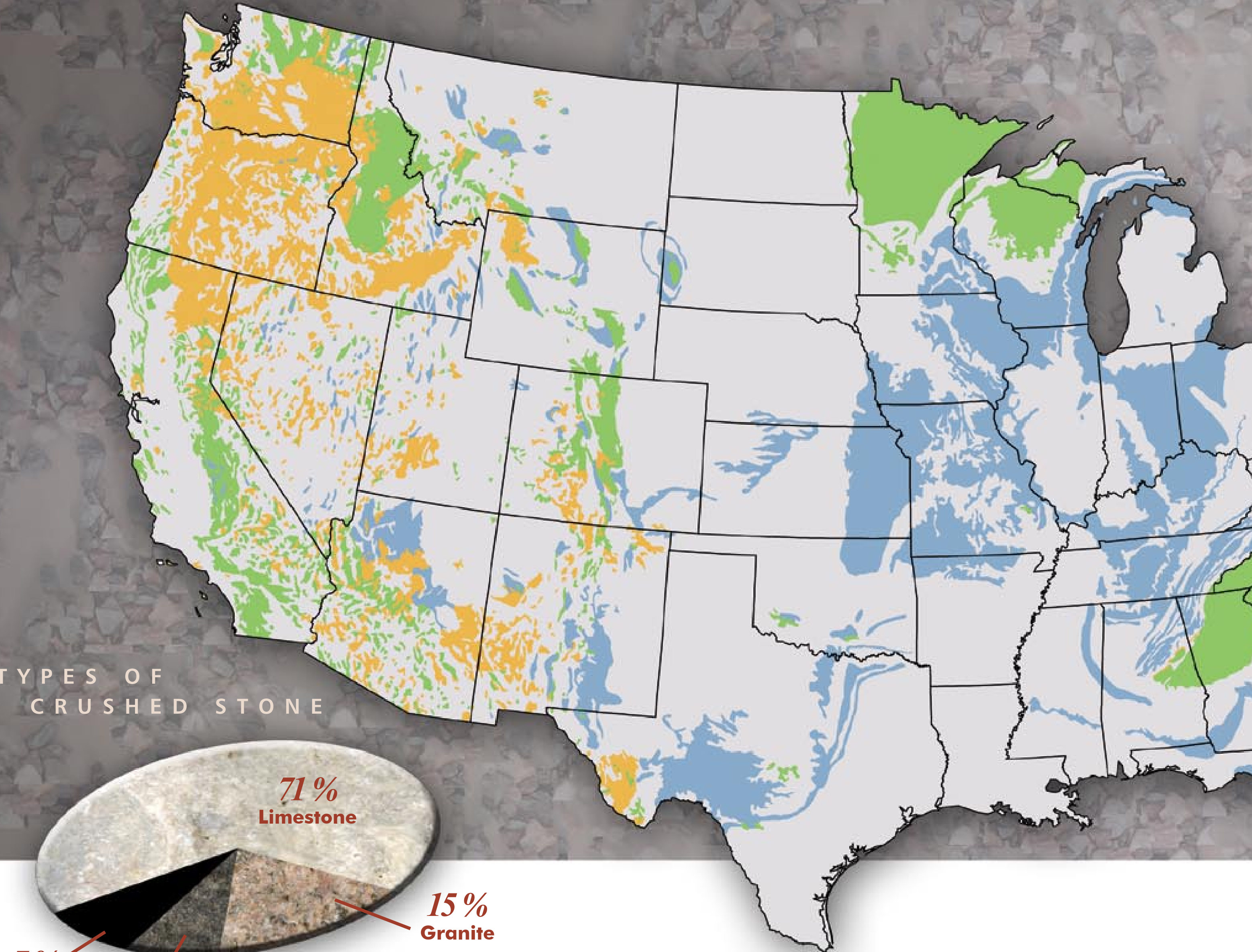


Fig. 11. Sand and gravel are formed by geologic processes. ***(a)*** *Rivers or streams have deposited sand and gravel widely throughout the United States as stream-channel or terrace deposits.* ***(b)*** *Many valley basins in the arid and semiarid western United States contain thick fan-shaped deposits of unconsolidated clay, silt, sand, or gravel. These alluvial fans were deposited during torrential floods.* ***(c)*** *Glacial melt-water transports particles. Finer materials are deposited in lakes and ponds, while the coarser sand and gravel is deposited in and along stream channels.*

TYPES OF CRUSHED STONE



Crushed Stone 

Bedrock, the source material for crushed stone, is classified on the basis of origin as sedimentary, igneous, or metamorphic (Fig 12). Sedimentary rocks form by consolidation of loose sediment by chemical, biochemical, or mechanical processes. Chemically or biochemically deposited carbonate sedimentary rocks, such as hard, dense limestone (calcium carbonate) and dolomite (calcium-magnesium carbonate), commonly are referred to as "limestone" in the aggregate industry. Generally these rocks make good sources of crushed stone (Fig. 12a), however, some are too soft and absorptive, or may contain too much poor quality material to yield high-quality aggregate. Chert, also known as flint, is a tough fine-grained sedimentary rock made of quartz. Chert is used as aggregate but it may react with adverse consequences when used in concrete. Hard, dense sandstone, a mechanically-deposited sedimentary rock, is occasionally used as crushed stone.

Many igneous rocks are hard, tough, and dense, and they make excellent crushed

POTENTIAL SOURCE AREAS OF Crushed Stone

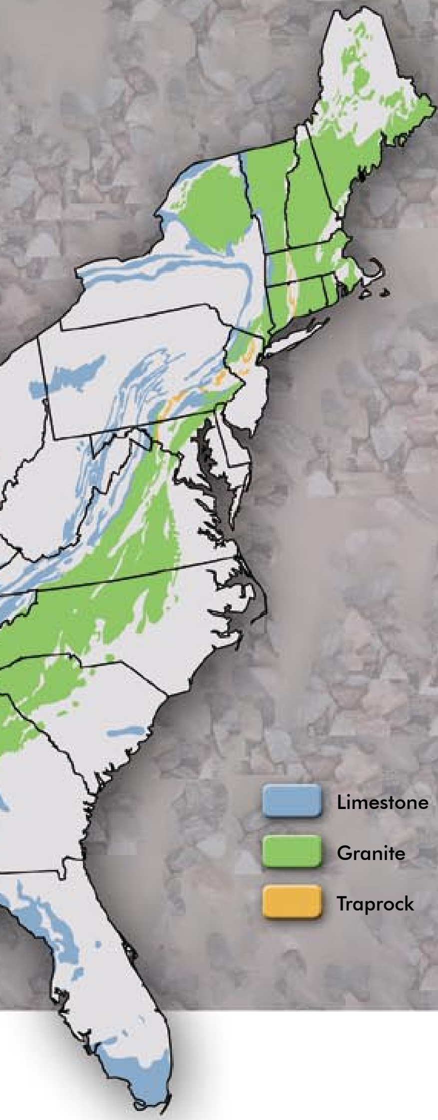


*Fig. 12. The geographical distribution of rock types suitable for crushed stone as well as production and transportation costs affect construction costs. Hard, dense rocks, such as limestone **(a)**, granite **(b)**, and traprock **(c)**, are generally good sources of crushed stone.*

stone for construction uses. However, some igneous rocks are chemically reactive when used as aggregate in concrete. Igneous rocks solidify from naturally occurring molten rock (magma) generated within the Earth, and they are classified further by their origin, composition, and grain size. Hard, coarse-grained rocks form from molten magma that cools slowly deep within the Earth. There rocks commonly are referred to as "granite" in the aggregate industry (Fig. 12b). Fine-grained volcanic rocks form as molten lava flows onto the Earth's surface and cools and solidifies relatively quickly. These igneous rocks commonly are referred to as "traprock" in the aggregate industry (Fig. 12c).

Metamorphic rocks form when existing rocks are subjected to heat and pressure within the Earth. Some metamorphic rocks are hard, tough, and dense and can be used as aggregate. These include gneiss (a banded crystalline rock); marble (metamorphosed limestone), and quartzite (metamorphosed sandstone).

Aggregate Producers

In the United States, more than 1,200 companies produce crushed stone from some 3,300 quarries, and 4,000 companies produce sand and gravel from about 6,400 operations. Five companies account for nearly 25 percent of the aggregate production. Even so, more than 5,000 companies are active in the aggregate business, and no single producer dominates the industry. Even the largest producers must compete at the local level. Five of the top 10 crushed stone companies and three of the top 10 sand and gravel companies are foreign owned. Consequently, acquisitions of companies have become commonplace. One of the major reasons for acquisitions is to obtain new high-quality reserves. Acquisitions are also being used by larger companies to spread the cost of technology over more production, thus achieving higher operating efficiencies.

Opening a new aggregate operation is a complicated process that can cost millions of dollars and take many years. Natural aggregate producers expend tremendous amounts of time and money locating potential aggregate resources and determining their quantity and quality. They also spend large amounts of money and effort determining the feasibility of production; identifying potential environmental impacts from production; making certain their operation will conform to the relevant laws; and obtaining the necessary permits to extract, process, and transport the aggregate.

The Exploration Process

Exploration for deposits of natural aggregate involves locating a suitable resource near where it is to be used. Thus, the process may involve interaction between the aggregate producer and the local community. Since the construction boom of the 1960s and 1970s, many convenient sources of aggregate have been depleted or covered over with buildings, parking lots, and other construction. In addition, the specifications used to establish the quality of aggregate for certain uses have become more stringent. Consequently, exploration for aggregate resources has become more difficult and costly.

In an urban area, the maximum economically feasible shipping distance from the market typically defines a crude target area for exploration. The first step in aggregate exploration is a preliminary geologic evaluation. Geologic and topographic maps and geologic and engineering reports aid in locating 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 that involve satellite imagery, aerial photography, geophysical studies, and field reconnaissance studies of target areas to define the limits of the potential sources of aggregate more accurately (Fig. 13). 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. Field studies commonly are augmented by samples collected using hand-sampling techniques of surface outcrops and various methods of drilling to obtain subsurface samples.

Detailed exploration of an identified source of aggregate varies depending on the nature of the potential resource and

Fig. 13.
Field studies, including investigations of active or abandoned aggregate operations, can be used to help locate potential sources of aggregate.

the intended uses. Backhoes can be used to collect bulk samples, and truck-mounted power augers or drill rigs can be used to collect deeper subsurface samples. In addition, geophysical studies may be used to determine the thickness of overburden (overlying material), to determine gross changes within the deposit (such as changes from gravel to sand or shale to sandstone), and to provide continuity between drillholes.

Exploring for natural aggregate resources generally is not disruptive to the environment. The minor environmental disturbances that result from trenching and digging test pits for sand and gravel resources, geophysical surveys, and the drill holes used to evaluate an area for crushed stone reserves are easily remedied and cause virtually no permanent environmental disturbance.

Aggregate Mining

Aggregate mining begins with removing the overburden to expose the sand, gravel, or stone. Soil and partially weathered rock can be pushed aside with a bulldozer and removed with conventional loaders and haul trucks. Organic soil commonly is stripped separately from the rest of the overburden and stockpiled for reclamation activities. Overburden may be used to construct mounds, walls or ledges called berms (Fig. 14), or it may be stockpiled, or sold. Following overburden removal, berms, haul roads, settlement ponds, processing and maintenance facilities, and other plant infra-structure are constructed by using standard building techniques. The methods to mine aggregate depend on whether the material being excavated is sand and gravel or crushed stone, the natural conditions at the site, the desired final product, and operator preference.

Fig. 14.
This berm was constructed to block the view of the quarry on the other side of the wall.

*Fig. 15. **(a)** Dry deposits of sand and gravel can be mined by using conventional earth-moving equipment. **(b)** Groundwater can be collected and removed from wet gravel pits. **(c)** Wet mining techniques, such as dredging, can be used when it is not practical to drain a pit.*

Mining

Mining Sand and Gravel

Sand and gravel are mined from open pits and dredged from underwater deposits (Fig. 15). In upland areas, such as alluvial fans, high terraces and some glacial meltwater deposits, the sand and gravel may be dry and can be extracted by using conventional earth-moving equipment, such as bulldozers, front loaders, back hoes, and scraper graders (Fig. 15a).

Where sand and gravel pits penetrate the water table, such as low terraces and some glacial meltwater deposits, pits can be made dry by collecting groundwater in sumps in the floor of the pit and pumping out the water (Fig. 15b). After the groundwater drains from the deposit, sand and gravel can be extracted by using dry mining techniques.

In some areas, such as floodplains or low terraces, it may not be practical to drain a pit, and the operator may prefer to extract the material by using wet mining techniques. Material may be excavated by using draglines, clamshells, bucket and ladder, or hydraulic dredges (Fig. 15c).

Some sand and gravel can be excavated directly from stream channels or from embayments cut into floodplains at the edges of stream channels. The material is extracted by using draglines, clamshells, bucket and ladder, or hydraulic dredges. During times other than flooding, aggregate can be skimmed from bars in channels or from active floodplains by using dry mining techniques.

Mining Crushed Stone

Mining crushed stone differs from mining sand and gravel because the bedrock, in most situations, must first be drilled and blasted (Fig. 16). The technology of blasting rock is highly developed and regulated. Holes are drilled into the rock and are partially filled with explosives (Fig. 16a). The top portion of the hole is filled with nonexplosive material (usually sand, crushed stone, or a manufactured plug) that is referred to as "stemming." The explosive in each hole is initiated with detonators that create delay periods between blasts in individual holes. The total blast commonly lasts only a fraction of a second and consists of many smaller individual blasts separated by delays of a few thousandths of a second.

Controlled sequential blasting commonly breaks the rock into pieces suitable for crushing. If the rubble is too large, secondary breaking may be required and usually is accomplished with hydraulic hammers (Fig. 16b), drop balls, or other mechanical devices. The blasted material is dry and can be extracted by using conventional earth-moving equipment, such as bulldozers, front loaders, back hoes, and hydraulic excavators (Fig. 16c).

Rock quarries that do not penetrate the water table and sites where groundwater naturally drains from the quarry commonly are mined dry. Where quarries penetrate the water table, they commonly are dewatered by collecting and pumping the groundwater. The rock is then mined by the same procedures used in a dry quarry. In some geologic terrains, such as limestone in areas of shallow groundwater, the flow of groundwater into the quarry exceeds the rate at which it can be drained. In those areas, the quarries are allowed to fill with water. The rock is drilled and blasted, and the rubble is extracted using draglines, clamshells, or other equipment.

Crushed stone is extracted from about 100 underground quarries in the United States. Most of these quarries, which are located in the central United States, produce limestone or dolomite. After quarrying has been completed, the underground spaces provide opportunities for future use, such as warehouses, offices, retail stores, and manufacturing.

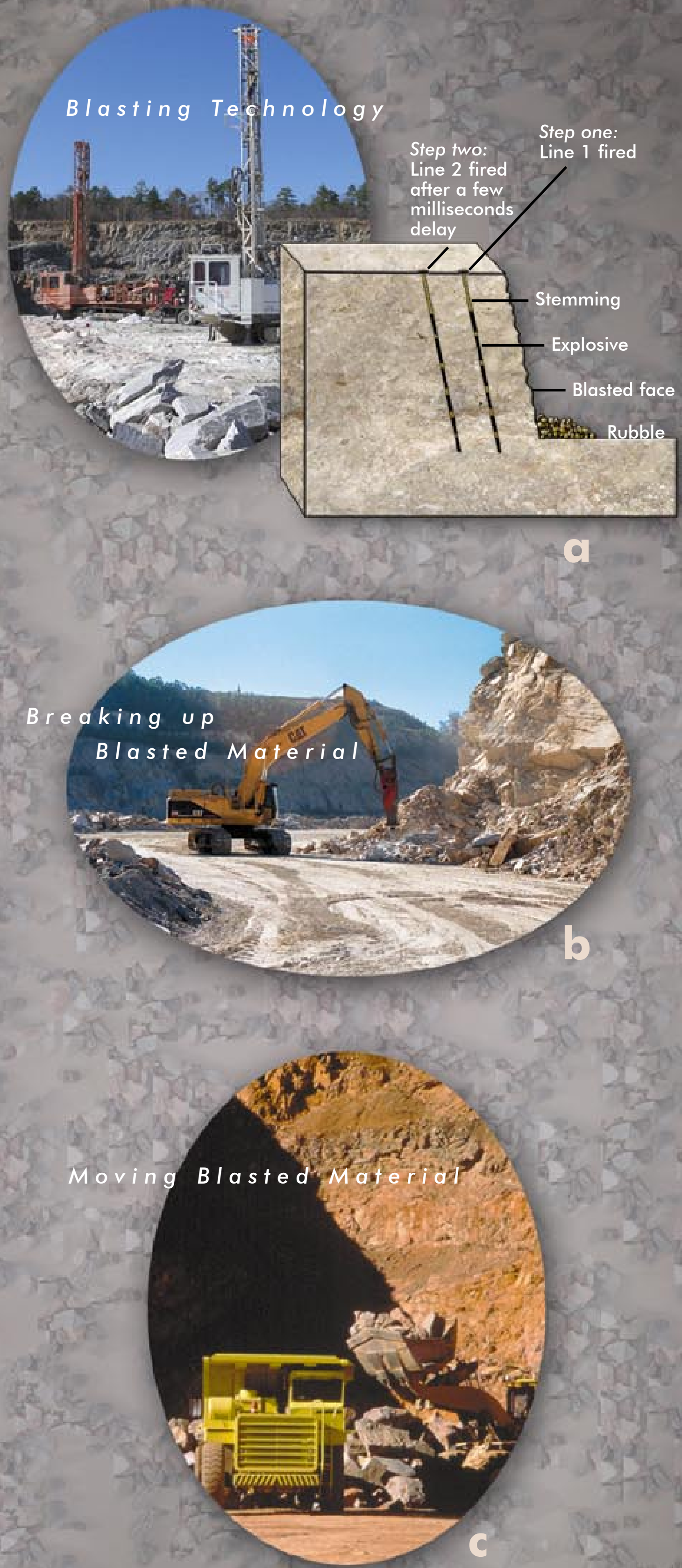


*Fig. 16. **(a)** Rock commonly is drilled and blasted before excavation. **(b)** This machine uses a hydraulic hammer to reduce large pieces of rock to a size that can be processed by the primary crusher. **(c)** The blasted material can be extracted by conventional earth-moving equipment.*

Processing Aggregate

Aggregate can be processed at remote locations using portable crushing and screening equipment, or can be processed at a plant consisting of a large amount of sophisticated equipment connected by a network of conveyors. Almost all the stationary equipment in a processing plant can be managed by a computer or one person situated in a centrally-located control tower.

Aggregate processing commonly consists of transporting rock rubble or sand and gravel to a plant, crushing, screening, washing, stockpiling, and loadout (Fig. 17). Typically, trucks or conveyors move material from the mining face to a primary crusher. The crushed material is moved via conveyor to a surge pile. A gate in a tunnel at the bottom of the surge pile releases the sand, gravel, or crushed stone at a constant feed rate via a conveyor to a secondary crusher and screening system where it is further crushed and sorted by size. Rock that is too large is sent back through the crushing and screening process. Depending on the type of material being processed and on the final product, the material may be washed. After screening, sorting, and washing (if necessary) conveyors move the material to bins or stockpiles. Upon sale, the product is loaded on trucks, railcars, or barges for transport to the final destination.

Fig. 17. Processing plants are generally constructed on the site of extraction. Processing of mined or quarried rock requires one or more rounds of crushing, sorting, and washing. The coarser aggregate commonly is moved by conveyors to bins or is stockpiled by size.


EXTRACTION 1
Sand & Gravel
Crushed Stone
HAULING 2
CRUSHING 3
PROCESSING PLANT as viewed from the control tower 4
Surge Pile
Rock moving on Conveyor Belt
Tunnel from Surge Pile
Screening System
Finishing Crusher and Screens
Secondary Crusher
FINAL PRODUCT 5
Sand & Gravel
Crushed Stone

Transporting Aggregate

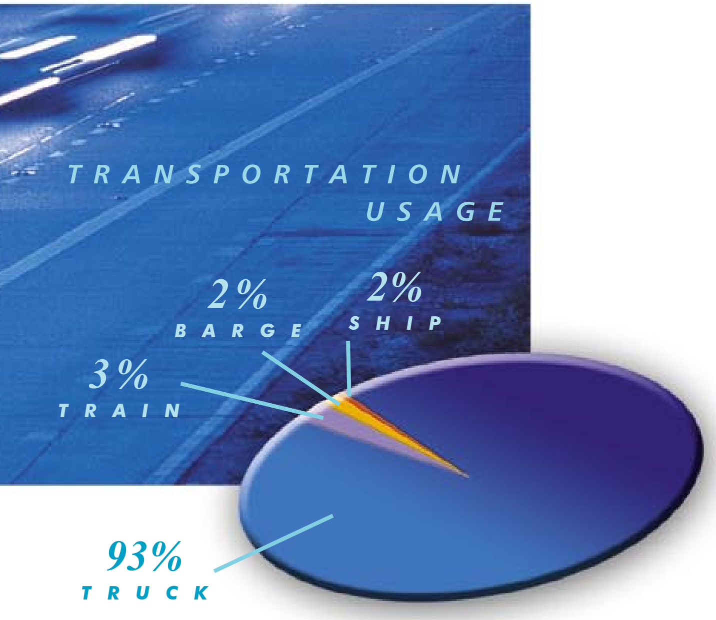
Aggregate can be transported by truck, train, barge, or freighter (Fig 18). The preferred mode of transporting aggregate depends on a variety of factors including delivery-schedule requirements, distance, volume of material, loading and unloading facilities, and the availability of transportation methods. Transportation decisions also involve trade-offs between expenditures of investment capital and operating expenses.

Ninety-three percent of aggregate is transported by truck. Trucks can move throughout most areas of an aggregate operation. They can be loaded quickly at points of origin and can dump or drop their loads unassisted at the destination. Trucks can deliver practically anywhere there is a road. From small pickups to rigs that carry 28 tons (25 metric tons), trucks can be matched to requirements and, thus, make cost effective deliveries.

Generally, truck traffic is concentrated near an aggregate operation, and many trucks may enter or leave an aggregate operation every day the plant is operating. In rural areas, the trucks may have to navigate narrow, twisting roads to the construction site. Ultimately, truck traffic must intermingle with automobile traffic. Large trucks of any type, including those transporting aggregate, create the nuisances of noise and diesel exhaust as they pass suburban dwellings. Also, large trucks create a potential danger to motorists on local streets and highways. The environmental impacts and hazards of trucks can be minimized when the trucks are well-maintained and operated, and when automobile drivers yield reasonable space so that truck drivers can maneuver and stop safely. Trucks that haul aggregate are typically equipped with mud flaps and load covers to prevent loose material from being thrown from wheels and off of loads. Loads can be wetted to reduce

Fig. 18. The preferred mode of transporting aggregate depends on delivery requirements, distance, volume of material, loading and unloading facilities, and the availability of transportation methods.

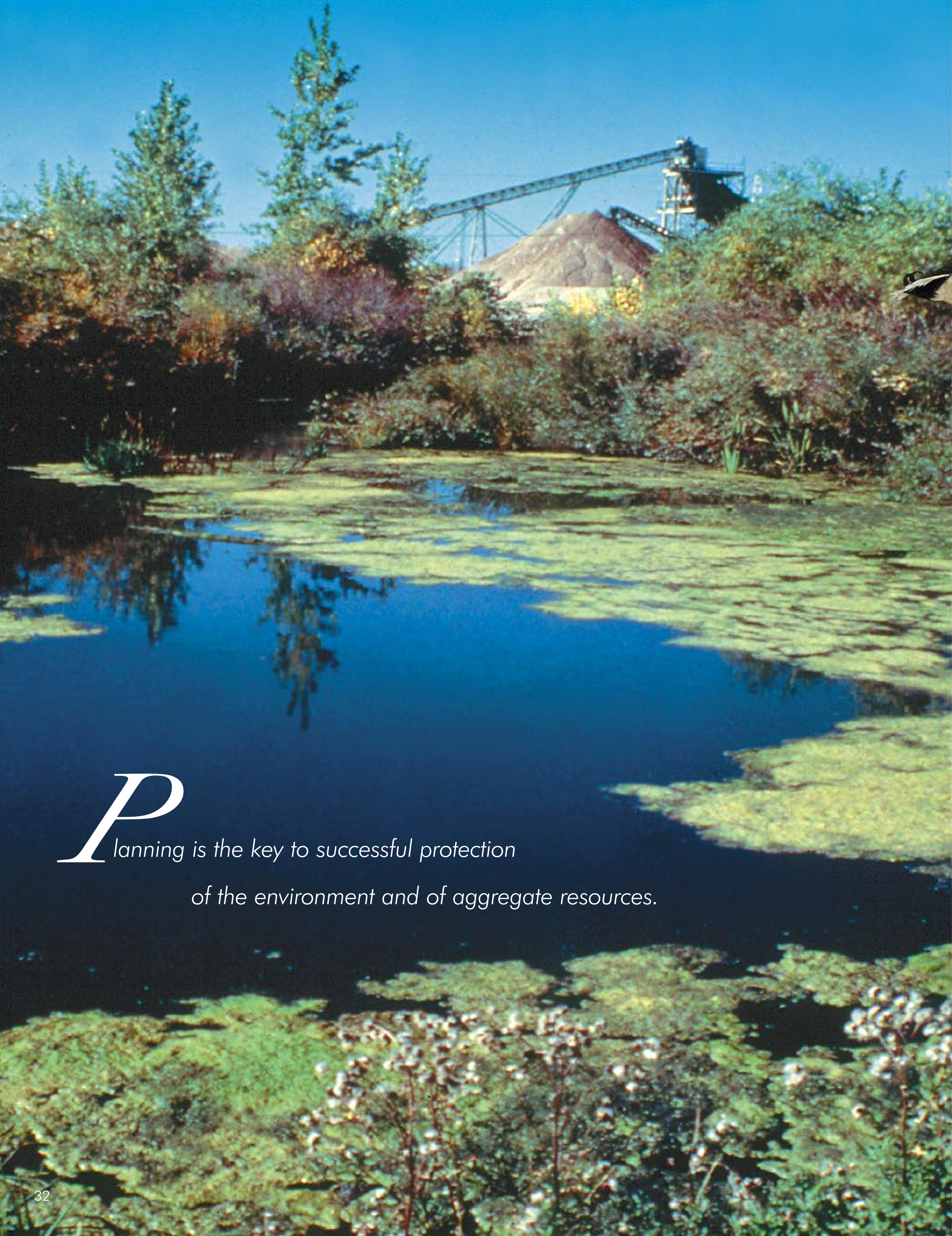
dust. Paving quarry access roads, limiting the number of quarry entrances and exits, and wheel-washing procedures can minimize the amount of material tracked onto adjacent roads. Acceleration and deceleration lanes can be constructed at the entrance of the pit or quarry to improve the ability of trucks to enter and exit civilian traffic more smoothly, and delivery routes can be designed to minimize interference with neighborhood traffic.



Where pits or quarries have railroad access, rail delivery may be more economical than truck delivery. In the United States, trains transport approximately three percent of aggregate. To move aggregate by rail, a plant must have rail access, a means to load the rail cars, a method to unload aggregate at the delivery point, and if the aggregate is not used at the delivery point, a system for further distribution. The choice depends on two principal variables — the tonnage of aggregate to be moved and the distance it must be hauled. Economic advantages of shipping by rail increase as tonnages and distances of transport increase. One hundred tons (90 metric tons) of aggregate can be loaded in either bottom-dump hopper rail cars or gondolas and moved in single rail cars (the most expensive way to ship by rail) or can be joined and moved as multiple cars or by unit trains (the least expensive way).

In some circumstances, moving aggregate by hopper or flat deck barges is economical. In the United States, about two percent of aggregate is transported by barge. Transportation rates are established by agreements between the user and the barge line. Economic advantages of shipping by barge increase as the tonnages and distances of transport increase. Hopper barges commonly hold 1,500 tons (1,360 metric tons) of aggregate, and they can be grouped into tows of 30 to 40 barges depending on the width and depth of the waterway to be traveled and the size and horsepower of the tow boat.

Lake or ocean freighters are an efficient means to transport aggregate. Freighters ship about two percent of aggregate production. Along the Atlantic, Gulf, and Pacific Northwest coasts of the United States where local supplies of good quality aggregate are in short supply, aggregates are transported by freighter from Mexico, Canada, and other countries. In some areas, transport 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 aggregate on the return voyage at a low price prevents the vessel from returning to the point of origin with an empty hold.



Planning is the key to successful protection of the environment and of aggregate resources.

PROTECTING THE ENVIRONMENT 3

Properly designed and operated aggregate production minimizes the impact on landscape, wildlife, surface and groundwater, and surrounding communities. The extraction and processing techniques and the natural site conditions determine which specific impacts may occur, how widespread they will be, and how long they will last. Mining aggregate, building a house, or building a highway all impact the environment. In comparison, the land disturbed to build a community or a highway is about 100 times greater than the land disturbed to provide the aggregate for those purpose (Fig. 19). An aggregate operation is a temporary land use, and when mining is completed, the site is likely to be converted into another beneficial use. Consequently, the overall environmental impact of aggregate extraction is usually relatively small over the long term. Aggregates are environmentally inert materials and their processing commonly requires only crushing, screening, and washing. Environmentally sound and safe aggregate operations effectively manage physical disturbance, protect ground and surface waters, control noise and dust, use safe blasting procedures, and have long-term operation and closure plans that recognize habitat and community needs.

Modern technology and scientific investigation methods have made it possible to reduce the environmental impacts from aggregate mining and to manage those impacts at acceptable levels. In addition, a variety of federal, state, and local regulations are designed to limit environmental impacts of industrial operations including aggregate extraction.

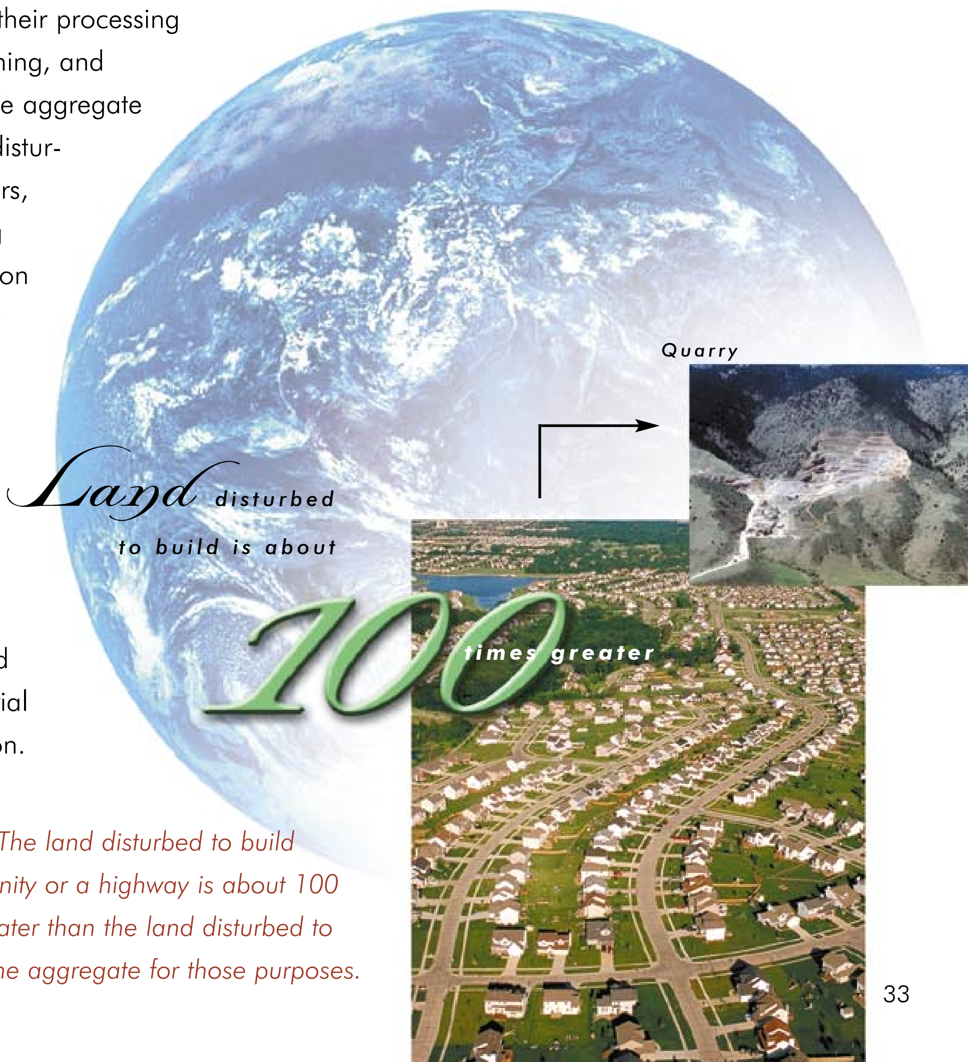


Fig. 19. The land disturbed to build a community or a highway is about 100 times greater than the land disturbed to provide the aggregate for those purposes.

impacts in absolute terms. Whether or not an aggregate operation is unpleasant to the eye is generally a matter of integrating the operation into the surrounding landscape. The physical impact is predictable and controllable because an aggregate operation is a designed facility, and good design is important.

Fig. 20. Aggregate operations, such as this one in Virginia, have made significant strides in site planning and beautification.

Managing Physical Disturbance

Changing a landscape from undeveloped or agricultural lands to a pit or quarry is an obvious impact of aggregate extraction. A quarry or gravel pit is dramatically different from other types of land use, and it is difficult to discuss the associated visual impacts in absolute terms.

Development of an aggregate operation is accompanied by a change to the landscape as observed from either the site or locations that surround it (Fig. 20). The nature of this modification depends on the surface forms, slopes, natural ground cover, and type of operation. Reaction to such changes tends to be subjective, and what is acceptable to some, others may find objectionable. Minimizing unsightly changes to a landscape can be achieved

- Through proper landscape analysis, design, and operations;
- By extracting aggregate from the most suitable deposits; and

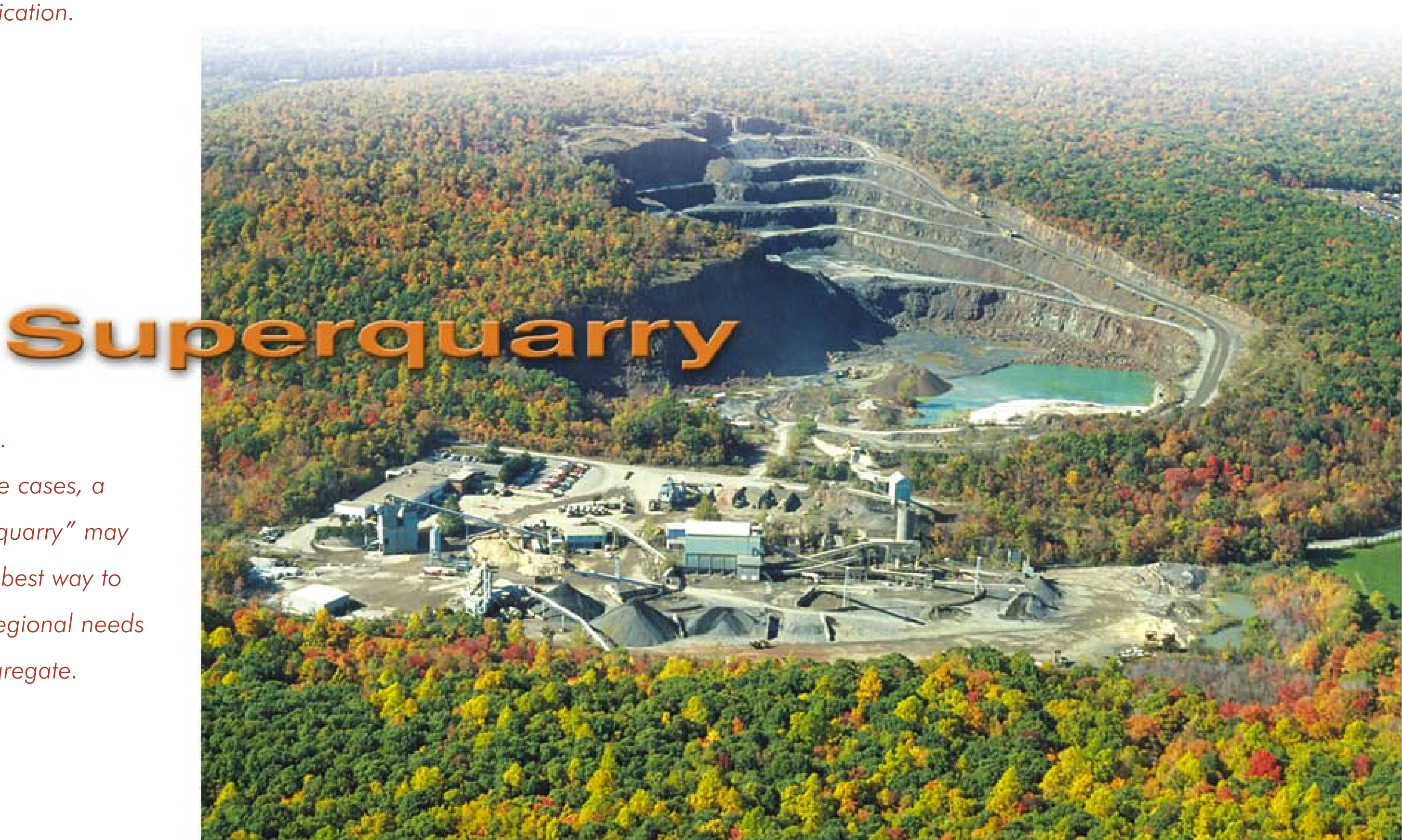


Fig. 21. In some cases, a "superquarry" may be the best way to meet regional needs for aggregate.

■ Through creation of superquarries and the use of underground mines, depending on local conditions.

To meet regional needs for aggregate, constructing a single large operation (superquarry) at an environmentally acceptable site may be preferable to many smaller operations at scattered locations (Fig. 21). However, to be economically viable, a large quarry depends on cost-effective, high-volume transport and support from the local residents and government.

The use of mining software and geographic information systems makes it possible to predict physical changes to a landscape, and visual impacts can be mitigated through careful design. Designing to minimize visual impacts includes

- Careful siting of the operation;
- Limiting active extraction areas;
- Sequential reclamation;
- Staining fresh rock to make it look weathered;
- Buffering, and
- Screening.

Screening includes construction of berms (Fig. 14, p. 25), tree plantings, fencing, or other landscaping techniques. Stockpiled overburden or other material can be designed as elongated rolling hills that mimic the natural landscape. Products can be stockpiled in places located out of view. Good housekeeping practices, such as maintaining equipment, and placing it out of the line-of-sight or in enclosed structures, further improve the appearance of a site.

Aggregate extraction results in a temporary loss or modification of wildlife habitat in the mined area. Habitats in river systems and karst areas are extremely susceptible to cascading environmental impacts. For example, stream erosion from improper aggregate extraction could cause stream bank failure. The bank failure could cause loss of adjacent streamside habitat and shade along stream banks and could result in major changes to aquatic and riparian habitat. Habitat loss can be regulated and controlled. Site inventories before extraction begins can identify rare or endangered species. Buffers can be set aside as wildlife habitat. Animals or plants can be relocated. Creation or improvement of habitat outside the pit or quarry can offset the loss of habitat on site, and sequential reclamation can restore habitat more quickly. In some cases, a site can be reclaimed to function similar to the original habitat (Fig. 22). In other areas, new habitat may be created thus increasing biodiversity.

Fig. 22. An active limestone quarry on the Marblehead Peninsula in Ohio provides habitat for the Lakeside Daisy, a rare and endangered wild flower. The only other sites where these daisies grow naturally today are the Bruce Peninsula and Manitoulin Island in Ontario, Canada.

Minimizing Impacts from Blasting

Blasting usually is restricted to quarry operations; generally, it is not used in sand and gravel extraction unless the deposits are heavily cemented. The blasting process is tightly controlled by local, state, and federal regulations and is usually carried out by highly trained blasting professionals. As a rule, quarry operators work closely with blasting specialists to assure that each event is carefully monitored and that any potential impacts are minimized. Ground vibrations, noise, and dust (Fig. 23) are potential impacts from blasting. Most of the energy of a properly designed blast is expended to shatter and displace rock from the quarry face. The remaining energy is released as vibrations through and along the surface of the Earth and through the air.

Fig. 23. Aggregate operators work to confine the noise, dust, and vibrations that result from blasting in their quarry.

Vibrations represent wasted energy, and because blasting accounts for a large percentage of production costs, it is to the operator's advantage to minimize them.

Most of the blast vibrations that enter the Earth come to the surface within a few feet of the detonation and travel along the surface in the form of waves, which may cause ground vibrations. The properties of the rock determine the speed at which the vibrations travel, and, although perceptible, ground vibrations decrease rapidly with distance. Rock properties, such as density, bedding planes, joints, cracks, faults, cavities, mud seams, and zones of weak or incompetent rock, also affect the amount of ground shaking. Therefore, the properties of both the rock being blasted and the rock between the quarry and its neighbors should be considered. Seismic equipment can be used to monitor ground vibrations in terms of particle velocity, which is the speed at which the ground moves. Limiting the size of the blasts or using time-delay blasting are ways to control ground vibrations.

During a blast, some energy escapes into the atmosphere causing an airblast or air concussion. Airblast creates a pressure differential between the outside and inside of a structure that causes the structure to vibrate. The shaking, which may be mistaken for ground vibrations, is most noticeable within a structure when windows and doors are closed. Airblast vibrations generally increase with the amount of explosive and proximity to a blast. The area in front of the rock face being blasted commonly receives more noise than the

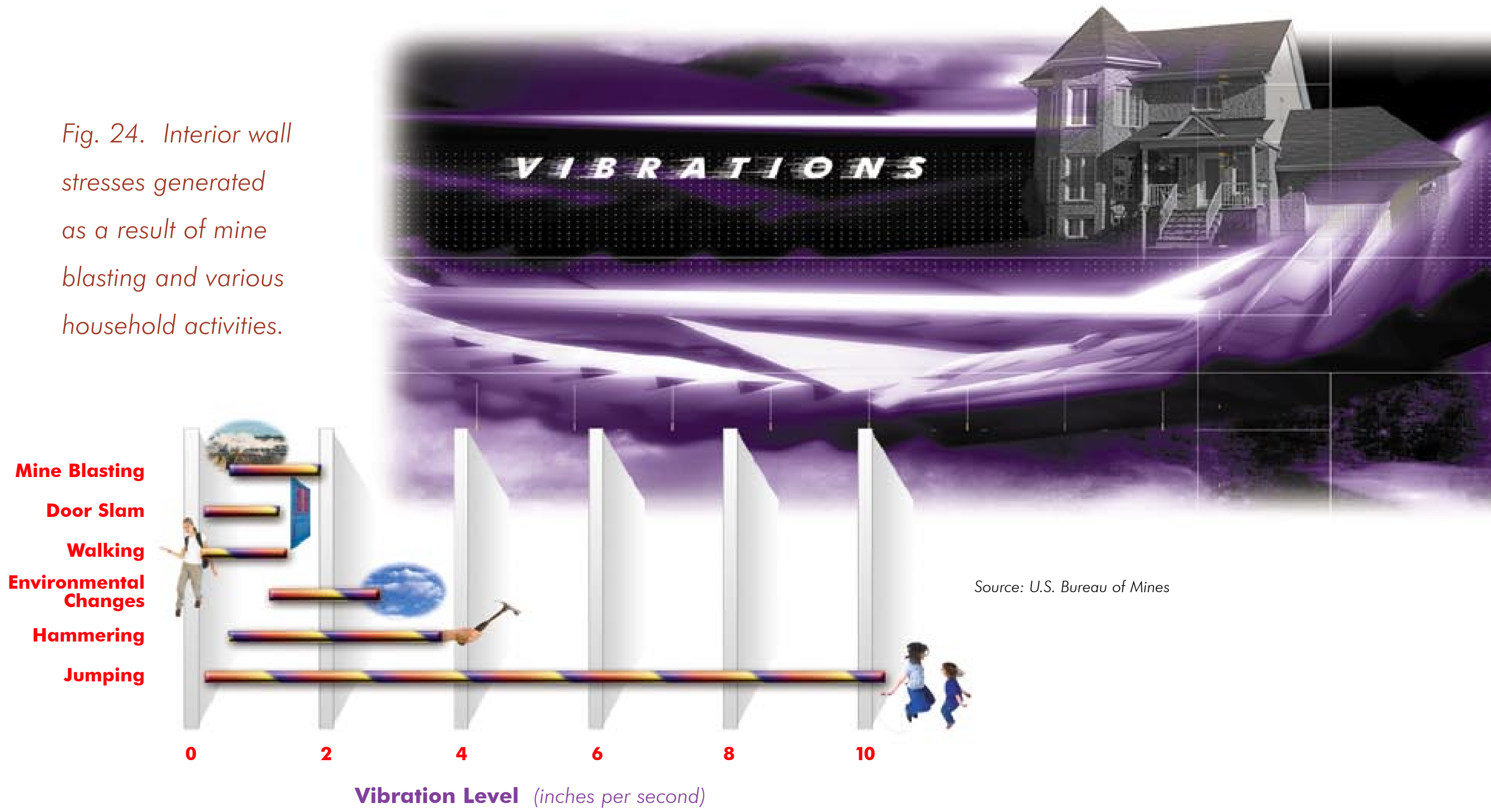


Fig. 24. Interior wall stresses generated as a result of mine blasting and various household activities.

area behind the rock face. Airblast travels at the speed of sound, and wind and temperature inversions, topography, and vegetation affect the speed. Airblast can be monitored with seismic equipment equipped with a special microphone that measures air vibrations in terms of decibels.

Blast design parameters, including maximum instantaneous charge; delay timing; hole diameter, spacing, and orientation; amount and type of stemming; and the amount of material being blasted (Fig. 16, p. 27), can be altered to limit levels of ground vibration and airblast. The impacts from blasting can be controlled by blasting during favorable weather conditions and orienting quarry faces away from sensitive receivers. A routine monitoring program can be implemented to manage vibration, noise and airblast throughout the life of a project.

Ground vibration standards developed by the former U.S. Bureau of Mines (USBM) have become industry standards for safe blasting throughout the United States and many other developed countries. Damage from ground vibration due to blasting can be avoided by restricting peak particle velocity to 0.5 to 2.0 in/sec (1.27 – 5.08 cm/sec). Damage from airblasts can be limited by restricting airblast intensities to 128 to 130 decibels.

Because people may feel vibrations at very low levels, they may over-estimate the risk of blasting damaging their homes even if the vibrations are kept within USBM guidelines. Also, low-level vibrations may still be an annoyance. Everyday activities, such as slamming doors, running up and down stairs, and pounding nails, as well as outdoor environmental changes, such as wind and temperature, produce strains on houses greater than legal blasting limits (Fig. 24). These activities tend to go unnoticed because they are expected, whereas blast vibrations can be unexpected. This element of surprise can be avoided by using a preblast signal to warn nearby residents, blasting at a predetermined time, and scheduling blasting times to coincide with daytime periods of high residential or neighboring activity.

Controlling Dust and Noise

Although dust and noise are part of aggregate mining, they can be minimized and adverse effects can be avoided. A carefully prepared and implemented operational plan will keep dust and noise within the required regulatory limits.

Dust Control

The word "dust" is used generically to describe fine particles that are generally less than 75 microns (μm) in diameter and that can be transported in the atmosphere. Dust in the urban environment commonly includes sources from industry, vehicles, coal and wood smoke, and particles from the soil. Typically, the dust associated with aggregate operations consists of particles from exposed soil and rock.

The presence of dust sometimes raises concerns that are not directly proportional to its impact on human health and the environment. Dust concentrations, deposition rates, and potential impacts tend to decrease rapidly away from aggregate operations. Federal, state, and local regulations put strict limits on the amount of airborne material that may be released from an aggregate site, especially dust that could be inhaled.

Blasting, excavation, loading and unloading material, stockpiles, and haul roads may be nonpoint sources of "fugitive" dust. Point sources, such as drilling, crushing, screening, and conveying, may also generate dust (Fig. 25). Site conditions, including rock properties, moisture, ambient air quality, air currents and prevailing winds, the physical size of the operation, production levels, and other nearby sources of dust, affect the amount of dust generated during aggregate mining.

The impacts from operations-generated dust commonly can be mitigated through process design and engineering and by the use of dry dust collection or wet suppression systems. Controlling fugitive emissions commonly depends on good housekeeping practices. Measures to reduce dust include

- Controlled blasting;
- Careful location of process equipment and stockpiles;
- Dust collection on drill rigs and stationary process equipment;
- Use of telescopic chutes, dust skirts, and screen covers;
- Reducing drop height of dusty material;
- Use of sweepers;
- Water or chemical applications on haul roads and rubble piles (Fig. 26);
- Control of vehicle speeds; and
- Construction of windbreaks, buffer zones, and plantings.

The creation of buffer zones and construction of windbreaks and plantings can restrict transport of dust. Dry dust collection systems include the use of enclosures and covers on conveyors, screens, and crushers and the use of vacuum systems and bag houses, which remove dust before the air stream is released to the atmosphere (Fig. 27). Wet dust suppression systems consist of pressurized water (or surfactant treated water) sprays located at dust-generating sites, such as conveyors, crushers, and screens. Suppression systems can also be used to wet loads before vehicles leave the plant.

Dust has the potential for being an occupational health concern, if it contains specific types and high concentrations of respirable crystalline silica. Silica is

Dust Control

"FUGITIVE" DUST

Fig. 25. Dust concentrations and potential impacts are largely confined to an aggregate operation.

CONTROL BY WETTING

Fig. 26. Water trucks play a key role in minimizing fugitive dust in and around aggregate operations.

VACUUM SYSTEM

Fig. 27. This enclosure is equipped with a vacuum system (notice the air ducts coming out of the side of the building) to reduce the dust generated by crushing and screening equipment.

nontoxic and safe except where specific crystalline forms of respirable size occur in dust that workers can breathe. Before World War II, some workers in mines and quarries extracting and processing silica-bearing rock, who were exposed to breathing dust containing high concentrations of crystalline silica, developed silicosis or other severe respiratory illnesses. Silicosis is caused by chronic over exposure such as in an occupational environment. Dust suppression and collection equipment are now standard in the United States, and, as a result, the number of cases of silicosis has declined dramatically since 1950.

A concern about the possible presence of asbestiform minerals in industrial minerals has recently developed, especially in regards to worker safety. The asbestos minerals contain silica and magnesium; some also contain calcium and iron. A rock that does not contain silica and magnesium will not contain asbestos. Asbestiform minerals form only in metamorphic rocks or in a few fairly uncommon types of intrusive igneous rocks. Only a few metamorphic rocks, even those containing silica and magnesium, contain asbestiform minerals. Therefore, an unaltered sedimentary rock, such as high purity limestone, has neither the ingredients nor the geologic origin that promotes the creation of asbestos minerals. In areas where all the geologic conditions exist, an examination of quarry reserves for the presence of asbestos is prudent. Where asbestos occurs, it is possible to isolate that zone in a quarry and work around it. In addition, effective dust control measures help prevent exposure to asbestos minerals.

Noise Control

The primary sources of noise from aggregate extraction are blasting, earth-moving equipment, processing equipment, and truck traffic. Sound travels farther in dense, cold air than in warm air, and when there are atmospheric inversions. The impacts of noise depend on:

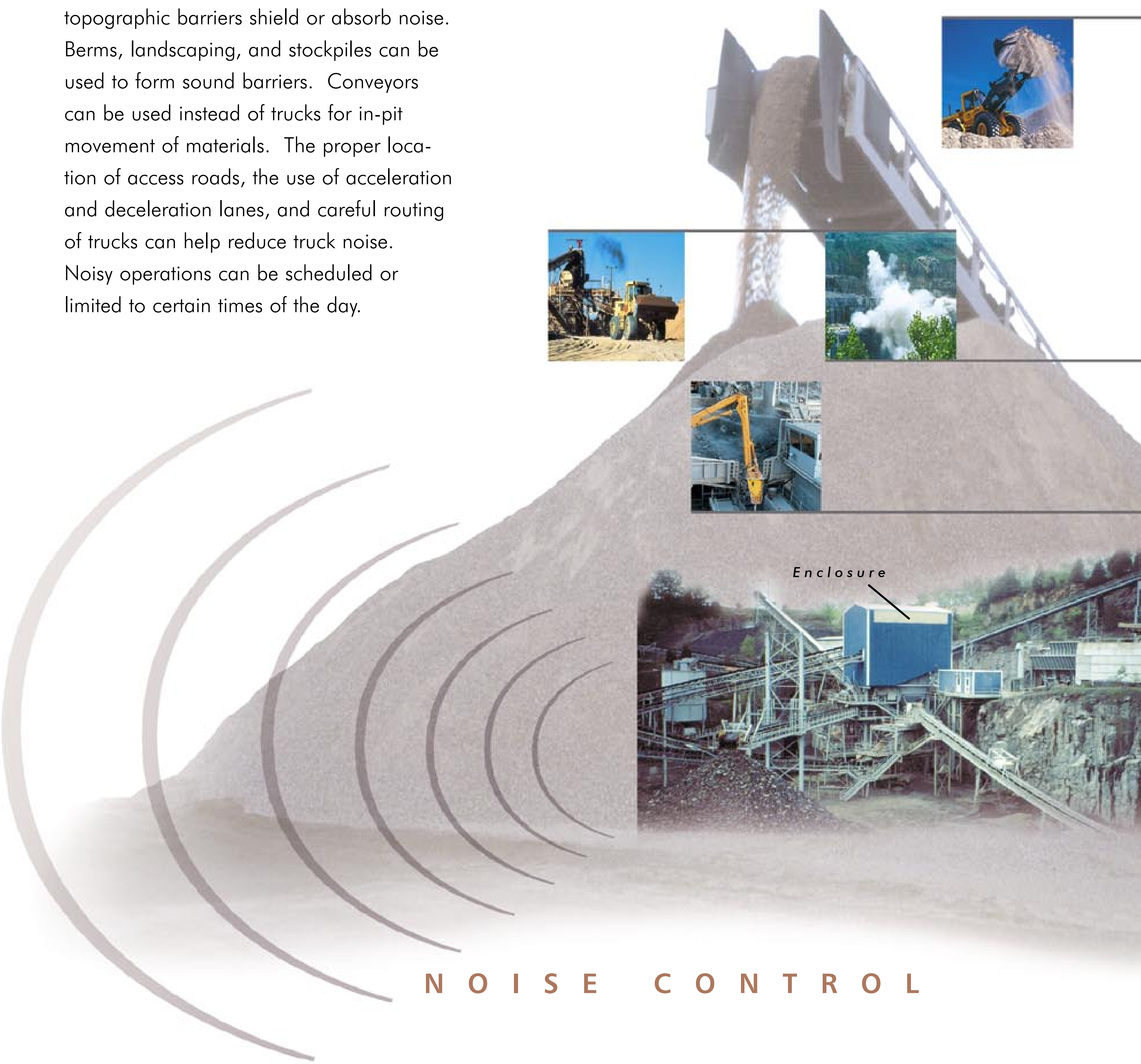
- Sound source;
- Topography, land use, and ground cover of the surrounding site;
- Climatic conditions; and
- Sensitivity of receivers.

The beat, rhythm, and pitch of noise affect the impact of the noise on the receiver. The accustomed level of background noise is an important factor in determining a person's tolerance to a new noise. In an urban or industrial environment, background noise may mask noise from an aggregate operation, whereas the same level of noise from an operation in a rural area or a quiet residential neighborhood may be more noticeable. If a specific noise is identifiable, it tends to be noticed. For example, the noise from a single truck can commonly be distinguished from an equally loud volume created by automobile traffic.

Aggregate operators are responsible for assuring that the noise emitted from the operations does not exceed the level set by regulations. Acoustic maps can be prepared to chart sound sources and determine corrective action so that the impacts of noise can be mitigated through various engineering techniques. Means for limiting noise from mobile equipment include the use of mufflers, "smart" backup alarms that adjust their volume relative to ambient noise levels, broadband alarms, and the use of strobe light back-up alarms at night. Selecting low-noise plant equipment, such as rubber or urethane screens and chute liners, flexible equipment mounting systems, and locating noisy equipment in sound-deadening (acoustical) enclosures can help limit noise from stationary equipment (Fig. 28).

Equipment can be located so that naturally vegetated areas, quarry walls, or topographic barriers shield or absorb noise. Berms, landscaping, and stockpiles can be used to form sound barriers. Conveyors can be used instead of trucks for in-pit movement of materials. The proper location of access roads, the use of acceleration and deceleration lanes, and careful routing of trucks can help reduce truck noise. Noisy operations can be scheduled or limited to certain times of the day.

Fig. 28. Noisy equipment can be located below ground level in quarries and can be placed in sound-deadening enclosures or behind barriers such as stockpiles.



N O I S E   C O N T R O L

Protecting Water Resources

Potential impacts to water resources, and the techniques to avoid those impacts, vary from site to site, just as the techniques for extracting and producing aggregate vary according to the type of material being produced and the natural site conditions.

Surface Water and Stream Channels

If aggregate extraction involves the removal of vegetation and soil cover, standard engineering practices can be followed to control erosion and sedimentation. The amount of ground disturbance for facilities can be limited by making roads, drainage ditches, and work areas fit the site conditions. Disturbed areas can be covered with mulch, vegetation, or other protective cover, and they can be protected from storm water runoff by the use of dikes, diversions, and drainage ways. The amount of disturbance during excavation can be minimized through mine planning and concurrent reclamation. Sediment can be retained on site by using retention ponds and sediment traps. Aggregate mining may change runoff patterns and increase the suspended sediment load of streams. Retaining the runoff in filtration basins and filtering or containing wash water can mitigate these potential impacts.

Mining sand and gravel from stream channels has the potential to create cascading environmental impacts (impacts that create secondary impacts). The nature and severity of cascading impacts are highly dependent on the geologic setting and characteristics of a stream. For example, one set of cascading impacts can be a result of extracting too much sand and gravel from an eroding stream. (The impacts may be less serious or inconsequential in a stream that is depositing sand and gravel.) Removing sand and gravel can cause an increased stream gradient at the site of excavation and a decrease in bedload, which might cause stream erosion in an upstream or downstream direction. Stream erosion can, in turn, cause bank failure and the undercutting of structures (Fig. 29). In-stream mining can also result in changes in the sediment load, lowering of alluvial

Fig. 29. These photos of the same location show changes caused by intensive illegal in-stream sand and mining operations. Mining along a 30-mile stretch of the river caused erosion, called head cutting, and extensive damage for at least another 35 miles upstream.

water tables, and stagnant low flows. All of these impacts can result in major changes to aquatic and riparian habitat.

One method of preventing or minimizing impacts from in-stream mining is to define a minimum elevation for the deepest part of the channel along the river and to restrict mining to the area above this line. Another method is to estimate the annual bedload of a stream and restrict extraction to that value or some percentage of it. However, it is difficult to determine the actual annual bedload. A third method is to gain an understanding of the behavior and dynamics of a stream and to design extraction techniques with those dynamics in mind. Although mining sand and gravel from stream channels may be done in some places with little impact to the environment, mining activities should be conducted within the parameters established by nature. In some situations, aggressive extraction activities can dramatically impact a stream channel.

Restoring streams or mitigating the impacts to environments that have suffered from in-stream mining normally requires reduction or cessation of the removal of sand and gravel. Stream recovery from impacts caused by sand and gravel mining is highly dependent on the local geologic conditions and, therefore, can either be quite fast or take decades (Fig. 30).

Groundwater

Predicting and controlling environmental impacts to a groundwater system is relatively easy with most sand and gravel deposits and with rocks that have well-defined hydrologic properties and boundaries. However, predicting impacts to a hydrologic system can be extremely difficult in some other settings, particularly bedrock with fracture flow and bedrock in cavernous limestone areas.

Groundwater flow in springs, gaining streams, and wells may be impacted by nearby aggregate operations that pump groundwater from the pit or quarry. The impacts to the water table from dewatering can be monitored by use of observation

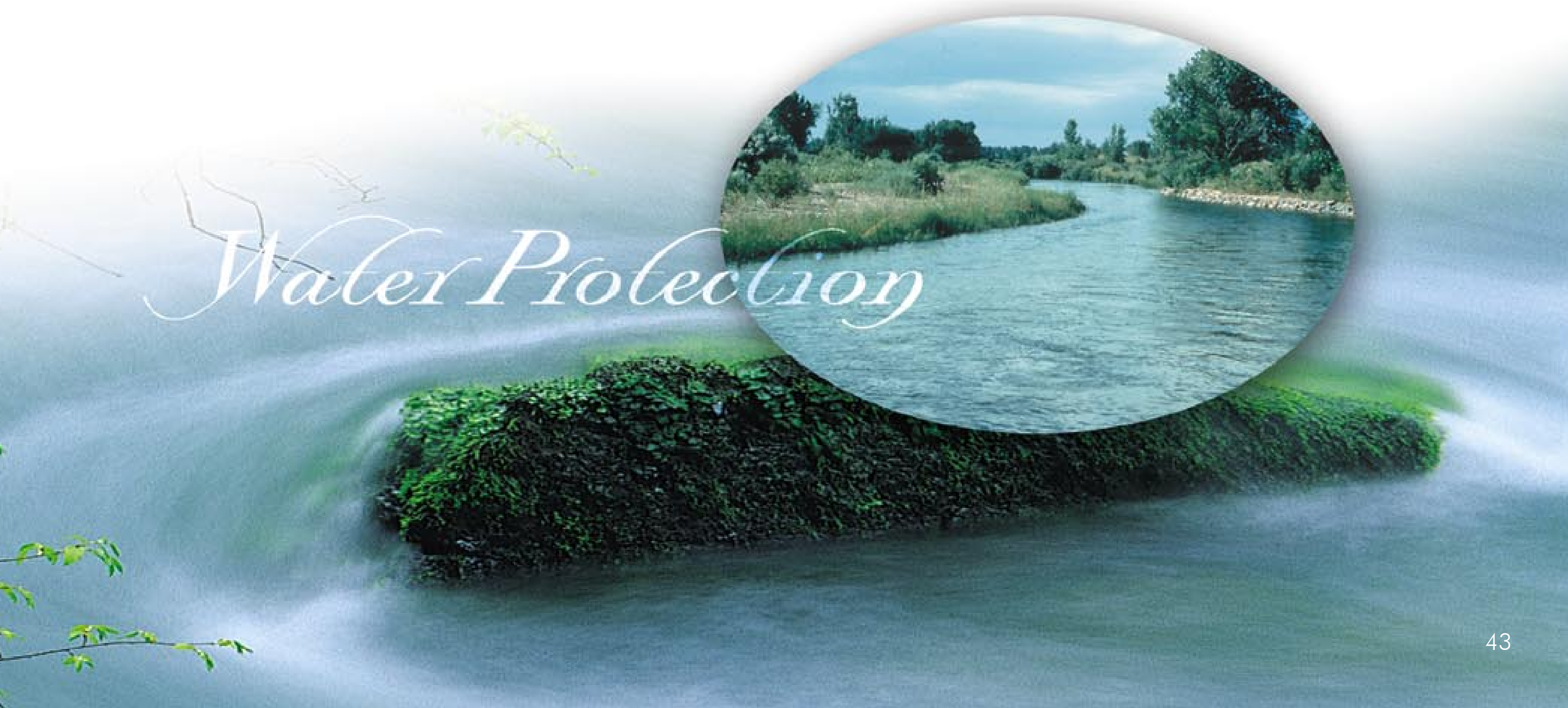


Fig. 30. This stream, previously mined for sand and gravel, has been restored to replicate the natural system.

wells; recharging aquifers or augmenting flows to streams with water that drained into a pit or quarry can maintain water levels.

Any opening in the Earth can act as a conduit for the entry of contaminants. A pit or quarry may act as such a conduit if the potential impacts are not properly controlled. Maintenance of equipment may result in the accidental spill of chemicals, such as solvents or fuels that could contaminate surface or groundwater. Leaking storage tanks may pollute surface or groundwater. Limiting the amount or type of chemicals on hand, storing all chemicals and petroleum products in impervious containment areas (Fig. 31); careful operating, safety, and training procedures; and controlling surface runoff can prevent these types of impacts. In critical environmental areas, biodegradable oils can replace standard oils, such as those used in hydraulic systems, in order to avoid long-term pollution in the event of an accidental spill.

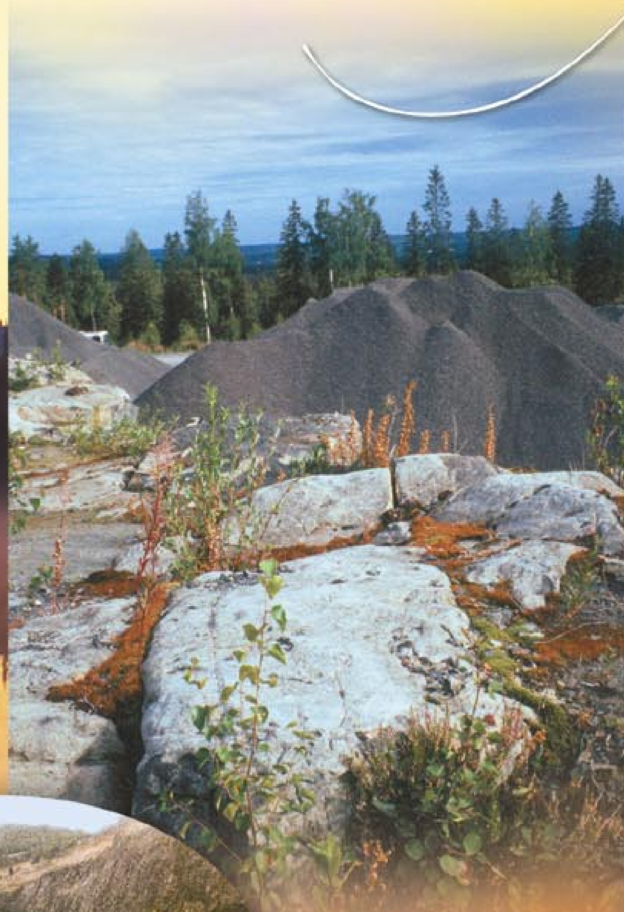
Some karst areas (landscapes formed primarily through the dissolving of rock), especially those with high aquifer storage and conduit flow, are particularly susceptible to cascading environmental impacts. In such areas, the overburden or target limestone may act as a protective cover for an underlying aquifer. If the protective cover is removed, the hole created by the mining operation may act as a sinkhole and convey contaminated surface water into the groundwater system. Poorly designed or poorly controlled blasting in some karst areas can fracture the surrounding rock, resulting in the disruption of groundwater-flow paths. Changes in the patterns of groundwater movement can cause changes in the quantity of water that flows through the system and in the degradation of groundwater quality. Groundwater pumping associated with quarrying may reduce the yields of down-gradient springs or wells, may cause sinkhole collapse, and may negatively impact some karst habitat.

These types of potential environmental issues can be avoided by designing and operating pits or quarries within the limits of the natural geologic and hydrologic systems. Environmental risk analysis and environmental management systems are valuable tools the aggregate industry can use to help maintain acceptable levels of environmental protection. The final step in the aggregate mining cycle is reclamation. A strategy for reclaiming the disturbed land and its ecosystem should be a part of every aggregate mine plan (Fig. 32).

Fig. 31. Properly constructed containment facilities can protect groundwater and aquifers from potential fuel oil spills.

CONTROLLING SPILLS

A sound and economical approach is to plan reclamation before the aggregate is extracted.



RECLAMATION

Fig. 32. This tidal-zone park created in Quarry Cove, near Newport, OR, allows visitors close views of marine life.

"A diamond in the rough is nothing compared to a diamond which has been polished in a beautiful setting. My grandmother, Mrs. R. P. Butchart, found this diamond, and my grandfather provided the setting."

R. Ian Ross
1918-1997

PROVIDING FOR THE FUTURE

4

Society has created a continuing demand for high quality aggregate, which must be obtained without causing unacceptable environmental impacts. The aggregate industry can make use of reclamation, recycling, and environmental risk management to help protect the environment while meeting this demand. However, to ensure a ready supply of aggregate, government, industry, and the public must accept the responsibility to identify and resolve legitimate concerns, by constructively contributing to a decision-making process that addresses a wide range of objectives and interests.

Reclamation

Mined-out aggregate pits and quarries are converted into second uses that include home sites, wildlife refuges, golf courses, watercourses, botanical gardens (Fig. 33), and wetlands. Restoration to the original condition is seldom possible. We do not yet have the level of information and skill required to return ecosystems exactly to their original structure nor is the same amount of excavated material available to fill a pit and return it to the original ground contours. In addition, the new land is environmentally unstable, and exotic species invade disturbed sites. Many native organisms do not return or fill the same ecological niche.

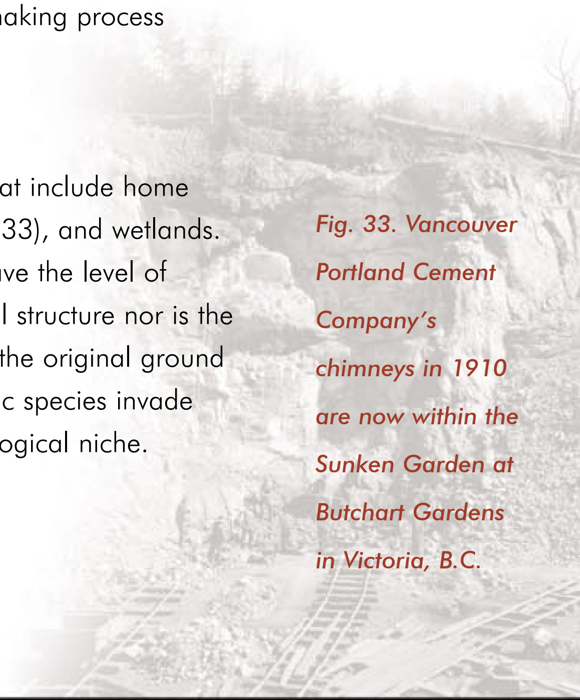


Fig. 33. Vancouver Portland Cement Company's chimneys in 1910 are now within the Sunken Garden at Butchart Gardens in Victoria, B.C.

Butchart Gardens

RECLAMATION

Instead of returning an area to its original condition, a more-realistic approach is to approximate the new habitat as closely as possible to its original function and to recapture the landscape character.

The oldest reclamation approach is nature itself. Given enough time, a suitably small site, and stable adjacent ecosystems, disturbed areas may recover by themselves. Researchers studying the Niagara Escarpment in Ontario, Canada, recognized natural cliffs as special places that provide refuge for rare species of plants and animals. Much of the vegetation on the older walls of carbonate rock quarries abandoned from 20 to 100 years ago replicates the biodiversity of natural landforms.

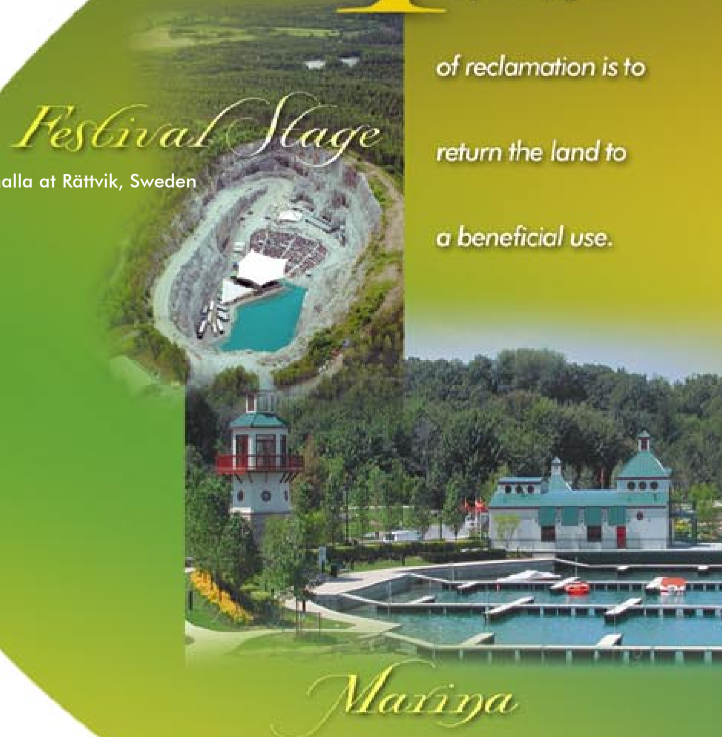
In some areas, long-term natural recovery alone may not bring about the specific changes people find desirable. The natural reclamation process of abandoned or mined-out quarries can be accelerated through a process called landform replication. Through carefully designed "restoration" blasting, slopes, buttresses, and headwalls of rock quarries can be created to produce landforms that can be planted with assemblages similar to those that occur on natural valley sides.

Reclamation can blend natural and human needs. The quarry at Quarry Cove on the Newport, Oregon, coastline has been converted to a "natural" biological laboratory (Fig. 32, p. 45). Quarry Cove provides a variety of wildlife habitats and is expected to have species diversity comparable to a natural tidal pool. The quarry is wheelchair accessible, and all visitors can view nature taking its course as marine life invades the area.

Reclamation can focus on human needs including residential, business, and recreational uses (Fig. 34). The festival stage Dalhalla at Rättvik, Sweden, was built in Draggängarna, which was a former limestone quarry. The resulting natural amphitheater seats 3,000 people. In this unique setting, Dalhalla hosts operas with stage and light settings adapted to the mighty rock walls, all types of choir music, jazz and big band concerts, and symphonic and chamber music. Dalhalla demonstrates that holes in the ground can be filled with nearly anything — even music!

Fig. 34

The primary goal of reclamation is to return the land to a beneficial use.



Dalhalla at Rättvik, Sweden

Hidden Lakes Housing Marina
Detroit, MI

Reclamation

Bend Area Master Plan near Grand Rapids, MI, consists of a county park, private recreation and waterfront housing.

Columbus Cliffs Office Park, Columbus, OH

Columbus Cliffs Lakefront Condominiums, Columbus, OH

Black Diamond Golf Course Orlando, FL

Fig. 35.
Some construction material is recycled at the demolition site using portable equipment.

R E C Y C L I N G

Recycling

Much of the infrastructure in the United States, particularly older roads, bridges and buildings, is in need of repair or replacement. Demolishing roads and buildings generates large quantities of waste as asphalt and concrete, and much of this material can be recycled. Even old railroad ballast can be reused. Today, used asphalt pavement and concrete yield more than 200 million tons (180 metric tons) per year of recycled aggregate. Recycling saves huge amounts of space in landfills and allows natural aggregate to be used in applications that require higher quality.

The decreasing availability of landfill space, tipping fees, which are the costs of depositing material in landfills, and environmental concerns have worked to stimulate the recycling of asphalt- and concrete-bound aggregate. There are two approaches to recycling aggregate — hauling the concrete or asphalt debris to the nearest permanent recycling facility for crushing and screening, or removing and processing the debris at the demolition site, where the aggregate is reused as soon as it is processed (Fig. 35). Recycling at the demolition site reduces heavy materials hauling, thereby reducing energy use, transportation costs, and wear and tear on roads and equipment.

Asphalt paving materials recovered from demolished or refurbished roads are valuable for the asphalt binder as well as the aggregate. More than 100 million tons (90 metric tons) per year of worn-out asphalt pavement is recovered. Similarly, about 100 million tons (90 metric tons) per year of concrete is recycled into usable aggregate.

The future for recycling aggregate will be influenced by landfill availability, greater product acceptance, government recycling mandates, regional economics, increased availability of material for recycling, and the demand for sustainable and wise use of resources.

REGULATORY FOUNDATIONS OF STEWARDSHIP

All states are subject to federal law, whether land within state boundaries is federal, state, or privately owned. Indian tribal lands are considered sovereign and are subject to federal law, but without state jurisdiction or taxation.

FEDERAL REGULATIONS

At the federal level, the Mine Safety and Health Administration (MSHA) establishes occupational safety and health standards for miners.

The **General Mining Act of 1872** encouraged exploration of federal lands for mineral resources, including common minerals. In 1955, Congress removed common construction materials (termed "saleable minerals," including aggregate) from the mining law and made them available through a contract or bidding process at the discretion of the land management agency.

The **Water Quality Act of 1965**, and the Federal Water Pollution Control Act Amendments of 1972 (retitled the Federal Clean Water Act), were enacted to provide efficient programs of water pollution control. Every major point source (a confined conveyance such as a pipe or ditch draining a pit or quarry) from which pollution is discharged into the waters of the United States, requires a federal-state permit.

The **Air Quality Act of 1967** (amended with the Clean Air Amendments of 1970 and 1990) gives states and local governments the responsibility to develop and implement plans to address airborne pollution at its source.

Other federal regulations that indirectly relate to the production of aggregate resources include the **Fish and Wildlife Resource Act,** the **Fish and Wildlife Coordination Act,** the **Migratory Bird Treaty Act,** the **Endangered Species Act,** including the **Rivers and Harbors Act,** the **Coastal Zone Management Act,** the **Emergency Planning and Community Right-to-Know Act,** and the **National Environmental Policy Act**.

STATE REGULATIONS

Some states issue permits for aggregate mining; others leave that authority with local agencies. Commonly, state agencies enforce federal regulations such as air quality, water quality, diversion or impoundment of surface water, and withdrawal of groundwater. At least 37 states regulate non-coal surface mining on a statewide basis. Thirty-five states require some sort of bond or security from the operator. At least 26 states provide for public comment at permit review.

LOCAL REGULATIONS

The federal government encouraged state and local governments to create zoning codes through the Standard Zoning Enabling Act of 1922. The authority of governments to enforce zoning regulations was upheld by the Supreme Court in 1926 in the landmark case of Village of Euclid, Ohio v. Ambler Realty. Since then, every state has enacted zoning legislation. Many states transfer zoning authority to county or municipal authorities. However, some rural areas in the United States remain unzoned.

The United States is made up of over 3,000 counties and many more local governmental authorities. Counties and other local governments may or may not have final permitting authority for aggregate mining. Even where local governments do not have this authority, they commonly influence the aggregate mining by controlling land use activities such as ground disturbance, noise, traffic, aesthetics, storm water, erosion and sedimentation, land use, building codes, hours of operation and regulation of utilities.

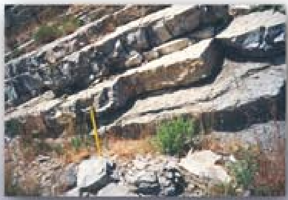
Environmental Risk and Management Systems

By its very nature, aggregate extraction involves development in three dimensions. What is below the land surface cannot completely be characterized before mining and the exact type and extent of adverse impacts that might arise is almost always unknown. To further complicate matters, the physical, biological, and cultural characteristics of an area impacted by or impacting an aggregate operation are in a constant state of change, and those changes may modify the environmental impacts of mining. For example, an environmentally sound crushed stone operation could start contributing to environmental damage if the nearby groundwater system is modified by natural conditions, such as a prolonged drought, or by human activity, such as increased groundwater withdrawal by a nearby water-well field.

Environmental risk analysis uses a systematic approach to identify potential environmental impacts and hazards, the consequences of those impacts or hazards, and the likelihood of those impacts or hazards becoming real. The environmental risks are evaluated, and opportunities for risk reduction are identified.

Environmental risk analysis generally is a part of an overall environmental management system that can be fully integrated within aggregate mining operations. Key steps of an environmental management system include

- Establishing an environmental policy that defines desired outcomes of the management system;
- Identifying and understanding environmental legislative requirements;
- Identifying and understanding potential environmental impacts that may result from the operation;
- Identifying performance targets to limit potential impacts;
- Developing management action plans to achieve each target, and



- Monitoring performance, reviewing the management plan, and taking corrective action.

The National Stone, Sand, and Gravel Association has created an Environmental Management System template that offers practical guidance for implementing environmental initiatives. This template can be a starting point for meeting broader standards, such as International Organization for Standardization (ISO) 14001, which is an internationally recognized set of environmental standards. An effective Environmental Management System can help organizations maintain environmental compliance, improve employee and community relations, and create economic benefits. For example, the opposition to seeking a permit could be minimized and thus the prospect of costly and time-consuming litigation reduced or eliminated.

Balancing our Needs

During the next 25 years, the United States could use about 100 billion tons (90 billion metric tons) of aggregate — the amount of aggregate needed to construct every building or highway built in the United States during the 20th century. Given the current state of the mining industry, and allowing for reasonable technological progress, plus the use of alternate resources, recycling, and reclamation, the aggregate industry is capable of maintaining a resource supply while reducing environmental impacts. There are challenges. Obtaining permits to initiate new aggregate operations is extremely difficult. The aggregate industry faces heavy opposition to opening a new pit or quarry in an area where aggregate has never been mined. This opposition has reduced the number of permits for new pits and quarries. Instead of exploring for new sources of natural aggregate reserves, the industry sometimes finds it more expedient to effect acquisitions and mergers to acquire and maintain required levels of reserves. These measures only postpone the inevitable encroachment upon and sterilization of potential aggregate resources. To protect aggregate resources from avoidable conflicts, it is necessary for local jurisdictions to have a clearly defined policy to include natural resource development in the comprehensive planning process.

Today, over a third of the individual states in the U.S. each produce more aggregate than the entire Nation did at the start of the 20th century.

Fig. 36

TOELLE COUNTY, UTAH

Mesa Arch, Canyon Lands, Utah

Between 1990 and 2000, the population of Toelle, Utah, increased 51.3 percent to 40,735. As demand for construction and aggregate increased, the expanding neighborhoods began encroaching on aggregate operations. The new residents considered the appearance, noise, dust, and traffic associated with the aggregate operations and the odors from the asphalt plants to be a nuisance. Pressure was brought to bear on operators and county leaders to restrict operations. The situation reached critical limits in the late 1990s when residents, producers, and the county became entangled in litigation.

During 2001, the Toelle County Commission approved the addition of "Chapter 27 — Mining, Quarry, Sand and Gravel Excavation Zone (MG-EX)" to its Uniform Zoning Ordinance. The new zoning district allows and protects the crushed stone and sand and gravel industry and also protects the environment. The zone was designed to assure that aggregate operations do not impact adjoining uses and are not encroached upon by surrounding noncompatible land uses, such as residential development.

This approach provides public input and includes strict requirements for the application, operation, and reclamation of pits or quarries. Once the zoning is in place the process of getting final approvals for operation is streamlined, and producers are assured the opportunity for continual operation (renewable every 5 years), as long as they follow best management practices. The advantage is that aggregate extraction and related activities are separated from other noncompatible land uses. The ordinance has been presented to other jurisdictions to consider as a model for creating new mineral extraction zones.

West Temple and Towers of the Virgin

Utah

One step toward ensuring a continuing and uninterrupted supply of aggregate is to identify and protect existing resources. This step is particularly important where supply is limited or in high-demand areas, even where sources of aggregate are abundant. Land-use planning and aggregate resource development, which includes the associated noise, traffic, and visual impacts, are commonly controlled by zoning at the local community level. In addition to setting standards for aggregate extraction, zoning can be used in a number of ways to protect aggregate resources (Fig. 36):

- Potential aggregate resources can be mapped into existing use districts, typically agricultural, industrial, or open space with mining considered a special exemption;
- Overlay districts can be created that identify where aggregate resources are located and where mining operations would not create a conflict; and
- Special extraction districts can be created in which mining is considered to be the best use in the district.

Zoning commonly permits a variety of land uses and can be subject to change. Therefore, zoning tends to be effective only for sites that are likely to be developed in the near future. The following long-term techniques have been used to protect aggregate resources and involve actions that clearly identify the land for aggregate extraction:

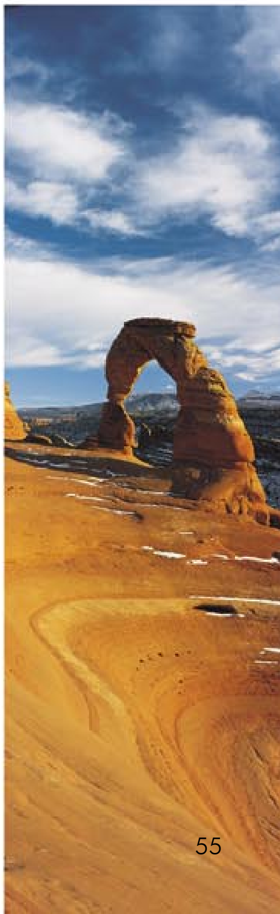
- Operators purchase or lease the land and a surrounding buffer area;
- Local governments reimburse land owners or offer tax incentives in return for an agreement to delay development for other purposes until aggregate is removed; and
- Local governments buy resources for later resale to operators; this approach is referred to as "land banking."

Governments of some U.S. states, many provinces or territories in Canada and Australia, and many countries within the European Union and elsewhere have developed Sustainable Mineral Resource Management policies that recognize minerals and mining in general — and the aggregate industry in particular — as key sectors contributing to jobs, a high quality of life, and wealth for its citizens. Most of these mineral policies identify actions that should be undertaken to help industry meet society's demand for aggregate.

Key Sustainable Mineral Resource Management issues include

- Defining the need and estimating the future demand for aggregates;
- Assessing the distribution, quality, and availability of aggregates;
- Identifying, assessing, and mitigating environmental impacts of aggregate development;
- Identifying preferred areas for aggregate extraction;

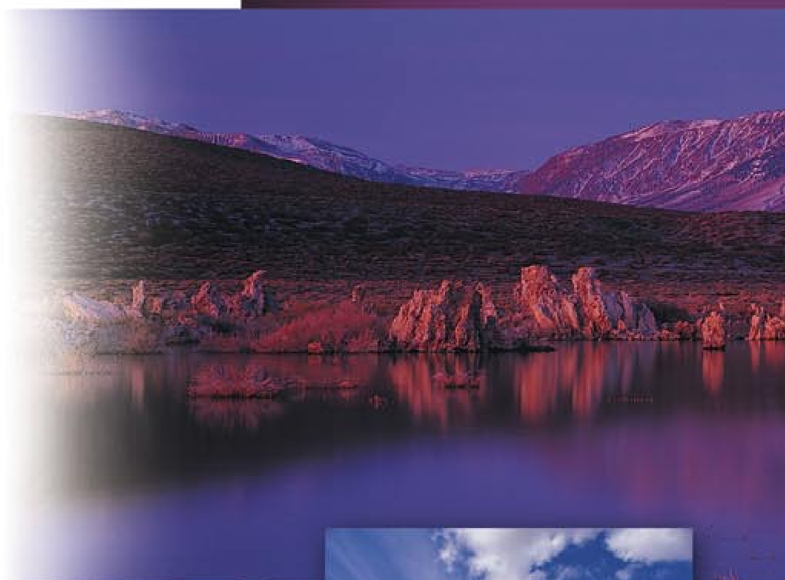
Delicate Arch,
Arches Natl. Park, Utah



- Considering the use of imports, exports, and inter-regional supplies;
- Encouraging multimodal transportation of aggregate; and
- Incorporating aggregate resource needs in plans for future development.

The government, industry, and the public must cooperate at the regional and local planning levels for sustainable aggregate extraction to be successful. Each of the primary stakeholders — government, industry, public, and other organizations — must accept certain responsibilities. Government has the responsibility to develop the policies, regulatory framework, and economic incentives that provide the climate for success. Industry must work to be recognized as a responsible corporate and environmental member of the community. The public and nongovernmental organizations have the responsibility to become informed about aggregate resource management issues. All stakeholders have a responsibility to identify and resolve legitimate concerns by constructively contributing to a decision-making process that addresses not only their own but a wide range of objectives and interests.

Aggregate resources are essential to maintain our way of life (Fig. 37). Developing those resources will create environmental challenges, and science can provide critical information that can be used to address those challenges. As a society, we must develop an appropriate balance for sustaining both aggregate resources and environmental resources.



AGGREGATE IS ESSENTIAL

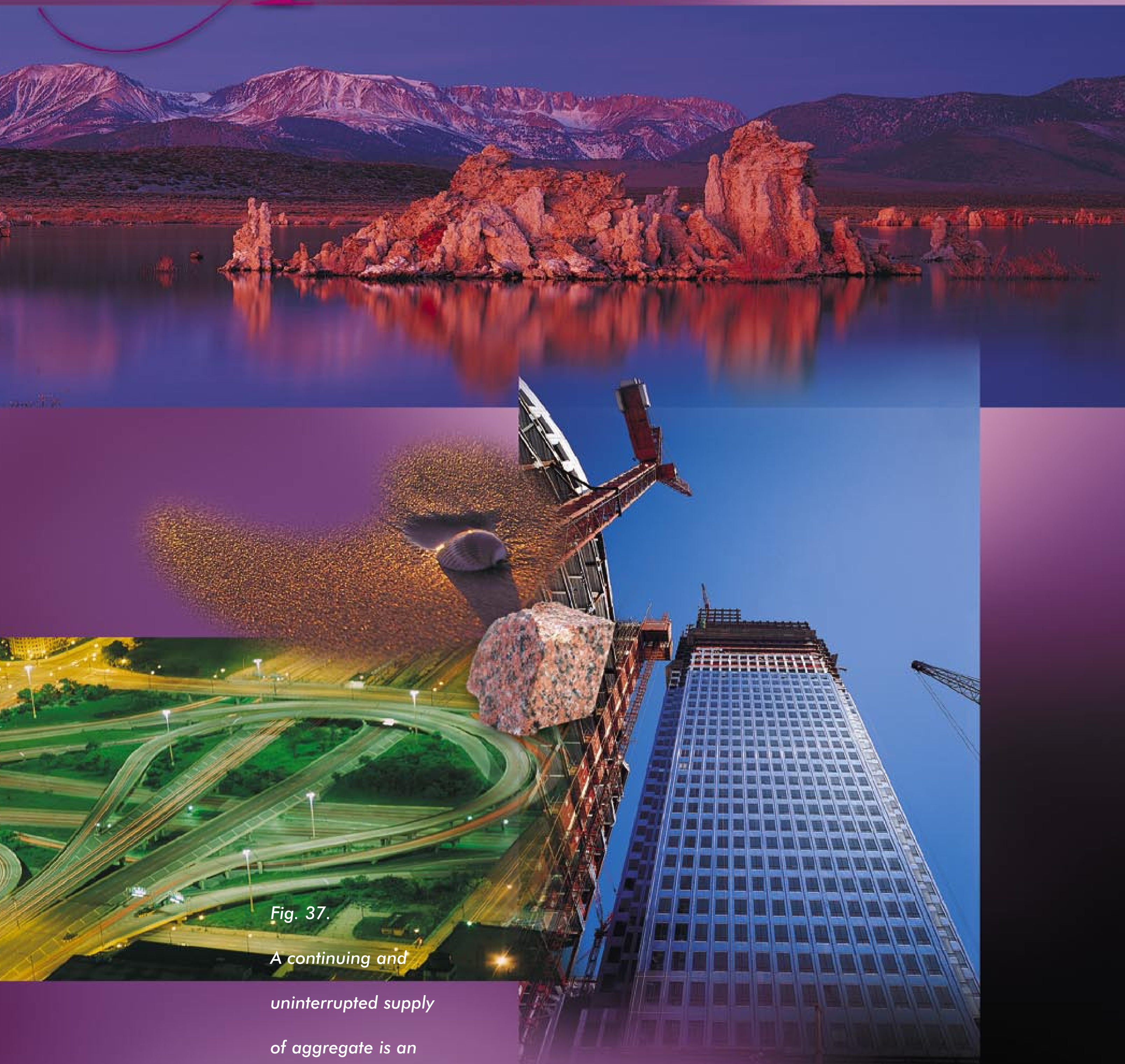


Fig. 37.

A continuing and uninterrupted supply of aggregate is an indisputable need.

GLOSSARY

aggregate Hard materials such as sand, gravel, and crushed stone, used for mixing with cementing or bituminous material to form concrete, mortar, or asphalt, or used alone as in railroad ballast, road base, landscaping rock, or graded fill.

cement A manufactured powder, which when mixed with water makes a plastic mass that will "set" or harden. It is combined with aggregate to make concrete.

chert A hard mineral composed mainly of microscopic silica crystals. It commonly occurs in limestone and is also called flint.

concrete A mixture of cement, sand, gravel, and water, which will "set" or harden to a rock-like consistency.

crushed stone The product resulting from the artificial crushing of rocks, boulders, or large cobblestones. Substantially all faces of crushed stone have resulted from the crushing operation.

dolomite A carbonate sedimentary rock composed mainly of the mineral dolomite, $CaMg(CO_3)_2$. Commonly referred to by the aggregate industry as limestone.

granite A general term for coarse-grained igneous rocks that formed deep within the earth from cooled magma. Unlike the strict geologic definition, the term granite, when used by the aggregate industry, may include dark-colored igneous rocks such as gabbro, as well as coarse grained metamorphic rocks such as gneiss.

gravel Unconsolidated, naturally occurring rounded rock fragments resulting from erosion, consisting predominantly of particles larger than sand, such as boulders, cobbles, pebbles, and granules.

groundwater That part of the subsurface water in the zone where all the voids are filled with water. Loosely, all subsurface water as distinct from surface water.

igneous rock A rock that formed from magma that cooled while still deeply buried within the Earth. One of three main classes of rocks.

karst A type of topography that is formed primarily by dissolution of limestone, gypsum, and other soluble rocks. Karst areas are characterized by sinkholes, caves, and underground drainage.

limestone A carbonate sedimentary rock composed mainly of calcium carbonate, $CaCO_3$, primarily in the form of the mineral calcite. In the aggregate industry, the term limestone frequently includes dolomite and marble (metamorphosed limestone or dolomite).

magma Melted rock material generated at high temperatures within the Earth. When magma flows onto the Earth's surface it is called lava.

metamorphic rock A rock that formed from deeply-buried pre-existing rock that was altered by temperature and pressure. Examples include gneiss, marble (metamorphosed limestone or dolomite), and quartzite (metamorphosed sandstone). One of three main classes of rocks.

sand Granular material resulting from rock disintegration, consisting primarily of particles having a diameter in the range of 2 mm (about the size of a pin head) to 1/16 mm (like very fine sand paper).

sedimentary rock A rock resulting from the consolidation from loose sediment that has accumulated in layers. One of three main classes of rocks.

traprock A general term used by the aggregate industry for fine-grained, generally dark-colored, igneous rocks that formed from cooled lava. Also referred to as basalt.

CREDITS

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Inside Front Cover/Title Page — Bridge, Shell in sand (Digital Vision).

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Jackson, J.A., ed., 1997. *Glossary of Geology*, 4th Edition: American Geological Institute, Alexandria, VA, 769 p.

Kuula-Väisänen, P., and Uusinoka, R., eds, 2001, *Aggregate 2001 — Environment and economy*: Tampere University of Technology, Tampere, Finland, 510 p. (This comprehensive collection of individual papers provides case histories of global issues related to aggregate resources.)

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Teoprdei, V.V., 2002, "Crushed stone:" U.S. Geological Survey *Minerals Yearbook*, pp. 72.1-72.6 and 27 tables. (The U.S. Geological Survey *Minerals Yearbooks* provide comprehensive statistics about aggregate resource production.)

Sources of

ADDITIONAL INFORMATION

Aggregate Industry Periodicals

Aggregates Manager (United States)
www.aggman.com

Pit & Quarry (United States)
www.pitandquarry.com

Rock Products (United States)
www.rockproducts.com

Quarry Management (United Kingdom)
www.qmj.co.uk

Organizations and Web Sources

The organizations listed here offer a variety of information about aggregates and the industry. Individual state geological surveys are a good source of information about specific areas. The state survey listings and web sites appear on the following page.

American Institute of Professional Geologists
www.aipg.org

Association of American State Geologists
www.kgs.ukans.edu/AASG/AASG.html

Association of Engineering Geologists
www.aegweb.org

International Association of Engineering Geologists
Commission No. 17 on Aggregates
www.sgu.se/hotell/iaeg/iaeg_e.html

Minerals Information Institute
www.mii.org

National Stone, Sand, and Gravel Association
www.nssga.org

Society for Mining, Metallurgy and Exploration, Inc.
www.smenet.org

USGS science for a changing world

U.S. Geological Survey
www.usgs.gov

STATE GEOLOGICAL SURVEYS

Geological Survey of Alabama
www.gsa.state.al.us

Alaska Division of Geological and Geophysical Surveys
wwwdggs.dnr.state.ak.us/

Arizona Geological Survey
www.azgs.state.az.us

Arkansas Geological Commission
www.state.ar.us/agc/agc.htm

California Geological Survey
www.consrv.ca.gov/cgs/

Colorado Geological Survey
http://geosurvey.state.co.us/

Connecticut Geological and Natural History Survey
http://dep.state.ct.us/cgnhs/

Delaware Geological Survey
www.udel.edu/dgs/index.html

Florida Geological Survey
www.dep.state.fl.us/geology/

Georgia Geologic Survey Branch
www.dnr.state.ga.us/dnr/environ/aboutepd_files/branches_files/gsb.htm

Hawaii Geological Survey
www.state.hi.us/dlnr/cwrm

Idaho Geological Survey
www.idahogeology.org/

Illinois State Geological Survey
www.isgs.uiuc.edu/

Indiana Geological Survey
http://igs.indiana.edu/

Iowa Geological Survey Bureau/IDNR
www.igsb.uiowa.edu/

Kansas Geological Survey
www.kgs.ku.edu/

Kentucky Geological Survey
www.uky.edu/KGS/home.htm

Louisiana Geological Survey
www.lgs.lsu.edu/

Maine Geological Survey
www.state.me.us/doc/nrimc/mgs/mgs.htm

Maryland Geological Survey
www.mgs.md.gov/

Massachusetts Geological Survey
www.state.ma.us/envir/eoea

Michigan Geological Survey Division
www.michigan.gov/deq/1,1607,7-135-3306_3334_3568—,00.html

Minnesota Geological Survey
www.geo.umn.edu/mgs/

Mississippi Office of Geology
www.deq.state.ms.us/

Missouri Geological Survey and Resource Assessment Division
www.dnr.state.mo.us/dgls/homedgls.htm

Montana Bureau of Mines and Geology
http://mbmgsun.mtech.edu/

Nebraska Conservation and Survey Division
http://csd.unl.edu/csd.htm

Nevada Bureau of Mines and Geology
www.nbmg.unr.edu

New Hampshire Geological Survey
www.des.state.nh.us/descover.htm

New Jersey Geological Survey
www.state.nj.us/dep/njgs/

New Mexico Bureau of Geology and Mineral Resources
www.geoinfo.nmt.edu

New York State Geological Survey
www.nysm.nysed.gov/geology.html

North Carolina Geological Survey
www.geology.enr.state.nc.us/

North Dakota Geological Survey
www.state.nd.us/ndgs/

Ohio Division of Geological Survey
www.ohiodnr.com/geosurvey/

Oklahoma Geological Survey
www.ou.edu/special/ogs-pttc/

Oregon Department of Geology and Mineral Industries
www.oregongeology.com/

Pennsylvania Bureau of Topographic and Geologic Survey
www.dcnr.state.pa.us/topogeo

Puerto Rico Departamento de Recursos Naturales
www.kgs.edu/AASG/puertorico.html

Rhode Island Geological Survey
www.uri.edu/cels/gel_home/ri_geological_survey.htm

South Carolina Geological Survey
water.dnr.state.sc.us/geology/geohome.htm

South Dakota Geological Survey
www.sdgs.usd.edu/

Tennessee Division of Geology
www.state.tn.us/environment/tdg/

Texas Bureau of Economic Geology
www.beg.utexas.edu/

Utah Geological Survey
http://geology.utah.gov/

Vermont Geological Survey
www.anr.state.vt.us/geology/vgshmpg.htm

Virginia Division of Mineral Resources
www.geology.state.va.us

Washington Division of Geology and Earth Resources
www.wa.gov/dnr/htdocs/ger/ger.html

West Virginia Geological and Economic Survey
www.wvgs.wvnet.edu/

Wisconsin Geological and Natural History Survey
www.uwex.edu/wgnhs/

Wyoming State Geological Survey
www.wsgsweb.uwyo.edu/

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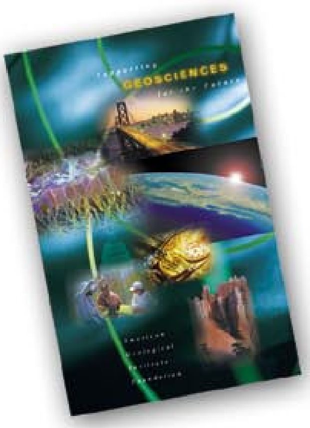

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AGGREGATE and the Environment

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Aggregate resources are vital to our way of life because they are the major raw materials used in construction of roads, rail lines, bridges, hospitals, schools, airports, factories, and homes, but the mining and processing of natural resources such as aggregate commonly raises concerns about potential environmental impacts. Nevertheless, we must have access to a readily available supply of high quality aggregate if we wish to maintain our current lifestyle. This book is designed to help you understand our aggregate resources — their importance, where they come from, how they are processed for our use, the environmental concerns related to their mining and processing, how those concerns are addressed, and the policies and regulations designed to safeguard workers, neighbors, and the environment from the negative impacts of aggregate mining. We hope this understanding will help prepare you to be involved in decisions that need to be made — individually and as a society — to be good stewards of our aggregate resources and our living planet.

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