

Aggregate Resource Availability in the Conterminous United States, Including Suggestions for Addressing Shortages, Quality, and Environmental Concerns

Open-File Report 2011–1119

U.S. Department of the Interior
U.S. Geological Survey

Aggregate Resource Availability in the Conterminous United States, Including Suggestions for Addressing Shortages, Quality, and Environmental Concerns

By William H. Langer

Open-File Report 2011–1119

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
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Aggregate Resource Availability in the Conterminous United States

Abstract Purpose and scope

Background photograph from the Federal Highway Administration



Abstract

One-third of America's major roads are in poor or mediocre condition, and over one-quarter of the bridges are either structurally deficient or functionally obsolete. A 70-percent increase in annual aggregate production may be required to upgrade the transportation infrastructure. Natural aggregate is widespread throughout the conterminous United States, but the location of aggregate is determined by geology and is non-negotiable. Natural aggregate is in short supply in the Coastal Plain and Mississippi embayment, Colorado Plateau and Wyoming Basin, glaciated Midwest, High Plains, and the non-glaciated Northern Plains. A variety of techniques have been used to overcome local shortages, such as the use of substitute materials, recycling, and importing high-quality aggregates from more distant locations.

Although potential sources of aggregate are widespread throughout the United States, many sources may not meet certain physical property requirements, such as soundness, hardness, strength, porosity, and specific gravity, or they may contain contaminants or deleterious materials that render them unusable. Encroachment by conflicting land uses, permitting considerations, environmental issues, and societal pressures can prevent or limit development of otherwise

Aggregate Resource Availability in the Conterminous United States

Abstract Purpose and scope

Background photograph from the Federal Highway Administration



suitable aggregate. The use of sustainable aggregate resource management (SARM) can help ensure an economically viable supply of aggregate. SARM techniques that have successfully been used include (1) protecting potential resources from encroachment; (2) using marginal-quality local aggregate for applications that do not demand a high-quality resource; (3) using substitute materials such as clinker, scoria, and recycled asphalt and concrete; and (4) using rail and water to transport aggregates from remote sources.

Purpose and Scope

This report discusses the types of aggregate, describes the occurrence of good-quality aggregate, and points out where good-quality aggregate is limited. Societal and environmental issues that limit aggregate development also are discussed. Example plans for growth and development are presented.

A similar version of this slide show was given as two separate presentations at the Transportation Research Board 2011 Annual Meeting Workshop 102 on Aggregate Sources Depletion and Future Supply, Washington, D.C., January 23, 2011

Introduction



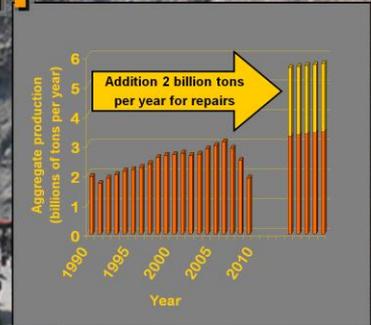
*One third of our major roads
are in poor or mediocre condition.*

*One fourth of our bridges
are structurally deficient
or functionally obsolete.*



According to the American Society of Civil Engineers 2009 Report Card (2009): 1) one-third of America's major roads are in poor or mediocre condition; 2) nearly half of the major urban highways are congested; 3) over one quarter of the Nation's bridges are either structurally deficient or functionally obsolete; 4) capital investments in airports are inadequate; and 5) almost all of the locks on the Nation's inland waterway have exceeded their design life by 20 percent.

Introduction



*One third of our major roads
are in poor or mediocre condition.*

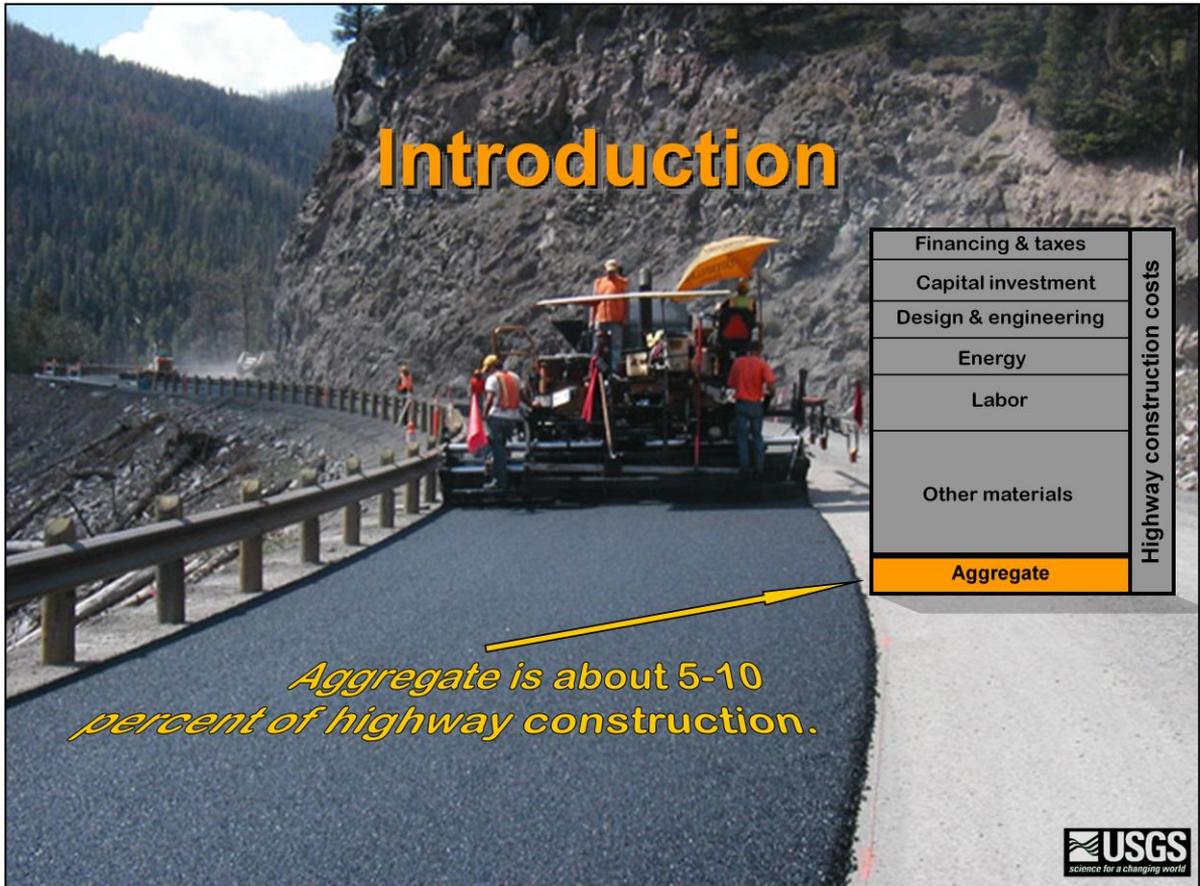
*One fourth of our bridges
are structurally deficient
or functionally obsolete.*



The American Society of Civil Engineers (2009) estimates that nearly \$186 billion annually is needed for 5 years to substantially improve conditions of the Nation's roads and bridges, with an additional \$40 billion needed per year for the remainder of the transportation infrastructure (aviation, rail, and inland waterways).

With aggregates representing 5 to 10 percent of total project costs, those projects would require about \$11.3 to \$22.6 billion worth of aggregate. Assuming aggregate is valued at about \$10 per ton, from 1.1 to 2.3 billion tons of aggregate per year may be required for upgrading and repairing the Nation's transportation infrastructure. This amounts to an increase in aggregate production of about 35 to 75 percent over 2006 levels.

Introduction



Tepordei (1995) reported that the total cost of materials for Federal Highway Aid contracts from 1980 to 1989 represented between 44 and 48 percent of the total cost. He calculated the put-in-place cost of aggregates to be between 9.6 and 15 percent of the materials used in highway construction, with the cost of aggregates representing 4.6 to 7.2 percent of the overall cost of highway construction. The California Department of Transportation (2007) estimated that aggregates account for 8 to 10 percent of total project costs.

Introduction

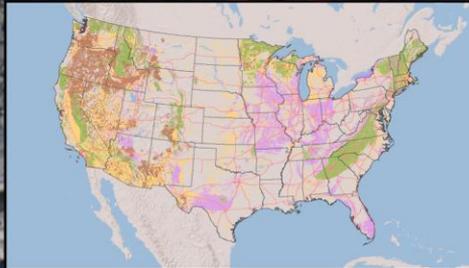


Transportation of 30 to 50 miles can more than double the put-in-place cost of aggregate.



Because aggregate is a high-bulk, low-unit-value commodity, transporting aggregate to the point of use can add significantly to the final cost of the product. Over 90 percent of aggregate transport is by truck. Generally, transporting aggregate to the end-user at truck haul distances of 30 to 50 miles can double the cost of the aggregate (Robinson and Brown, 2002). Consequently, it is most economical to have aggregate operations located as close to the final point of use as possible.

Presentation Outline



Aggregate supply

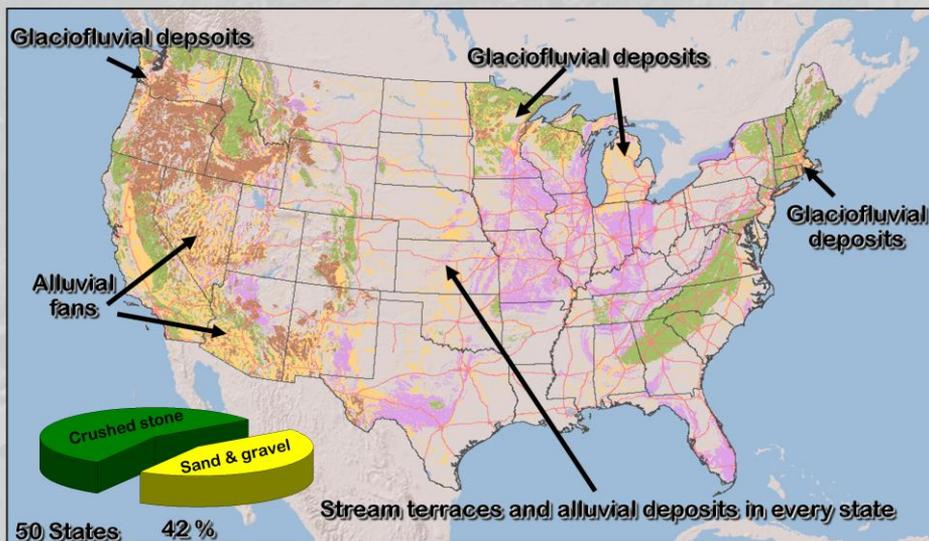
*Quality, societal and
environmental issues
limiting access to aggregate*

Case studies



This presentation addresses where aggregate occurs, or conversely where aggregate is non-existent or occurs in limited supplies; and how quality, societal, and environmental issues can limit access to good-quality potential sources of aggregate. The presentation uses case studies to demonstrate methods to address issues that limit aggregate supply and how to overcome shortages of supply.

Where aggregate occurs Sand & gravel

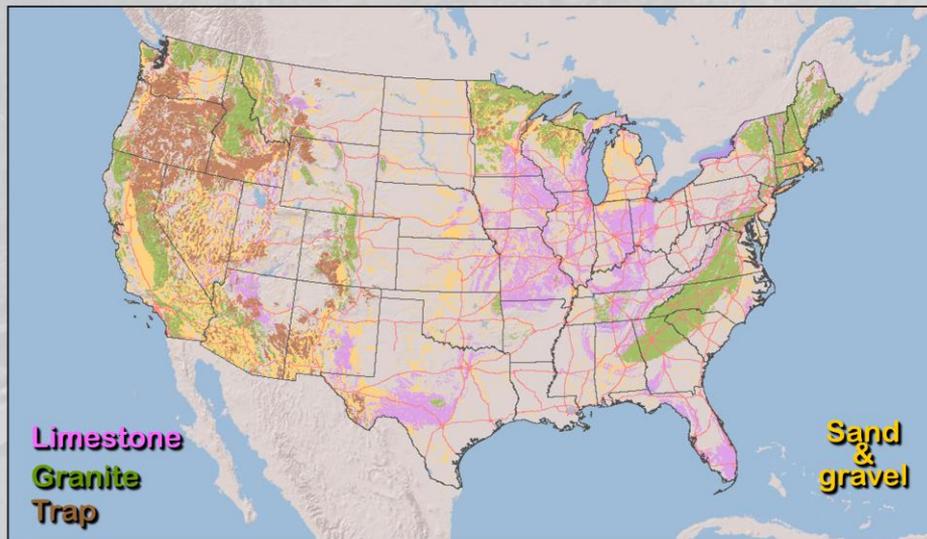


Glaciofluvial, alluvial fans, stream terraces, and alluvium.



The aggregate industry commonly refers to two general groups of aggregates; sand and gravel (s&g), and crushed stone. Sand and gravel make up about 42 percent of the total United States aggregate production. Sand and gravel is produced in every state (Bolen, 2008). Most sand and gravel produced in the United States is of glaciofluvial or alluvial origin. Glaciofluvial deposits are restricted to northern latitudes and high altitudes, and commonly make excellent sources of aggregate. Alluvial fans are typical of arid and semiarid regions and occur primarily in the Great Basin of the western United States. These materials tend to be poorly sorted and require significant processing before use as aggregate. Alluvial (river or stream) deposits are widespread. Their properties are highly variable and depend in large part on the parent material from which they are derived and the distance from the bedrock source area. Those parts of the United States that have sources of good-quality bedrock also commonly have good quality alluvial gravels. The amount of gravel-sized particles in alluvial deposits commonly decreases the more distant the deposits are from the source area.

Where aggregate occurs Crushed stone



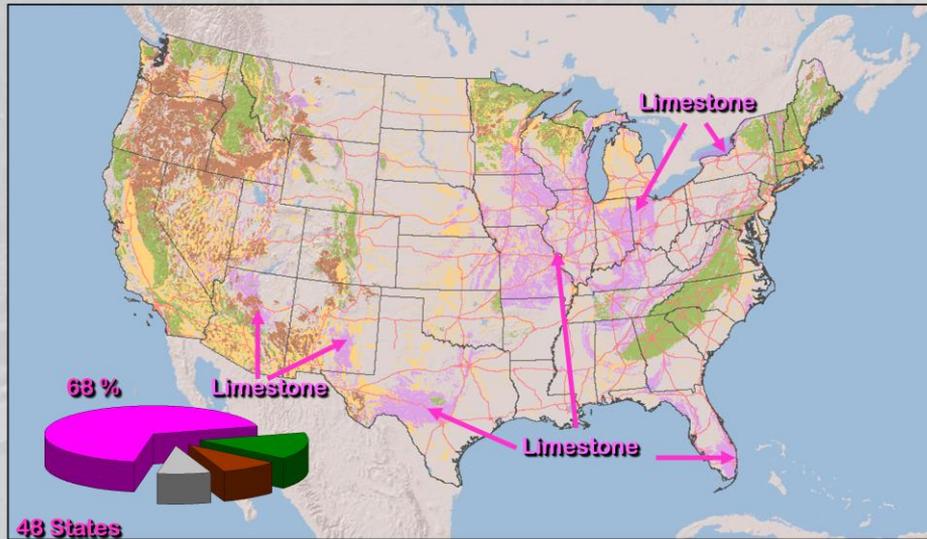
American Society for Testing and Materials (2011)
Designation C 294
Generally not applied



Crushed stone is the product resulting from the artificial crushing of rock. Crushed stone makes up about 58 percent of total United States aggregate production.

American Society for Testing and Materials (ASTM, 2011) Descriptive Nomenclature for Constituents of Concrete Aggregates C 294 provides brief descriptions of some of the more common rock types that comprise mineral aggregates as they occur in nature. Nevertheless, crushed stone commonly is divided into four general groups that are loosely tied to common petrological classifications—limestone, granite, trap rock, and other rocks.

Limestone



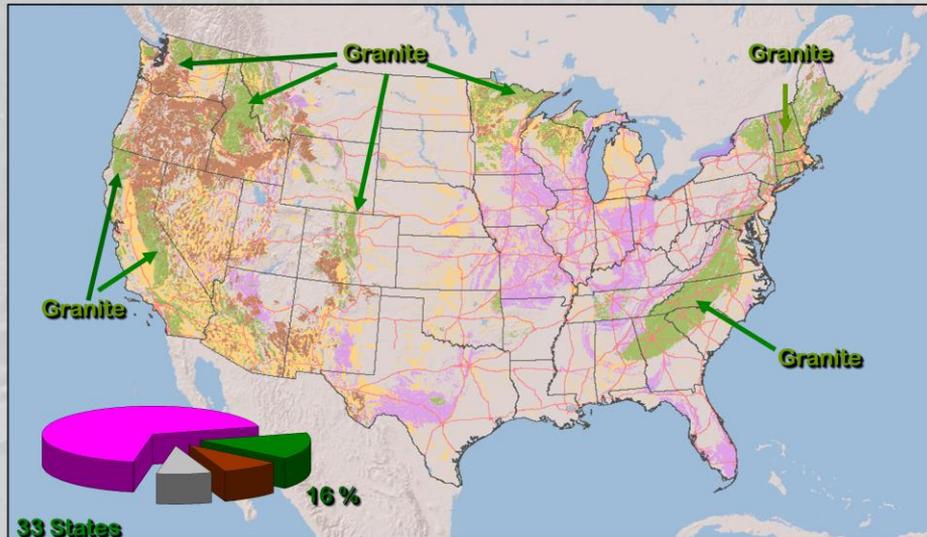
- Any common carbonate rock - limestone, dolomite, marble



'Limestone' consists of carbonate rocks including limestone, dolomite, and marble, and makes up about 68 percent of crushed stone production (Willett, 2008) or 39 percent of the total aggregate production. These carbonate rocks are widely distributed throughout the United States and they are produced in every state except North Dakota and Delaware. Their suitability for crushed stone varies greatly from location to location.

Carbonate rocks occur in the mid-continent from the Great Plains states eastward to the west flank of the Appalachian Mountains; the Coastal Plains of Florida, Mississippi, Alabama, Georgia and South Carolina; the Balcones Escarpment in Texas; the Black Hills of South Dakota and Wyoming; all of the far western States; and in parts of Alaska and Hawaii.

Granite



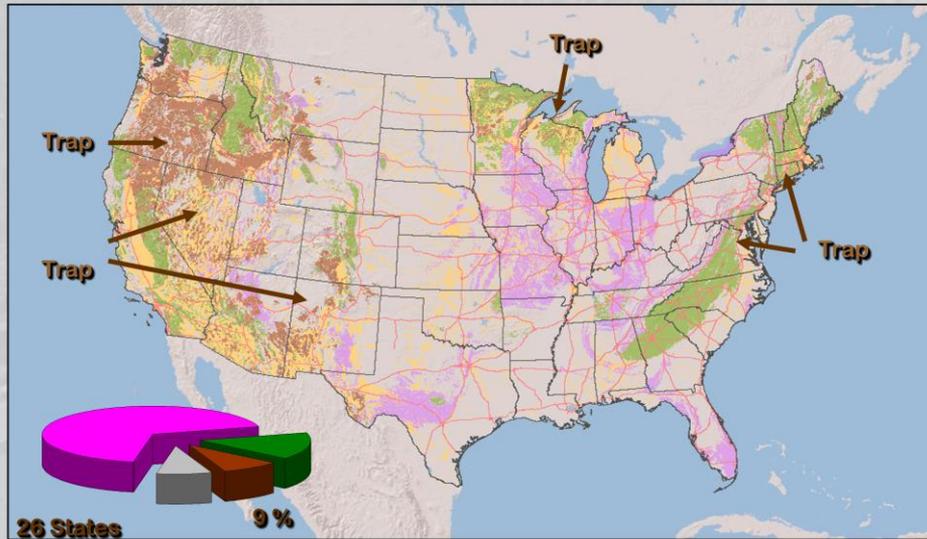
- **Igneous or metamorphic (crystalline) rocks**
- **Medium or coarse grained, any color – granite, gabbro, gneiss**



Granite refers to coarse-grained igneous or metamorphic rocks including true granite as well as other light colored rocks such as syenite, gneiss, and dark-colored gabbro. These make up about 16 percent of the crushed stone production (Willett, 2008) or 9 percent of the total aggregate production. Granite usually makes excellent crushed stone; however, some granitic-type rocks are too porous or too weak to make good aggregate or contain certain forms of silica that may react with alkali when used as concrete aggregate.

Granite-type rocks are widely distributed. They occur in the Appalachian and Adirondack Mountains, northern Minnesota and Wisconsin, the Black Hills of South Dakota and Wyoming, southeastern Missouri, central Arkansas, southern Oklahoma, central and southwestern Texas, all the western states, including the Rocky Mountains and areas to the west, and Alaska.

Trap



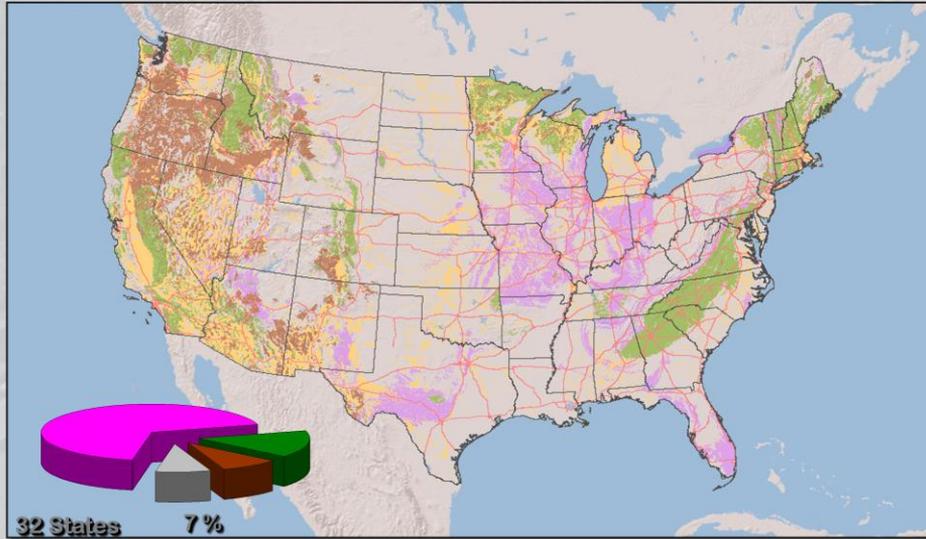
Trap – Dark, fine-grained, igneous – basalt, diabase



Trap is dark-colored, fine-grained, volcanic rock, and makes up about 9 percent of the crushed stone production (Willett, 2008) or 5 percent of the total aggregate production. Basalt and diabase are generally referred to as traprock and commonly make excellent crushed stone. Most other light-colored volcanic rocks contain certain forms of silica that may react with alkali when used as concrete aggregate, have vugs that contain deleterious minerals, or have physical properties that make them unsuitable for general use as aggregate.

Extensive amounts of trap rock occur in the western United States from the eastern flanks of the Rocky Mountains to the west coast. In the east, trap rock generally is restricted to the Triassic-Jurassic basins in the Piedmont Physiographic Province, primarily in the Connecticut River Valley of Connecticut and Massachusetts; the Palisades of New Jersey and New York; the Triassic Lowlands Section of Pennsylvania, Maryland, and northern Virginia; and in Georgia and Alabama.

Other

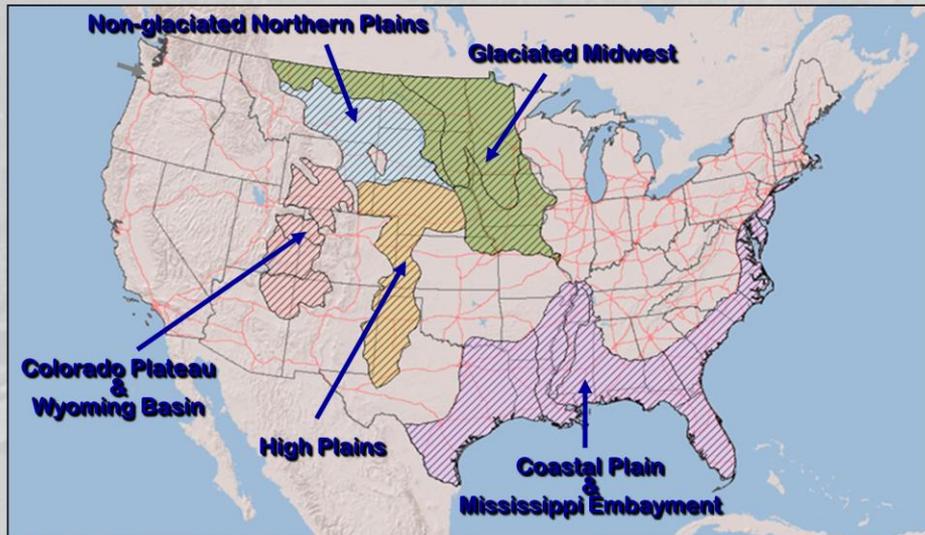


Other – Sandstone, quartzite, chert, shells, cinder, scoria, clinker, and other rock.



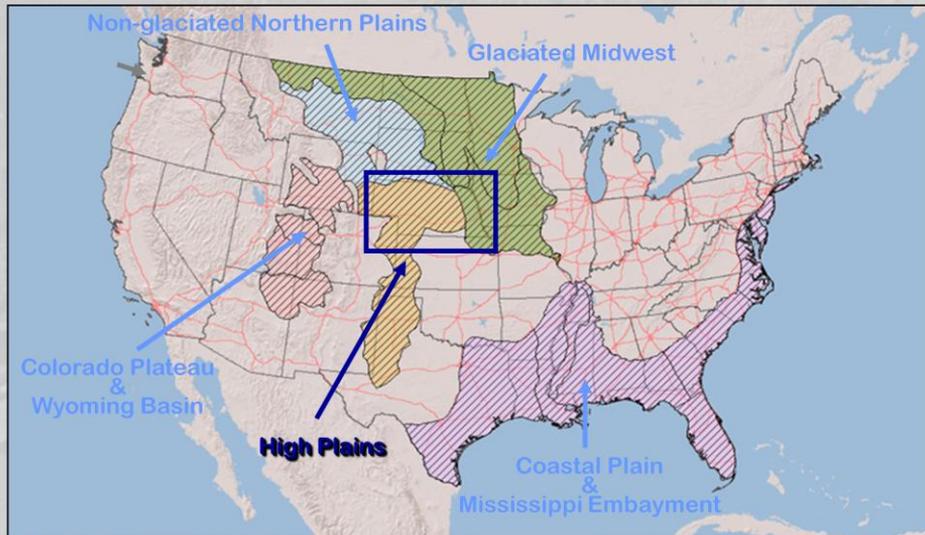
Other unclassified rocks include quartzite, sandstone, cinders, shell, and other rocks not widely used as aggregate. These rocks make up about 7 percent of the crushed stone production or 4 percent of the total aggregate production.

Where aggregate is in limited occurrence



Although potential sources of crushed stone or sand and gravel are distributed across most of the conterminous United States, they occur in limited quantities in some regions. The colored and ruled areas on this slide show where sources of aggregate, especially crushed stone, occur in very limited supply. The areas include the Coastal Plain and Mississippi embayment, Colorado Plateau and Wyoming Basin, glaciated Midwest, High Plains, and the non-glaciated Northern Plains. The areas conform to boundaries of Fenneman and Johnson (1946).

High Plains - Nebraska



The High Plains of Nebraska is selected as an example of the High Plains (tan ruled area) for this presentation.

High Plains - Nebraska



Sand Hills

Broad valleys

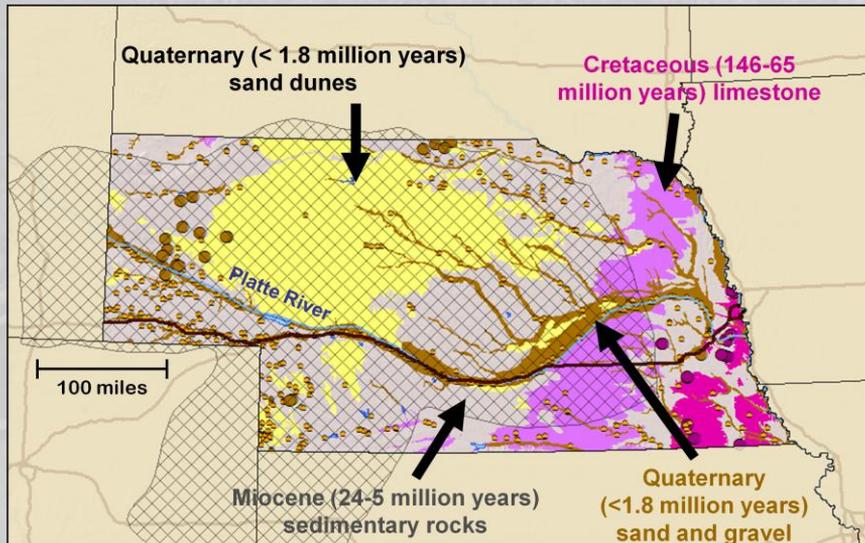


Photographs from the U.S. Geological Survey.



The High Plains is an area of large, relatively flat, gently sloping plains. Significant topographic features in Nebraska include an extensive area of sand dunes in western Nebraska, and broad valleys of braided streams that originate in the Rocky Mountains and flow eastward across the plains.

Geology



● Limestone

● Sandstone

● Sand & gravel



High Plains Province

Nebraska Conservation and Survey Division - Active aggregate operations

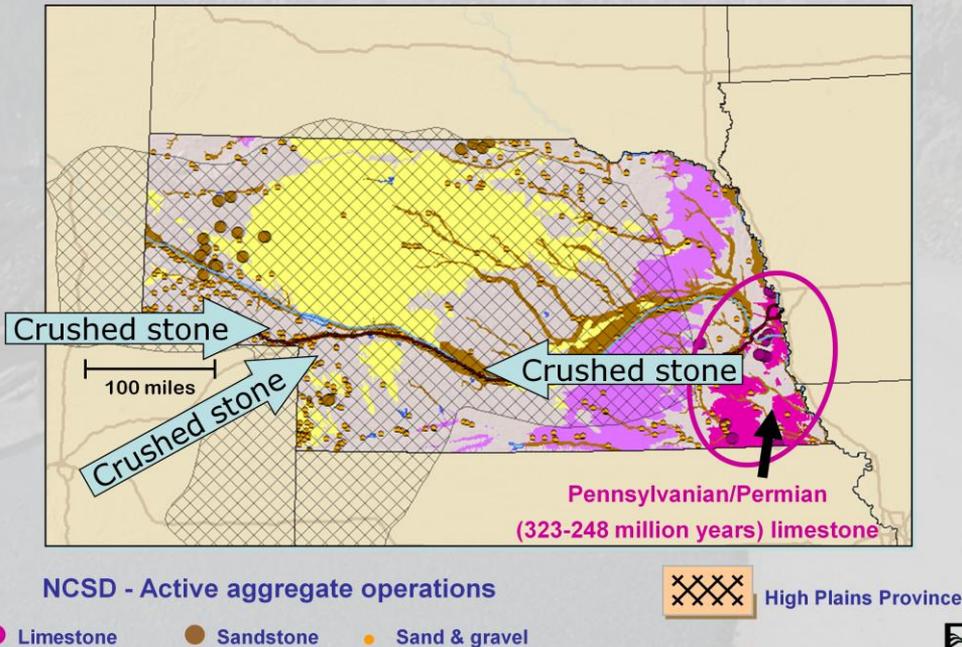


Sand and gravel is generally confined to the Platte River floodplain and terraces, and to its larger tributaries. Most of the alluvial deposits attributable to the Platte River are fine sand in the river channel and sandy silt on the terraces (Huntzinger and Ellis, 1993), and are deficient in coarse sizes. Gravels may have chemical or physical problems that limit their use as aggregate (Langer and Glanzman, 1993). The small orange dots show active sand and gravel operations, as described by the Nebraska Conservation and Survey Division (NCSD).

Much of the area is underlain by soft, semi-consolidated, Miocene sediments, almost all of which are unsuitable for use as crushed stone. The eastern part of the cross-hatched area (High Plains province) is underlain by Cretaceous limestones, most of which typically are also too soft for use as aggregate.

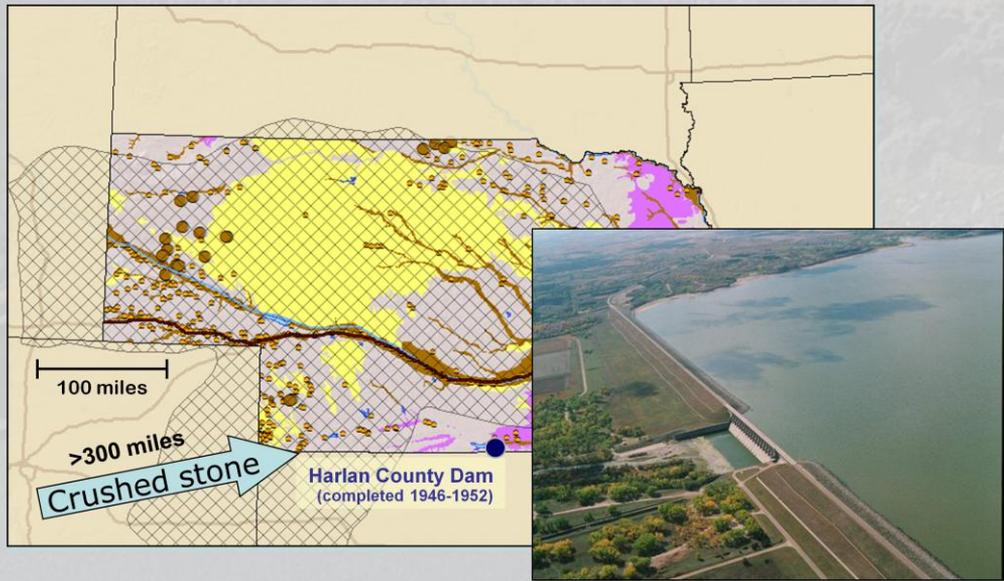
Sandstone in the western panhandle can be used for some applications such as roadstone. Active crushed sandstone operations are noted by the large brown dots.

Crushed stone sources



Permian limestones (280-248 million years) occur in eastern Nebraska (outside of the High Plains). These limestones generally make suitable quality crushed stone aggregate. To accommodate the demand for coarse aggregate, crushed limestone is transported to western and central Nebraska from quarries in the eastern portion of the state (shown by dark pink dots) or from quarries in Wyoming or Colorado to the west.

Special requirements



Photograph from the U.S. Army Corps of Engineers.



During the late 1940s to the early 1950s, the construction of Harlan County Dam near McCook, Nebraska, required aggregate with special quality requirements not satisfied by limestone. The Rogers Brothers quarry in Golden, Colorado, over 350 miles to the southwest, provided aggregate for the dam. The quarry, which was started in 1925, was enlarged in 1949 to meet the new demand (Langer and Tucker, 2003).

Backhaul



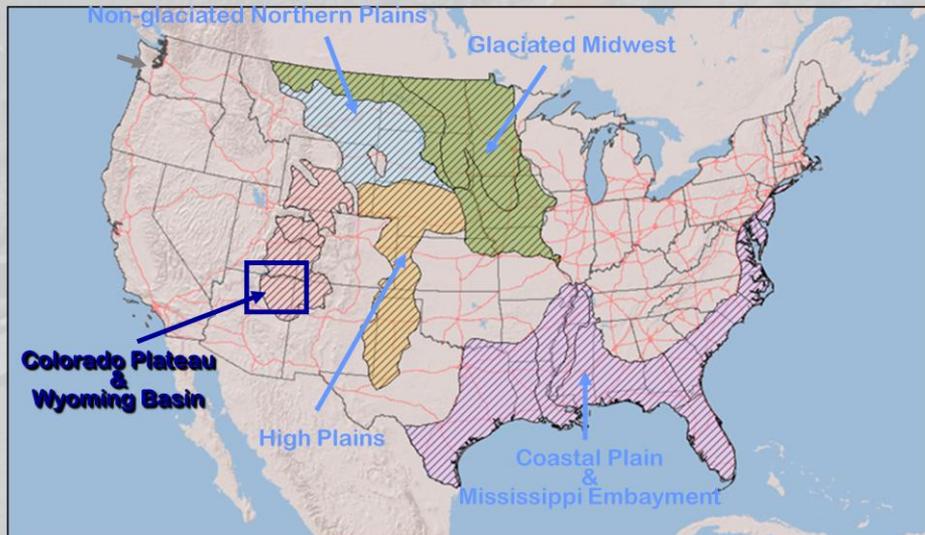
Photograph from the Federal Highway Administration.



A fortuitous situation in Nebraska helps reduce the cost of shipping some aggregate from Colorado to Nebraska. Large amounts of corn are grown in Nebraska, and some of that corn is shipped via truck to feedlots in eastern Colorado. To offset the cost of returning empty, some trucks return to Nebraska with granitic rocks quarried near Denver. Backhauling, in turn, offsets the cost of transporting aggregate.

Photograph from the Federal Highway Administration.

Colorado Plateau and Wyoming Basin Northeastern Arizona



The Colorado Plateau and Wyoming Basin have similar characteristics regarding the availability of aggregate. The Colorado Plateau in northeastern Arizona is selected as an example for this presentation.

Colorado Plateau & Wyoming Basin Northeastern Arizona



High desert

Photograph from the U.S. Geological Survey.

Buttes and steep cliffs



Photograph from the U.S. National Park Service.



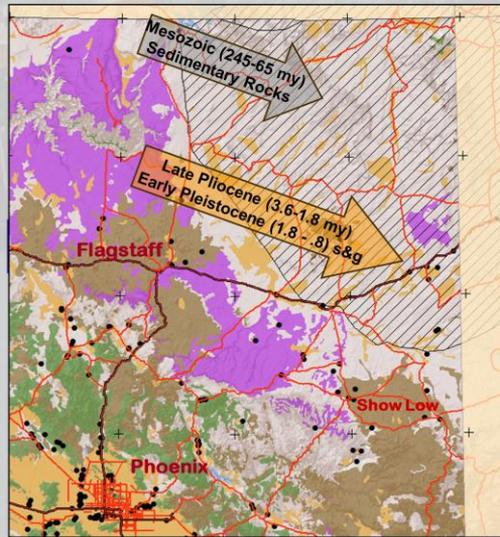
The Colorado Plateau consists of the high desert and buttes bordered by steep cliffs. The erosion on the cliff face in the right-hand photograph demonstrates the weakness of the rocks.

Geology

Limestone
Granite
Trap
Sand & gravel (s&g)

- Material sources that have completed the Arizona Department of Transportation (ADOT) Environmental Analysis Process

■ Area of limited aggregate resources



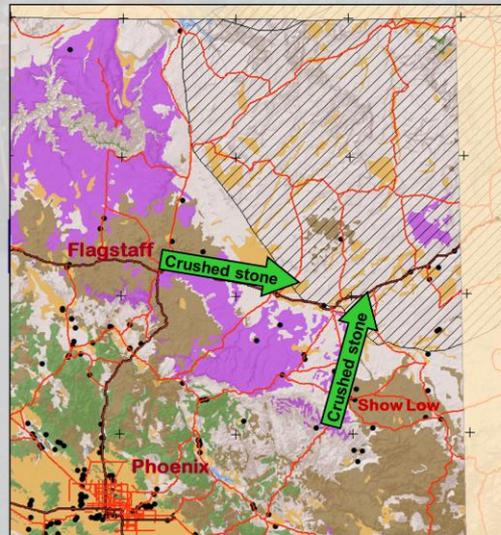
The area is generally underlain by poorly consolidated to consolidated Mesozoic sandstone, shale, and limestone, with the sandstone and shale being most prevalent. The soft sandstone and shale tend to yield poor-quality crushed stone. Sand and gravel occurs in limited supplies, and when weathered or when derived from the erosion of soft sandstone or shale, tends to be of poor quality (Langer and Glanzman, 1993). The black dots indicate material sources that have completed the Arizona Department of Transportation (ADOT) Environmental Analysis process and do not necessarily represent an active aggregate operation.

Crushed stone sources

Limestone
Granite
Trap
Sand & gravel (s&g)

- Material sources that have completed the Arizona Department of Transportation (ADOT) Environmental Analysis Process

■ Area of limited aggregate resources

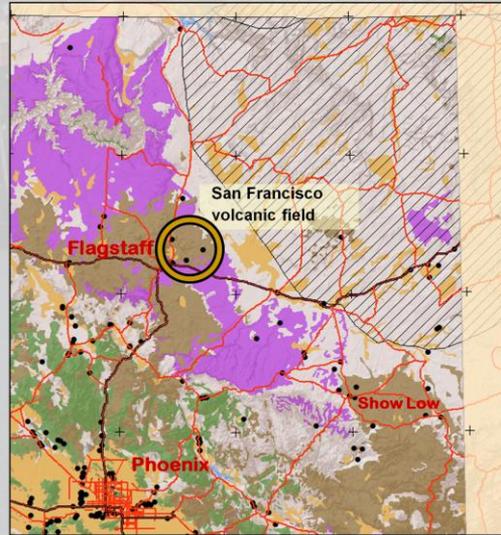


100 miles



There are very limited resources in the northwestern part of Arizona. Crushed stone is imported from north of Flagstaff and from near Show Low.

Marginal material - Cinders



Photographs from the U.S. Geological Survey.



As one approaches Flagstaff from the east or north a large number of cinder cones are encountered in an area referred to as the San Francisco volcanic field. Some of those cinder cones are quarried for aggregate.

Uses of marginal material



Block

Road base

Roads

Snow & ice control

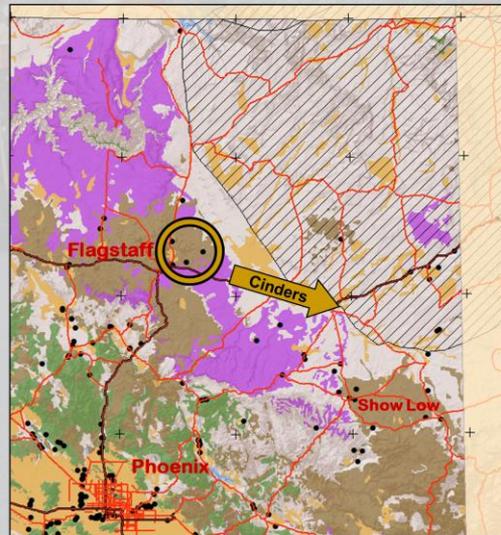
Driveways

Landscaping

Leach lines

Corrals

Yards



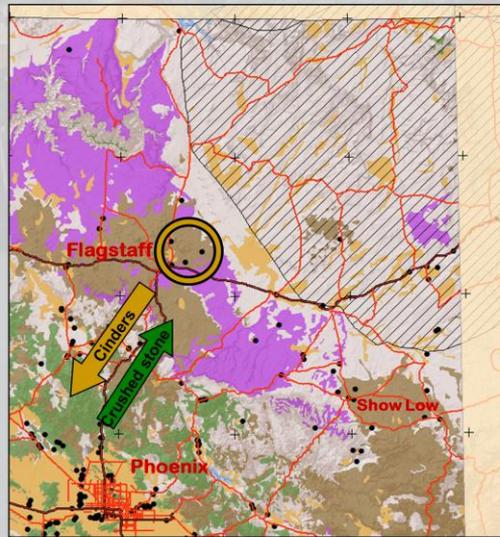
100 miles



Photograph from the U.S. Geological Survey.

Cinders tend to be a marginal aggregate but are used in some applications such as road base and as a surface for low-volume roads. Cinders can also be used as a high-quality, light-weight aggregate in certain applications.

Backhaul



Photograph from the U.S. Geological Survey.

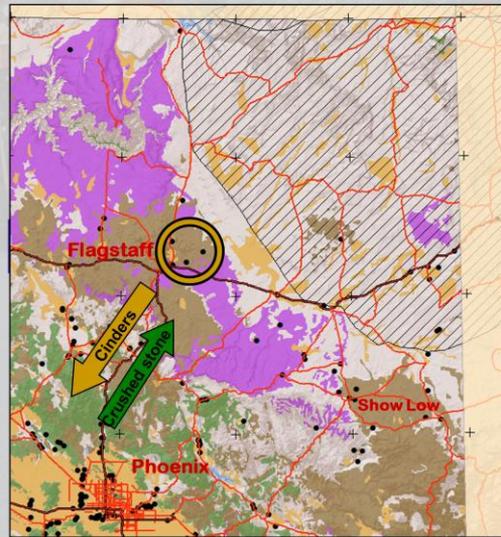


Most of the cinders used in the Phoenix area come from quarries near Flagstaff. Trucks that haul the cinders to Phoenix commonly return to Flagstaff with normal weight aggregate that is used near Flagstaff and areas to the east.

Backhaul



Cost of aggregate transport in congested urban areas or mountainous areas can be three to four times as expensive as open-highway transportation.

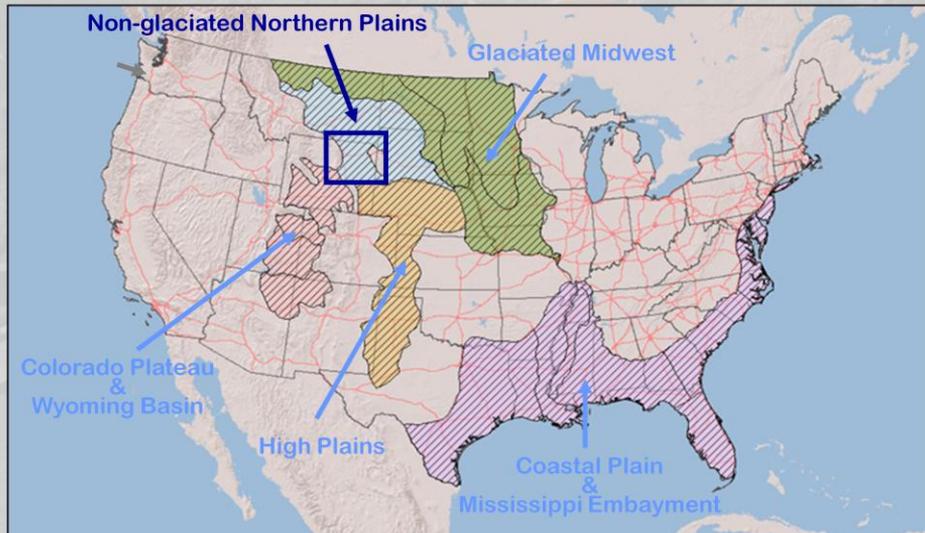


Photograph from the U.S. Geological Survey.



Even though the cost to transport aggregate in mountainous areas can be three to four times as expensive as for open-highway transportation (Achterman and others, 2005; Hull, 2001), it is still economical to backhaul aggregate from Phoenix to Flagstaff.

Non-Glaciaded Northern Plains Northeastern Wyoming



Northeastern Wyoming is selected as an example of the non-glaciaded Northern Plains (shown by the blue ruled area) for this presentation.

Non-glaciated Northern Plains Northeastern Wyoming



Rolling plains

Short grass prairie



Photographs from the U.S. Bureau of Land Management.

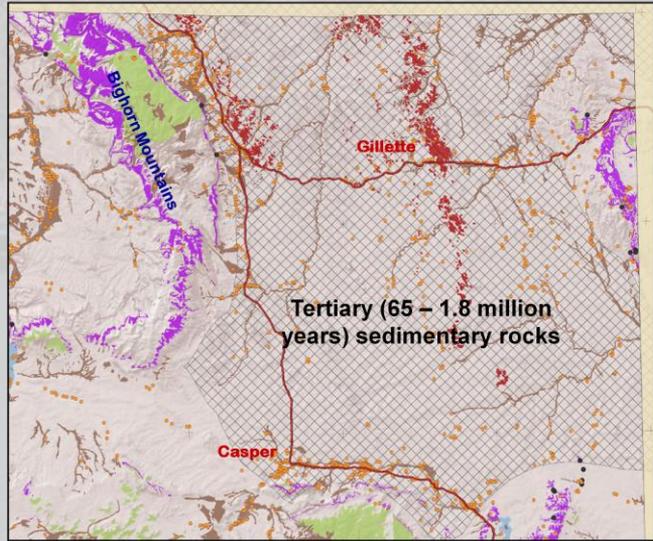


The non-glaciated Northern Plains consist of a variety of landforms, including gently rolling to steep dissected plains, flat-topped buttes, and steeply sloping badlands.

Geology

- Active crushed stone operation
- Active sand & gravel operation
- Areas of limited aggregate resources

Data from Wyoming Geological Survey
(Harris, 2004)



100 miles



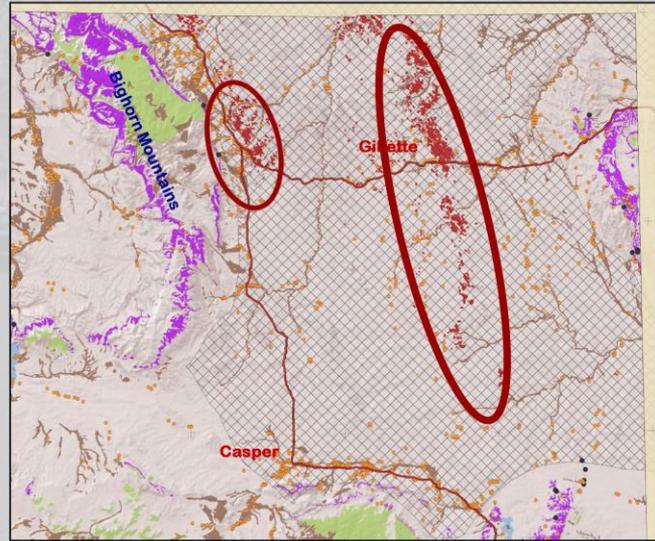
Most of the region is underlain by sedimentary rocks consisting of sandstone, shale, conglomerate, and scattered limestone. These rocks are generally poor sources of aggregate. Stream channel and terrace deposits are the source of sand and gravel, but the quality and clast size of the gravel is highly variable.

The black and yellow dots indicate active aggregate operations according to the Wyoming Geological Survey (Harris, 2004). There are no operations quarrying limestone, granite, or trap in the non-glaciated plains of Wyoming.

Unconventional material - Clinker



Clinker
(scoria, porcellanite, red dog)

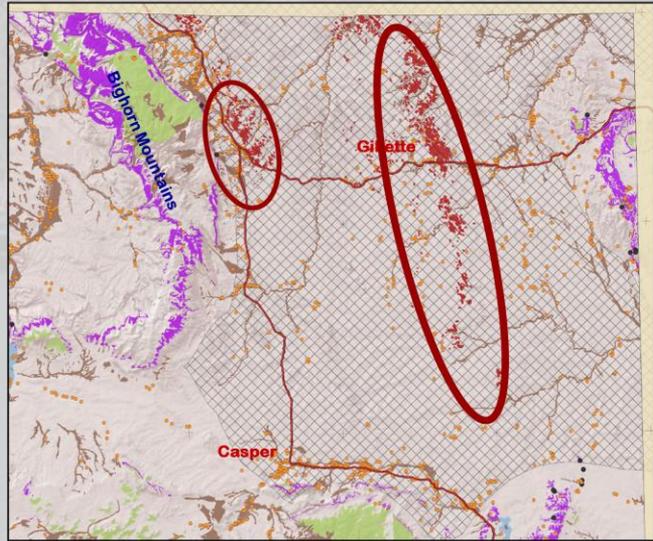
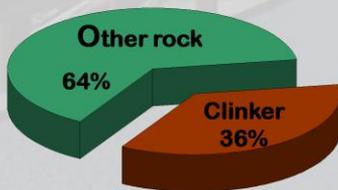


Photograph from the Wyoming Geological Survey.

In the portion of northeastern Wyoming, encompassed by the non-glaciated Northern Plains, traditional sources of aggregate are extremely limited. To avoid large transportation costs, clinker (the red areas highlighted by the red ovals) is often used as a substitute for gravel and crushed stone.

Clinker, also referred to as scoria, porcellanite, and red dog, is hardened claystone, siltstone, and sandstone that was baked by the natural burning of coal beds. The process is similar to firing clay to form brick. Claystone and siltstone near the burning coal are altered to a brick-like material, and sandstone is hardened by the heat (Hoffman, 1996).

Unconventional material - Clinker

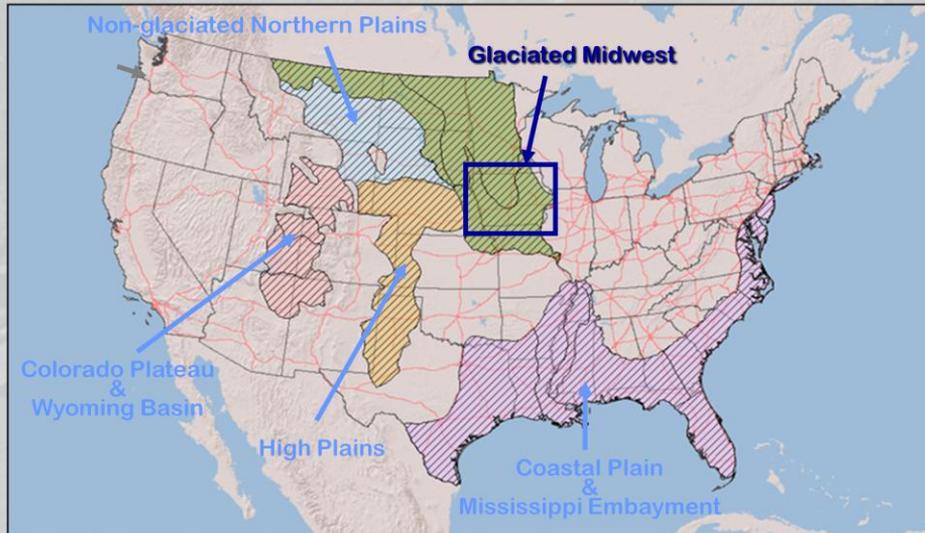


100 miles



Clinker makes up over one-third of the crushed stone produced in Wyoming (U.S. Geological Survey, 2007); the principal use is for surfacing roads.

Glaciated Midwest - Iowa



Iowa is selected as an example of the Glaciated Midwest (shown by the green ruled area) for this presentation.

Glaciated Midwest - Iowa



Loess hills

Glaciated plains

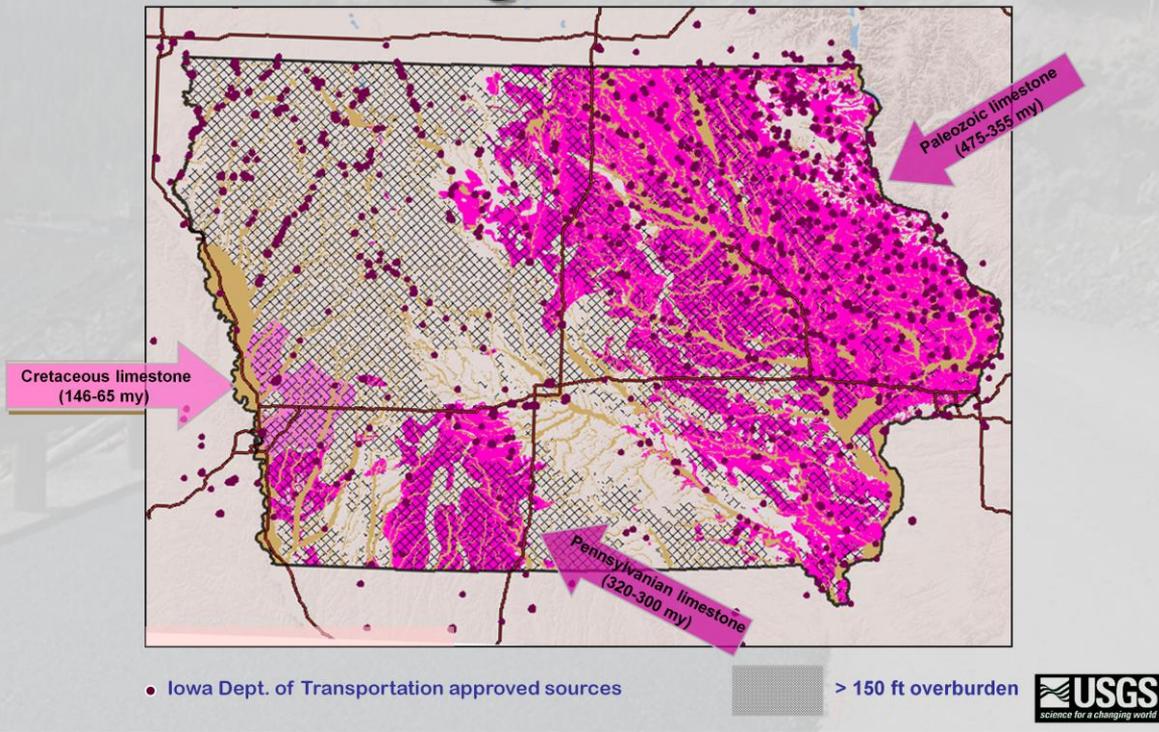


Photographs from the U.S. Geological Survey.



The glaciated Midwest is an area of loess hills in the western part of the state, and flat plains, rolling hills, and low rounded hills in the rest of the state. Much of Iowa is covered with thick unconsolidated material.

Thick glacial cover

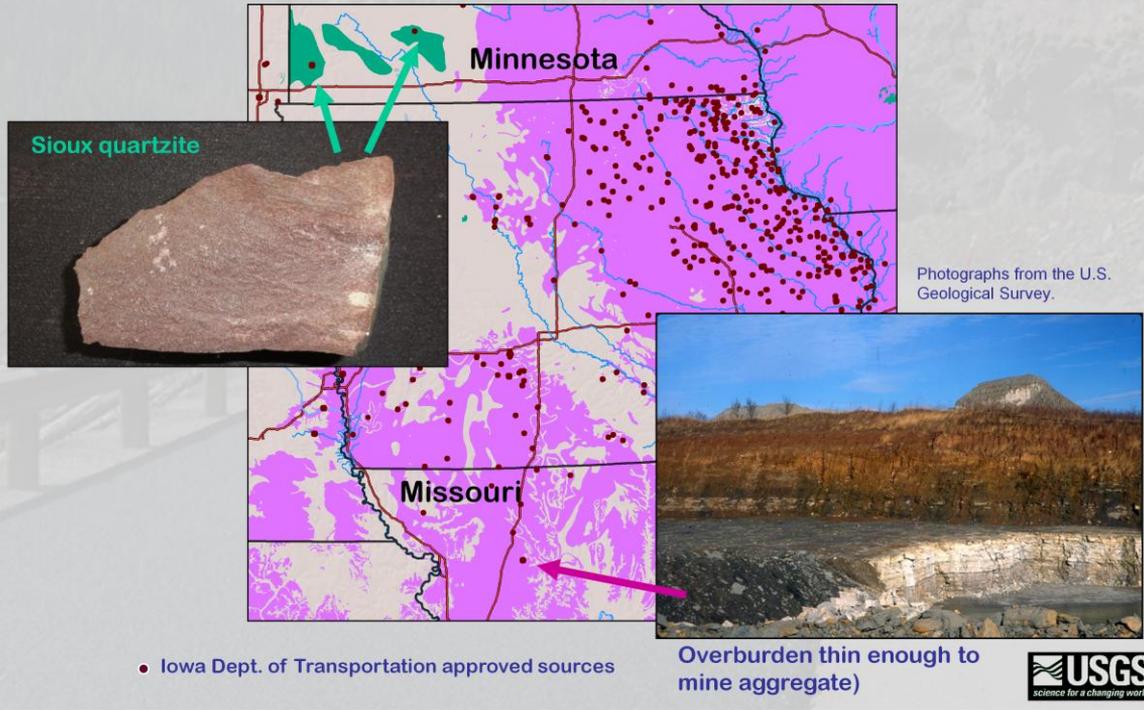


The cross-hatched pattern on this slide shows areas where the bedrock is overlain by overburden greater than 150 feet thick. The amount of overburden that a producer is willing to extract to access the underlying rock depends on a number of factors, including the mineable thickness of the underlying rock, the quality of the underlying rock, and the proximity to market area. In general, overburden of 150 feet or more will make crushed stone quarrying uneconomical.

Bedrock in the northwestern part of Iowa consists primarily of sandstone and shale that do not make good-quality aggregate. Much of the eastern part of the state is underlain with potentially suitable bedrock, more than half of which is covered with overburden too thick to allow economical extraction of the rock. Sand and gravel are abundant throughout the region, but in the northern part is commonly buried by fine-grained sediments. Aggregate from the Missouri River and tributaries may be contaminated with deleterious material from the underlying soft sandstone and shale bedrock (Langer and Glanzman, 1993).

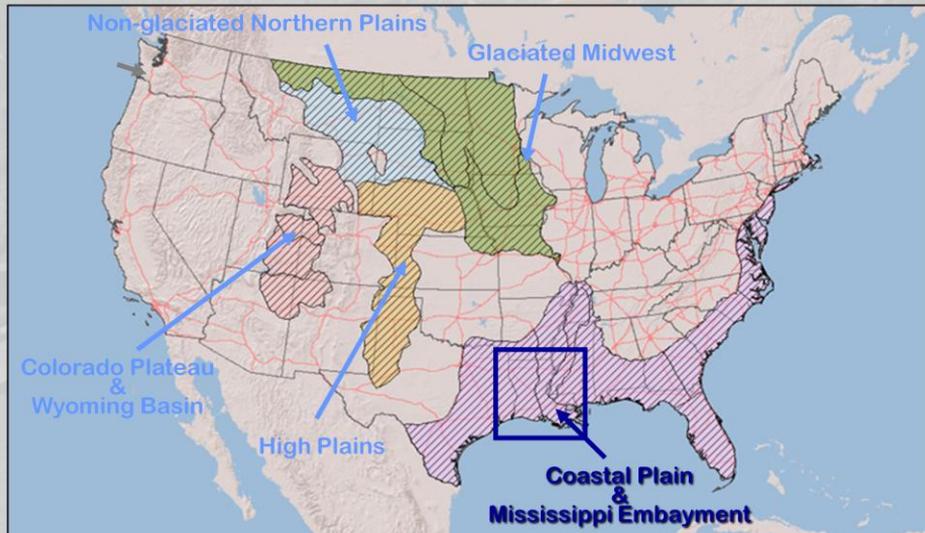
The purple dots are Iowa Department of Transportation (IDOT) approved sources of aggregates and may not be active quarries or pits.

Interstate Supply



The Iowa DOT approved sources of aggregates occur, not only in Iowa, but also in nearby states. This allows for more access to aggregates with special characteristics (such as the Sioux quartzite) and allows for access to nearby mineable limestone resources located outside of the state.

Coastal Plain & Mississippi Embayment Louisiana



Louisiana is selected as an example of the Coastal Plain and Mississippi Embayment (shown by the purple ruled area) for this presentation.

Coastal Plain & Mississippi Embayment Louisiana



Flood plains

Photograph from the U.S. Army Corps of Engineers.



Swamps

Photograph from the U.S. Geological Survey.

Pine barrens



Photograph from the U.S. Geological Survey.

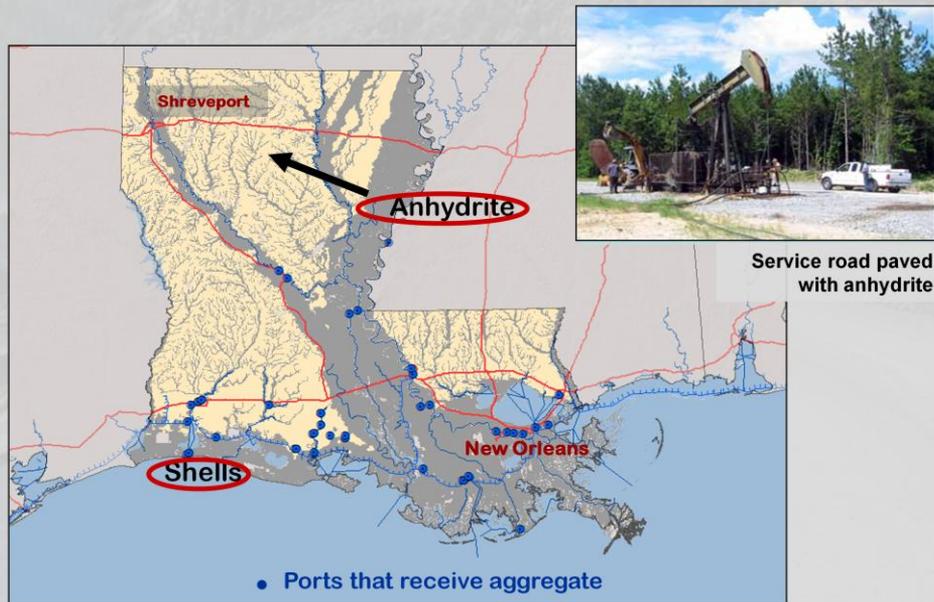


The topography of the Coastal Plain and Mississippi embayment in Louisiana includes nearly flat floodplains, swamps and marshes, and pine barrens.

Photograph of floodplain from the U.S. Army Corps of Engineers.

Photograph of cypress tupelo swamp and pump-jack from the U.S. Geological Survey.

Unconventional Material

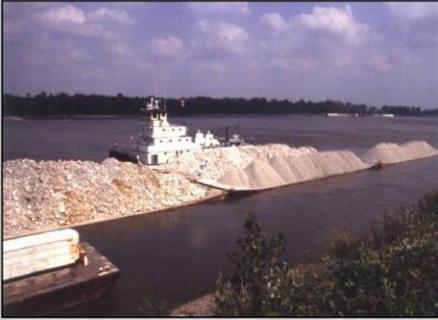


Louisiana is located primarily in the Mississippi embayment, a geologic trough where, as sea level has risen and fallen over geologic time, late Tertiary period and Quaternary period sediments have accumulated to a thickness of about 40,000 ft. These sediments consist almost entirely of unconsolidated sand, silt, clay, and organic matter (Saucier and Snowden, 2008), none of which can be used in their natural state as aggregate.

Louisiana mines very little stone, the only source is anhydrite (dehydrated gypsum) that is mined in Winn Parish in the north-central part of the state. Anhydrite has been used quite extensively in the past by local and parish governments for aggregate surface courses on unpaved roads near the deposit. The Louisiana Department of Transportation and Development has used anhydrite for shoulder surface course in some rural highways.

Gravel is so limited in the area that shells dredged from the Gulf of Mexico are commonly substituted for gravel in low-specification applications. Louisiana imports almost all of its aggregate. The blue dots show ports that, according to the Army Corps of Engineers, receive aggregate.

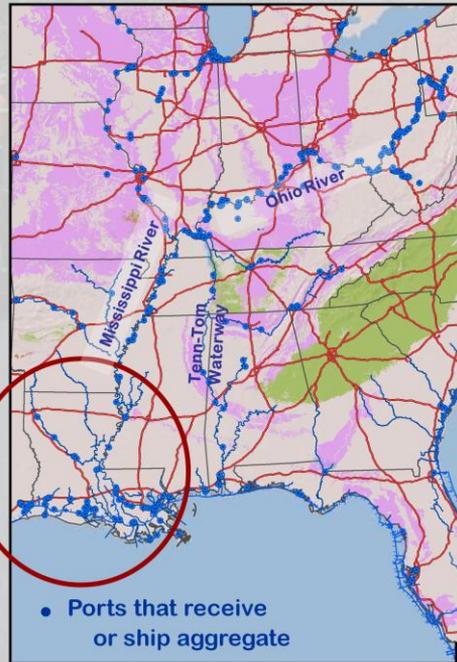
Supply by water transport



Photograph from the U.S. Army Corps of Engineers



Photograph from the U.S. Geological Survey.



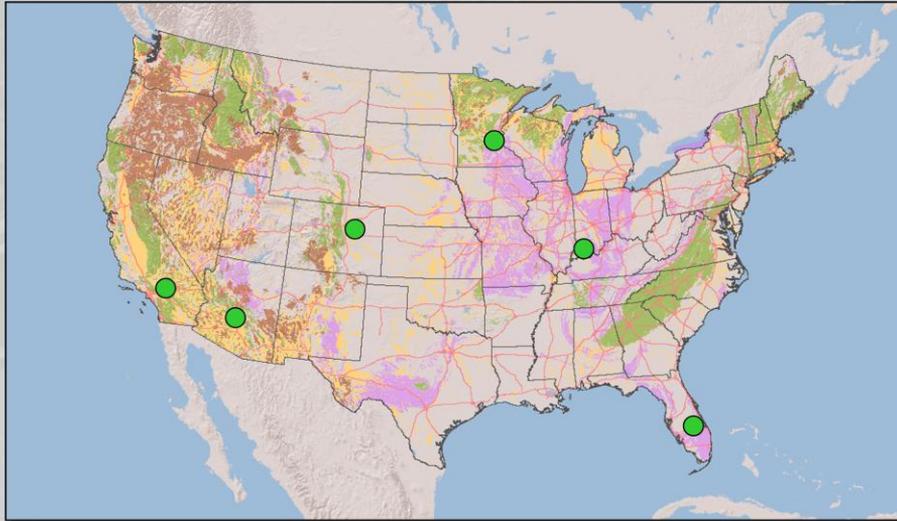
The majority of aggregate used in Louisiana (in the red circle) is shipped via barge from other states, including Arkansas, Illinois, Kentucky, and Missouri, and via freighter from Mexico. During 2006, over 11 million tons of limestone were shipped to Louisiana by shallow draft barge (U.S. Army Corps of Engineers, 2010).

The blue dots show ports that, according to the Army Corps of Engineers, either ship or receive aggregate.

Photograph of barge from the U.S. Army Corps of Engineers

Photograph of freighter from the U.S Geological Survey

Quality, Societal, and Environmental Issues Limiting Aggregate Availability



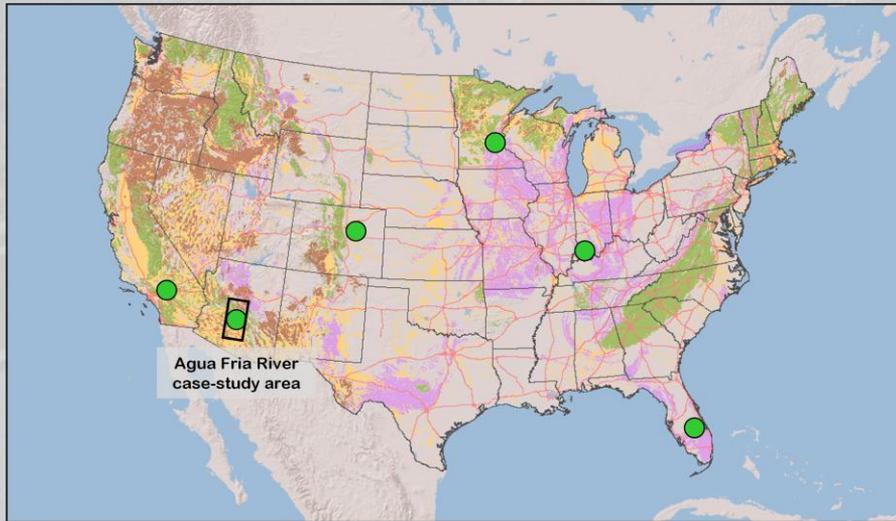
● Locations of case-study areas



If potential sources of aggregate are present, they must meet certain quality parameters before they can be put to use. Those quality parameters are determined by the final application and can restrict the development of otherwise high-quality aggregate. In general, aggregates must meet certain physical property requirements, including soundness, hardness, strength, porosity, and specific gravity, and they must not contain contaminants or deleterious materials. Societal issues, such as encroachment by conflicting land uses and permitting considerations, and environmental issues can prevent or limit development of otherwise suitable aggregate.

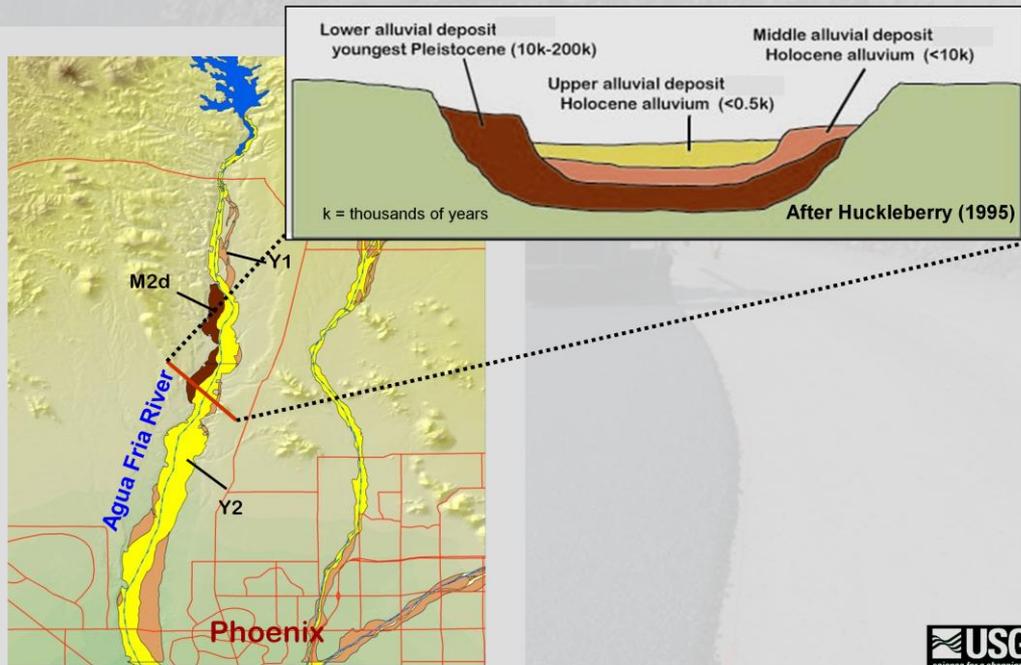
The remainder of this presentation will describe techniques that have been used successfully in six geographic areas to address those societal and environmental issues. The green dots show the locations of case studies on quality, societal, and environmental issues that limit aggregate development.

Quality Issues Agua Fria River - Phoenix, Arizona



The modern stream channel of the Agua Fria River west of Phoenix, Arizona, is mined and processed to provide aggregate to the greater Phoenix area. This example demonstrates how aggregate quality can change with depth and with weathering.

Geology

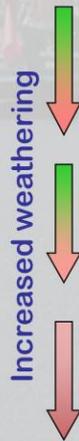


The alluvium in the lower reach of the Agua Fria River occurs as three distinct alluvial deposits. The ages of the deposits can be estimated through correlation with units described by Huckleberry (1995). The upper alluvial deposit correlates with Huckleberry's unit Y2 – the modern stream channel of the Agua Fria River (<0.5 thousand years old). The middle alluvial deposit correlates with deposits associated with Huckleberry's unit Y1 – Holocene alluvium located outside the modern stream channel of the Agua Fria River (<10 thousand years old). The lower alluvial deposit correlates with the deposits associated with Huckleberry's unit M2d – the lowest and youngest Pleistocene epoch stream terrace along the Agua Fria River (10-200 thousand years old).

Engineering properties vs depth



- Weathering increases with depth (age)
- Quality decreases as weathering increases



| Sample Location | * Specific Gravity (ASTM C 127) | *Absorption (ASTM C 127) | *Micro-Deval Abrasion Grading B (ASTM D 6928) |
|--------------------------|---------------------------------|--------------------------|---|
| Igneous rocks | | | |
| Upper alluvial deposit | 2.67 | 0.80% | 12% |
| Middle alluvial deposit | 2.62 | 1.40% | 13% |
| Lower alluvial deposit | 2.61 | 1.00% | 16% |
| Metamorphic rocks | | | |
| Upper alluvial deposit | 2.81 | 0.50% | 12% |
| Middle alluvial deposit | 2.79 | 1.00% | 12% |
| Lower alluvial deposit | 2.70 | 1.20% | 16% |
| Tertiary rocks | | | |
| Upper alluvial deposit | 2.62 | 2.50% | 24% |
| Middle alluvial deposit | 2.59 | 3.90% | 30% |
| Lower alluvial deposit | 2.51 | 4.00% | 35% |

Photograph from the U.S. Geological Survey.

* American Society for Testing and Materials, 2011



Gravel from the Agua Fria was first divided by deposit (upper, middle, and lower alluvial deposits), then into three general rock types—igneous, metamorphic, and Tertiary volcanic rocks. Each rock type from each deposit was subjected to three engineering tests. In almost every case the quality decreased with increase in depth. It is noteworthy that the best values of rock property for the Tertiary volcanic rocks are almost always worse than the worst values of the igneous and metamorphic rocks (Langer and others, 2010).

Photograph from the U.S. Geological Survey.

Engineering properties vs depth



- Weathered tertiary rocks generally lack strength



| | Specific Gravity (ASTM C 127) | Absorption (ASTM C 127) | Micro-Deval Abrasion Grading B (ASTM D 6928) |
|--------------------------|-------------------------------|-------------------------|--|
| Igneous rocks | | | |
| | 2.67 | 0.80% | 12% |
| | 2.62 | 1.40% | 13% |
| | 2.61 | 1.00% | 16% |
| Metamorphic rocks | | | |
| | 2.81 | 0.50% | 12% |
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| Lower alluvial deposit | 2.51 | 4.00% | 35% |

Photograph from the U.S. Geological Survey.



This photograph demonstrates that the Tertiary volcanic rocks (behind pencil) are so weak that they break apart rather than be plucked intact from the face of a pit when being excavated with earthmoving equipment.

Photograph from the U.S. Geological Survey.

Engineering properties vs depth



- Processing
- Blending

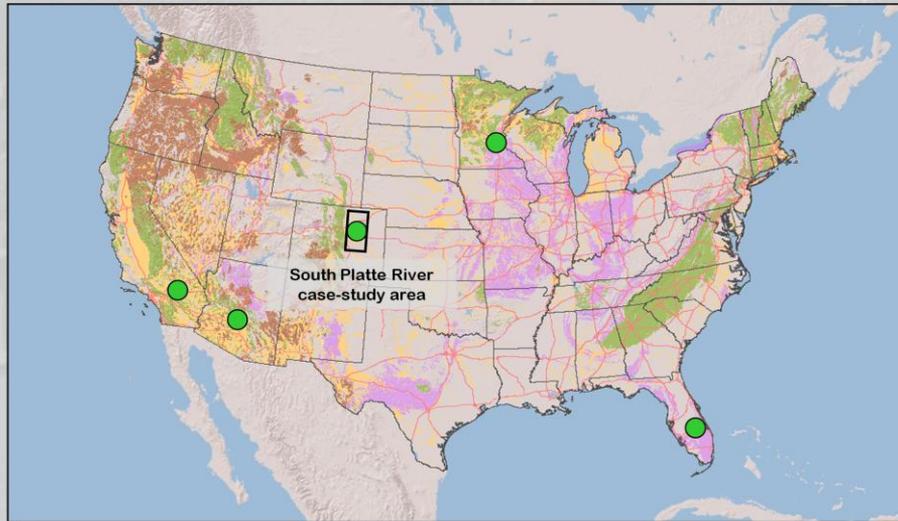
Increased weathering

| Sample Location | Specific Gravity (ASTM C 127) | Absorption (ASTM C 127) | Micro-Deval Abrasion Grading B (ASTM D 6928) |
|--------------------------|-------------------------------|-------------------------|--|
| Igneous rocks | | | |
| Upper alluvial deposit | 2.67 | 0.80% | 12% |
| Middle alluvial deposit | 2.62 | 1.40% | 13% |
| Lower alluvial deposit | 2.61 | 1.00% | 16% |
| Metamorphic rocks | | | |
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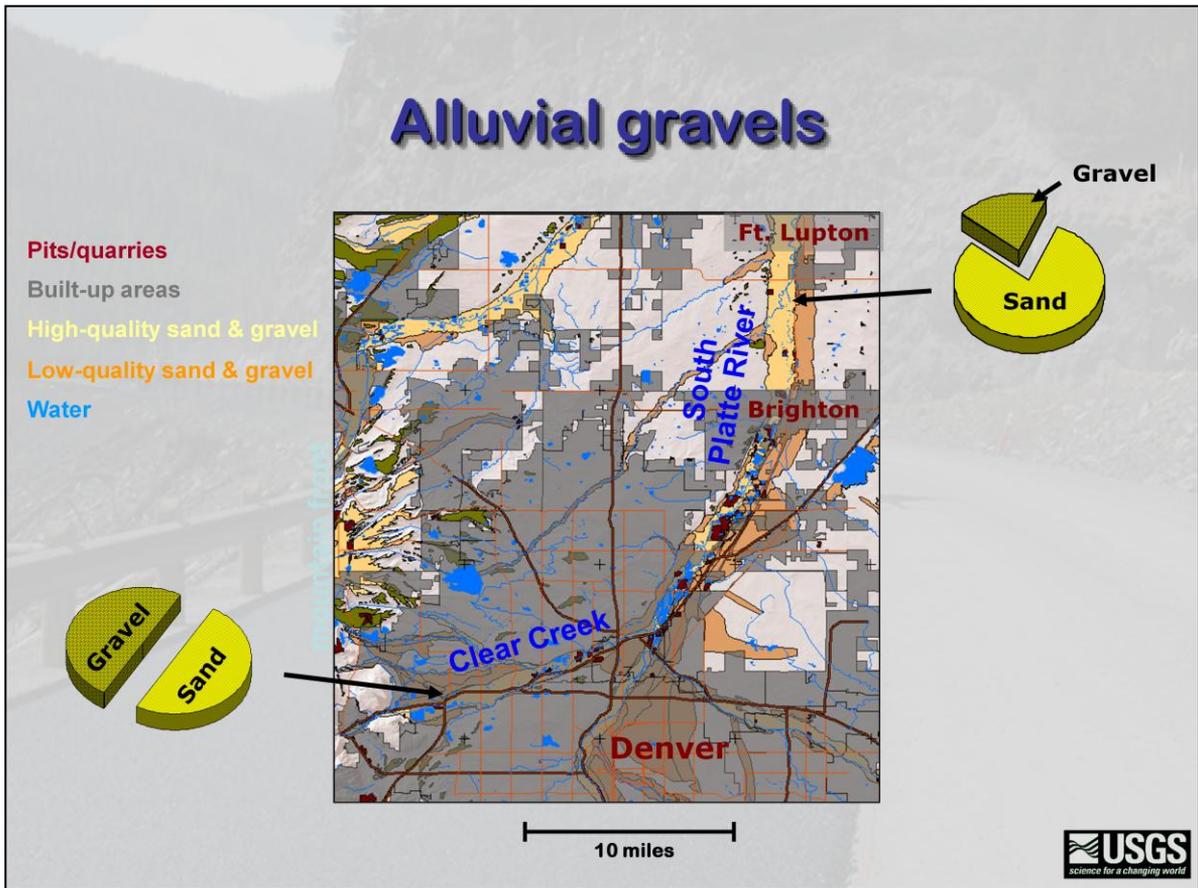


The upper alluvial deposit can easily be processed into material specification construction-grade aggregate. The middle alluvial deposit is generally lower quality than the overlying upper alluvial deposit. The middle alluvial deposit has more deleterious materials but commonly can be processed into specification-grade aggregate with the use of impact crushers. The lower alluvial deposit is the lowest unit that could theoretically be extracted without extensive interburden removal (Langer and others, 2010). Waste factors in lower alluvial deposit are 14 percent higher than the upper alluvial deposit, and the deposit commonly does not make construction-grade aggregate with current processing equipment. Blending material from the upper and middle alluvial deposits may extend the aggregate supply in this area.

Quality Issues South Platte River - Denver, Colorado



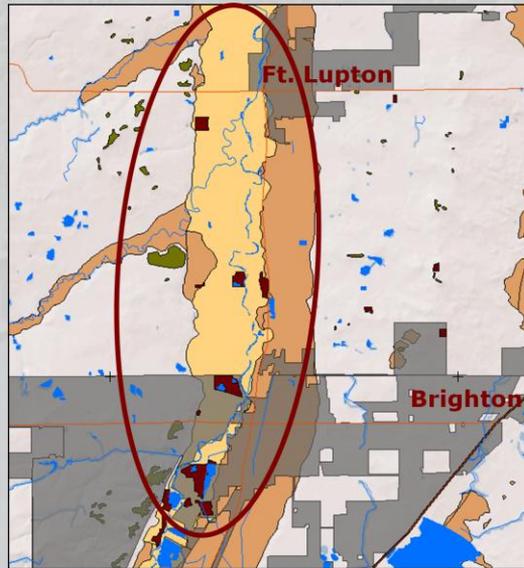
The stream channel and low terraces of the South Platte River north of Denver, Colorado, are mined and processed to provide aggregate to the greater Denver area. This example demonstrates how aggregate quality can change from one location to another.



Clear Creek flows eastward from the mountain front towards Denver, where it joins with the South Platte River, which flows northward toward Fort Lupton. Sand and gravel were mined along Clear Creek, but urbanization has shut off that area for most gravel mining. Most new gravel operations occur between Brighton and Fort Lupton.

Near the mountain front, the sand to gravel ratio in the Clear Creek alluvium is about 1:1. Downstream, between Brighton and Fort Lupton, the ratio is about 3:1. Significantly more material near Fort Lupton needs to be mined and processed to obtain an equal amount of gravel as can be obtained near the mountain front.

Gravel operations - 2010

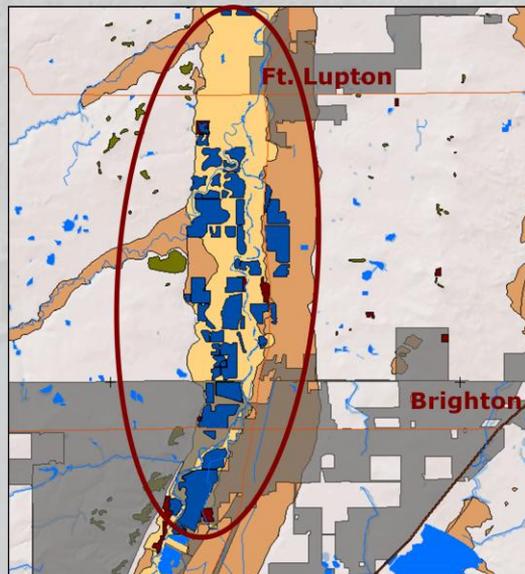


5 miles



This slide shows the area between Fort Lupton and Brighton in more detail. The next slide will show how the area will look in the future if all currently permitted sand and gravel operations are mined out and reclaimed as outlined in their permits (Langer, 2009).

Reclaimed operations - 2010



5 miles

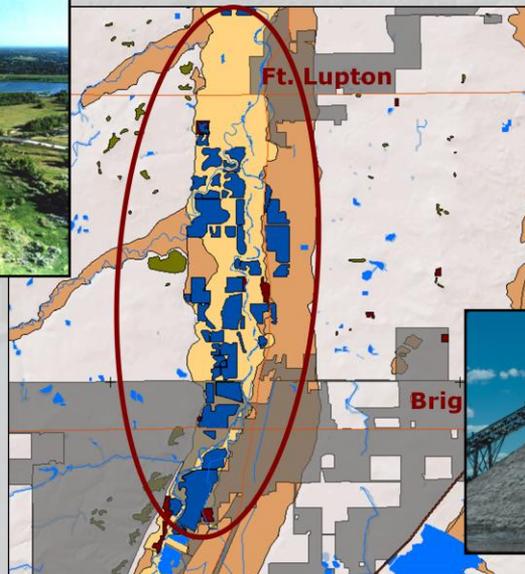


Almost all of the sand and gravel operations are planned to be reclaimed as reservoirs to hold water appropriated from the South Platte River.

Reclaimed operations - 2020



Photograph from the Minerals Information Institute.



Photograph from Amy Lilienfeld.

5 miles

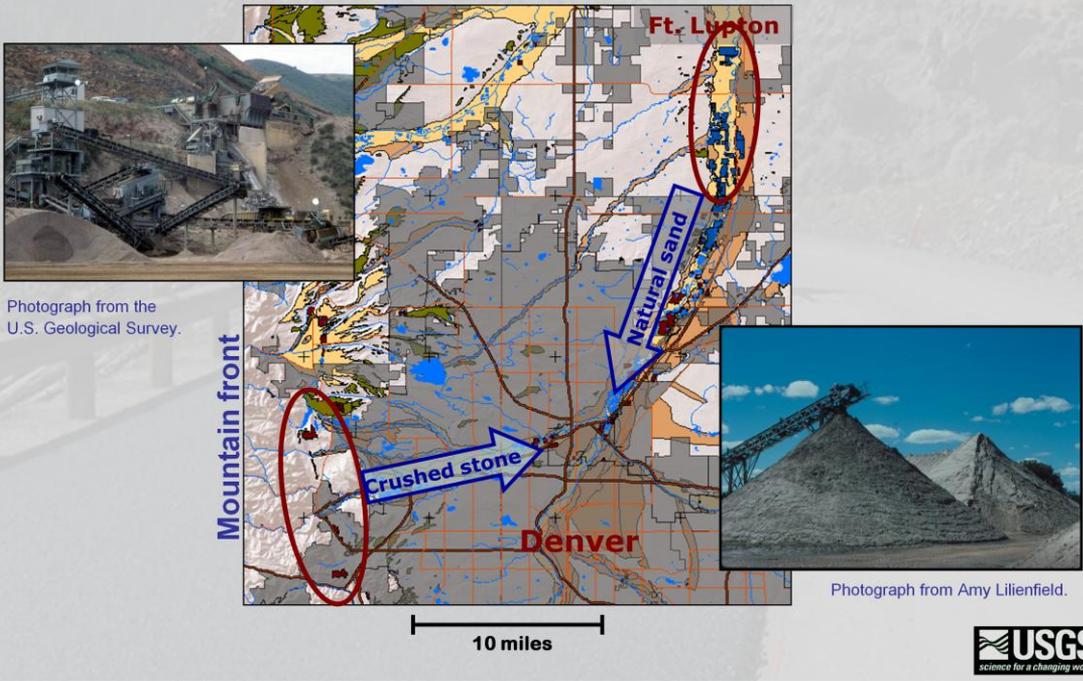


One of the consequences of mining sand and gravel with a high sand-to-gravel ratio is that there are large piles of sand that remain after processing and marketing the gravel.

Photograph of reservoir from the Minerals Information Institute.

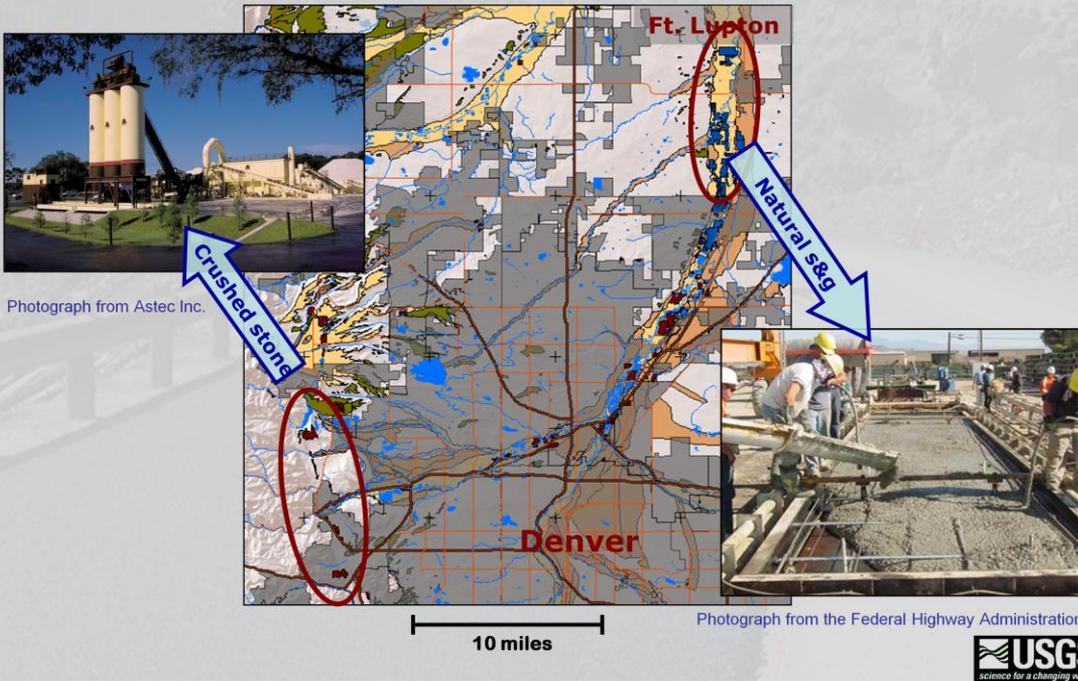
Photograph of sand piles from Amy Lilienfeld.

Blending supplies



To avoid wasting the sand, some operators have ready-mix or asphalt plants located midway between their crushed stone operations near the mountains and their sand and gravel operations near Brighton.

Matching supply to application

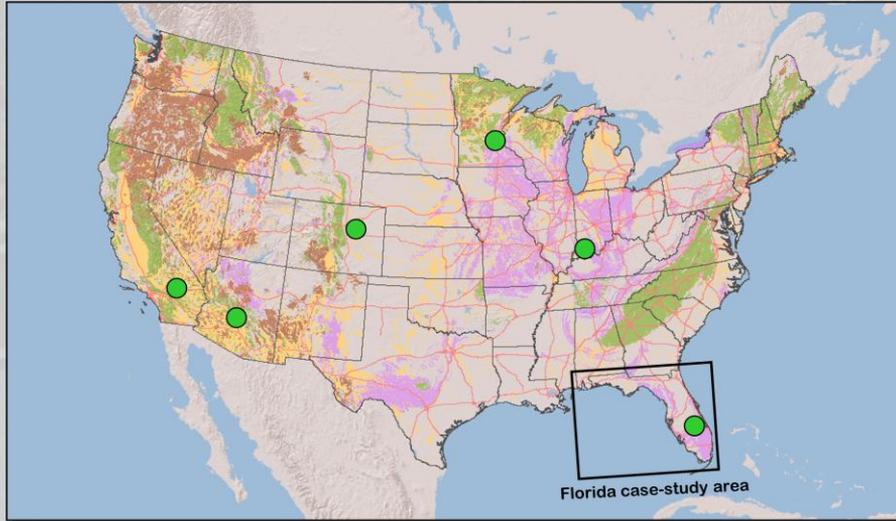


Crushed stone and manufactured sand can be used for applications such as SuperPave, and natural sand and gravel can be used for types of concrete that require surface finishing.

Photograph of asphalt plant from Astec Inc.

Photograph of concrete from the Federal Highway Association.

Quality Issues Florida



Limestone in Florida is mined and processed to provide some of the aggregate for in-state use. This example demonstrates how aggregate quality can affect its use and how a sophisticated transportation system can address aggregate shortages.

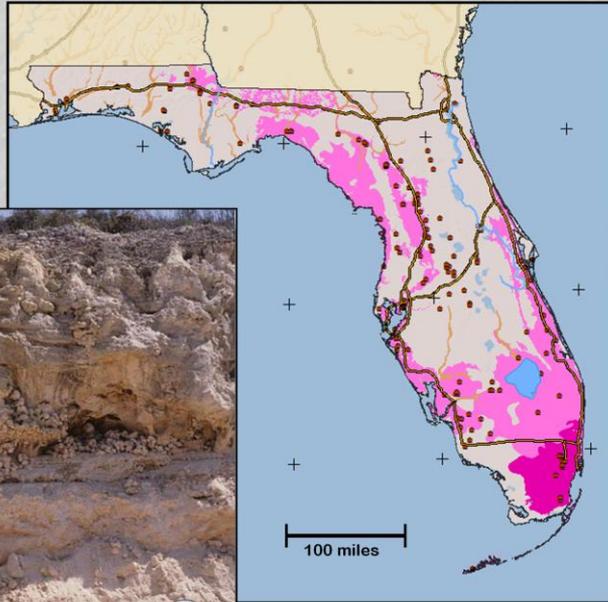
Geology

Miami limestone

Other limestone



Photograph from the Florida Geological Survey.



● Florida Dept. Of Transportation approved aggregate source

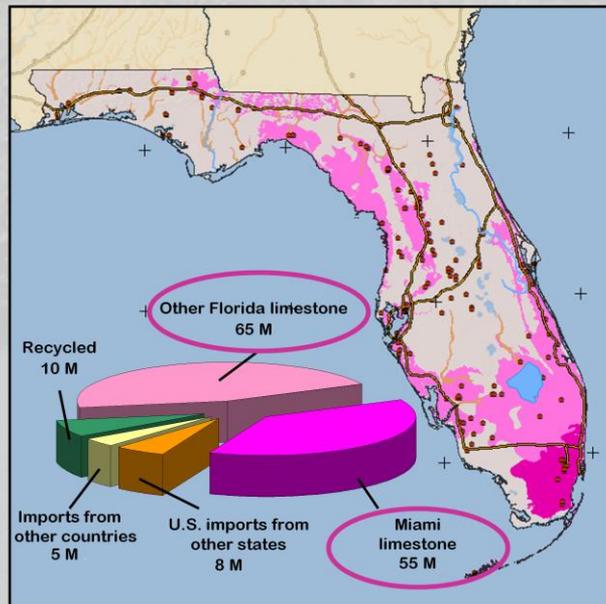


The geologic processes that created the limestone in Florida produced rocks that are not uniform in hardness, durability, or chemical composition. The red dots on this map show aggregate sources approved by the Florida Department of Transportation (FDOT). FDOT also defines acceptable applications for crushed stone, based on its quality.

Local production - 2006

Miami limestone – used as construction aggregate

Other limestone – used as limerock (compacted durable base beneath roads and buildings) and as low-strength concrete



M, million tons

100 miles

Florida Dept. Of Transportation approved aggregate source

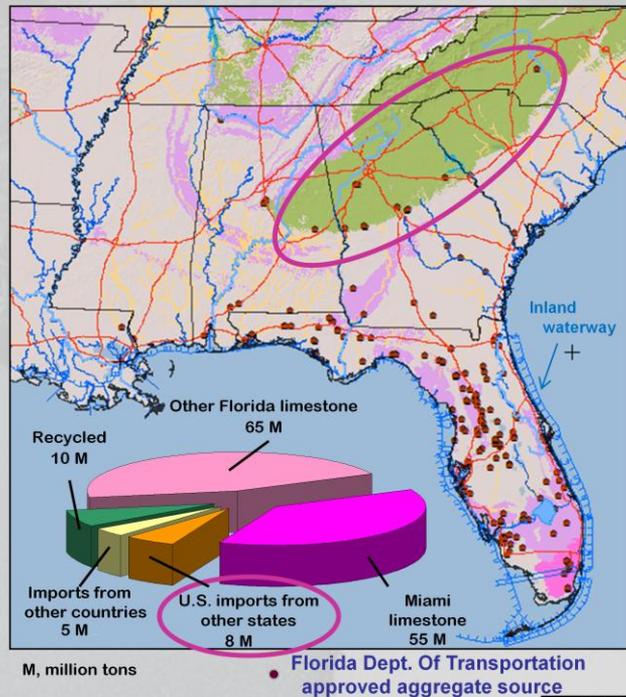


During 2006, about 120 million tons of aggregate was produced in Florida (Florida Department of Transportation, 2007). Aggregates for state projects must meet specifications prescribed by FDOT. The dark pink area on the map is underlain with limestone (Miami limestone) that generally is hard, durable, and acceptable for use as aggregates in the construction industry. Much of the limestone shown by light pink is soft and fails to meet specifications for engineered applications (Florida Department of Transportation, 2009). However, these softer rocks commonly can be used to create “limerock,” a fill material that can be compacted into a durable base for roads and buildings. Low-quality limestone also can be used in parking lots and sidewalks.

Imports from other states - 2006

Granite

- High friction
- Abrasion resistance
- Used in SuperPave
- Used to avoid D-cracking



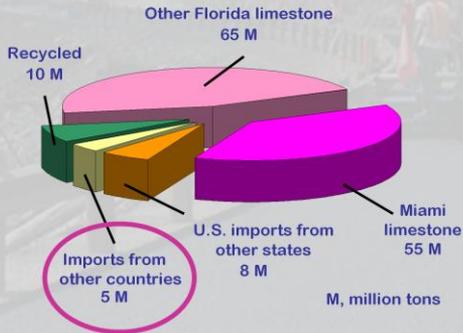
M, million tons

Florida Dept. Of Transportation approved aggregate source



During 2006, about 8 million tons of aggregate was imported to Florida from other U.S. states. Much of this material was granite, which is imported for wearing surfaces on high-traffic pavements where durable aggregates are needed to meet skid resistance and abrasion requirements.

Imports from other countries - 2006



- Granite from Canada
- Limestone from Bahamas
- Granite from Honduras

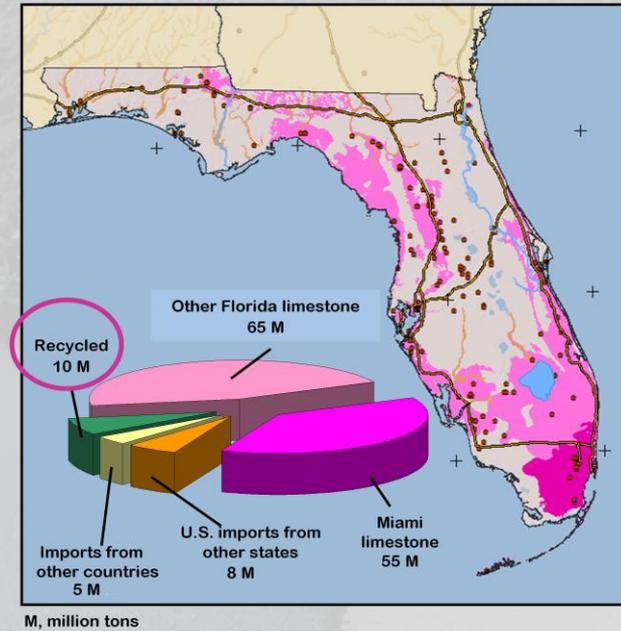


Florida imports granite from Canada and Honduras, and limestone from the Bahamas via freighter into facilities at the Port of Tampa, Port Manatee, Port Canaveral, and the Port of Jacksonville.

Recycled aggregate - 2006

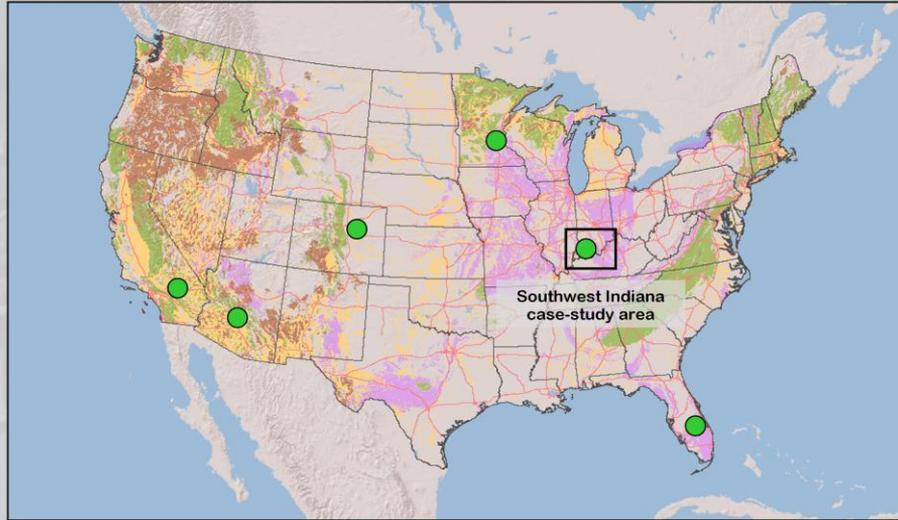


Photograph from Metso Materials.



About 10 million tons of aggregate used in Florida is recycled asphalt or concrete (Florida Department of Transportation, 2007).

Environmental Issues Southwest Indiana



Southwestern Indiana contains a large area that is underlain by potential sources of limestone. This example demonstrates how environmental issues can encumber access to aggregate resources.

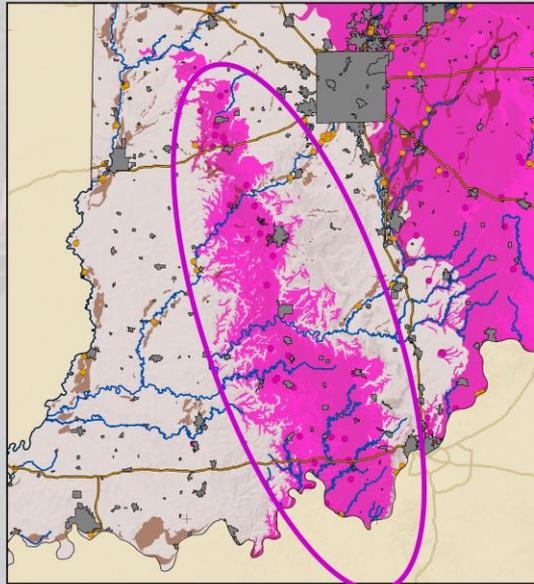
Environmental Issues

Potential sources of limestone

Potential sources of sand & gravel

Built-up areas

- Active aggregate operations (from Indiana Geological Survey, 2001)



100 miles



Over 4 million acres of land in the area enclosed by the oval are underlain by potential sources of limestone (shown in dark pink).

Environmental issues

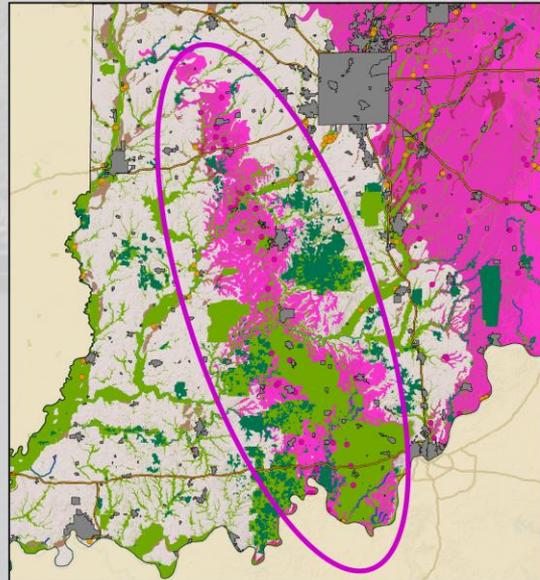
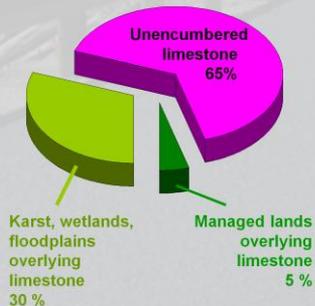
Potential sources of limestone

Potential sources of sand & gravel

Built-up areas

Managed lands

Karst, wetlands, floodplains

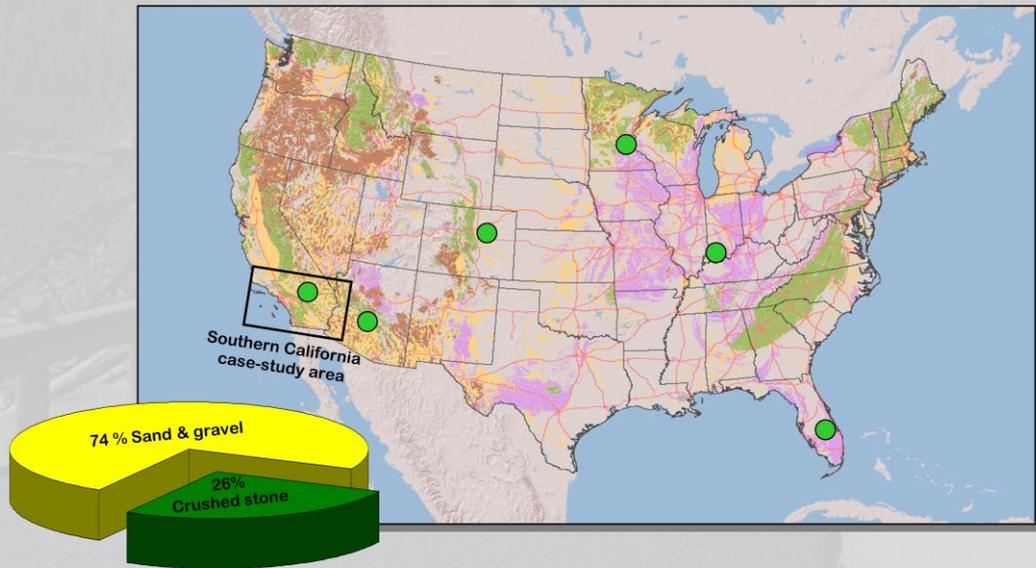


Managed lands, such as parks and conservation areas (shown by dark green), overlie about 0.14 million acres, or about 5 percent, of the limestone.

Karst, floodplains, and wetlands (shown by light green) overlie about 0.9 million acres, or about 30 percent of the limestone.

By employing best management practices, most environmental impacts can be controlled, mitigated, or kept at tolerable levels and can be restricted to the immediate vicinity of the aggregate operation. Nevertheless, some otherwise high-quality aggregate resources may not be developed because of environmental issues.

Societal Issues Permitting – Southern California



California is a state that primarily uses sand and gravel as aggregate. Southern California can be used as an example of how permitting affects the availability of aggregate.

SMARA - 1975

Surface Mining and Reclamation Act

California counties are required to have **permitted aggregate resources** that meet the 50-year demand.



The State of California passed the Surface Mining and Reclamation Act (SMARA) in 1975. SMARA requires that counties have sufficient permitted aggregate resources to meet the demand for the next 50 years (Kohler, 2006).

Permitted Aggregate Resources

“... aggregate deposits that have been determined to be acceptable for commercial use, exist within properties owned or leased by aggregate producing companies, and have permits allowing mining of aggregate material.”

Kohler (2006 p. 6),



According to Kohler (2006, p. 6), “Permitted aggregate resources (also called reserves) are aggregate deposits that have been determined to be acceptable for commercial use, exist within properties owned or leased by aggregate producing companies, and have permits allowing mining of aggregate material. A ‘permit’ is a legal authorization or approval by a lead agency, the absence of which would preclude mining operations.”

Required vs Permitted Reserves Southern California



During 2002, the California Geological Survey published a map containing data on the availability of permitted aggregate resources in 31 study areas throughout the state (Kohler, 2002). The 50-year demand for aggregate in each study area was estimated and compared with the amount of permitted aggregate at the time.

The exercise was repeated in 2006 (Kohler, 2006). The results for 12 of the study areas that occur in southern California are plotted on this map.

The yellow triangles show production areas. The size of the triangles reflect the relative amount of production, ranging from the smallest triangle, which indicates production of less than 0.5 million tons per year, to the largest triangle, which indicates production of greater than 10 million tons per year.

The blue circles indicate, by size, the relative 50-year reserve requirement. The green inner circles indicate, by size, the amount of permitted reserves.

Required vs. Permitted Reserves

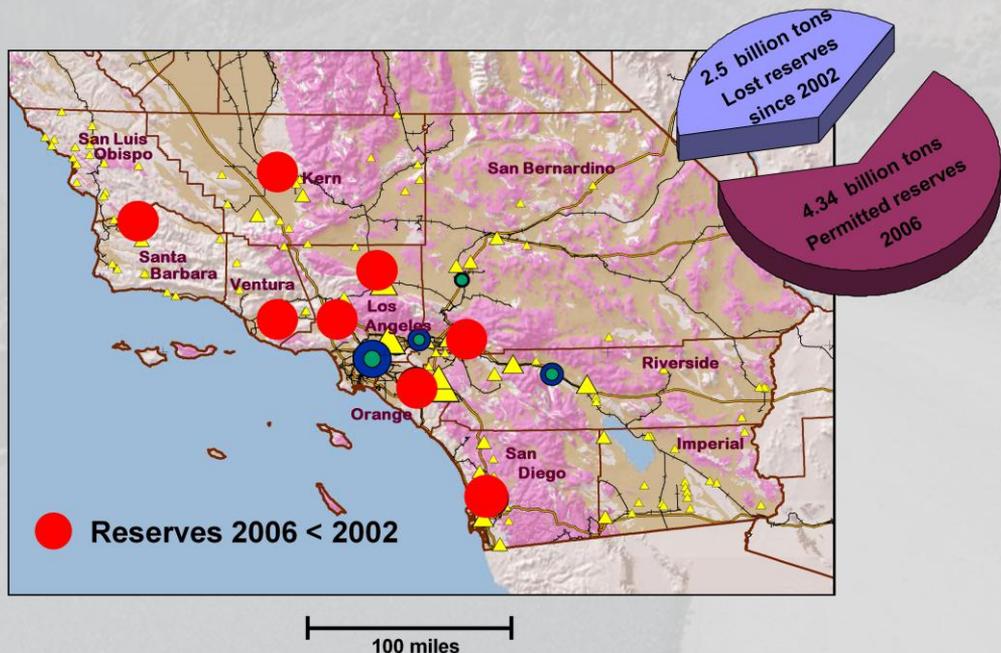


100 miles



In the entire state, 25 of 31 study areas have less than half of required reserves. In southern California, 9 (shown by the red dots) of the 12 study areas have less than half of the required reserves.

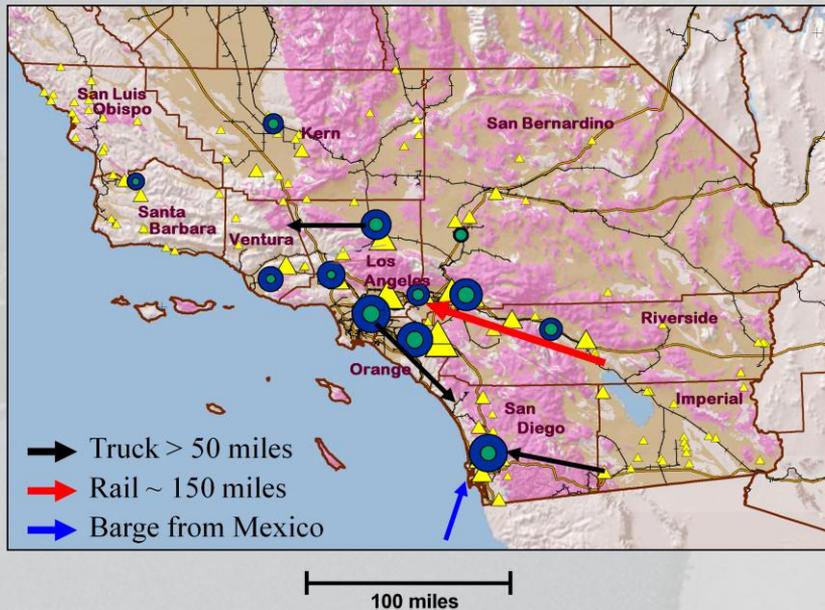
Permitted Reserves 2006 vs 2002



The data on the 2006 map were compared with the data on the 2002 map. Total permitted reserves in the state decreased from 6.848 billion tons to 4.343 billion tons, with a total loss of about 2.5 billion tons of aggregate reserves (Kohler, 2006).

Eighteen of the 31 study areas shown on the 2006 map experienced a decrease in permitted aggregate reserves, including 8 (shown by the red dots) of 12 in southern California.

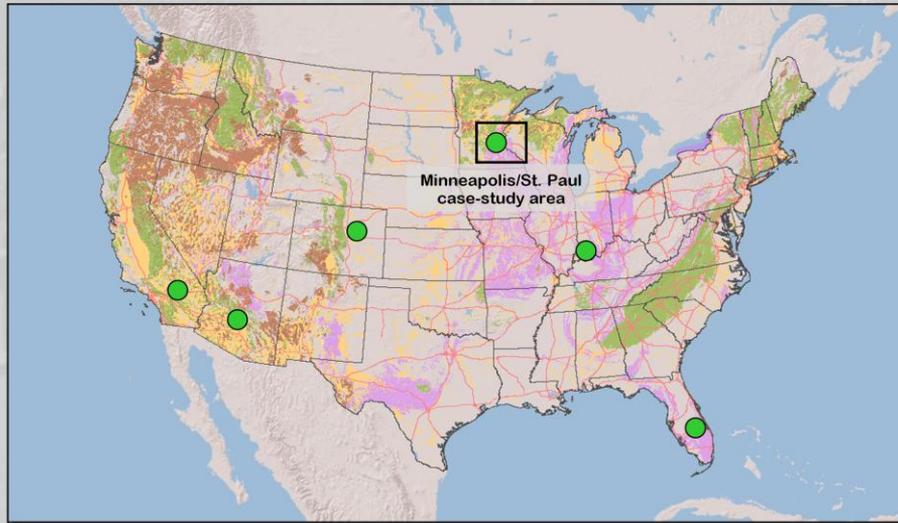
Transport to Overcome Shortfall



Aggregate is being transported long distances to accommodate the shortfall in permitted aggregate resources, resulting in significant transportation cost increases. Most of the transport is by truck. Aggregate is hauled from southwestern Imperial County into downtown San Diego, a distance of about 90 miles. Coarse aggregate from eastern Ventura County is hauled as far as 60 miles to western Ventura County. Aggregate from Orange County is hauled over 50 miles to northern San Diego County. Aggregate is transported over 30 miles among numerous production districts (Kohler, 2006).

In addition, between 1 million and 2 million tons of aggregate are annually shipped by rail nearly 150 miles from central Riverside County into Los Angeles County, and sand is being shipped by barge from Mexico into the San Diego Bay region (Kohler, 2006).

Quality Issues Minneapolis/St. Paul, Minnesota



This example from the Minneapolis/St. Paul metropolitan area demonstrates how aggregate quality can affect its use, how urban encroachment can limit its development, and how plans for growth and development can protect aggregate for future use.

Quality – Alkali-Silica Reaction

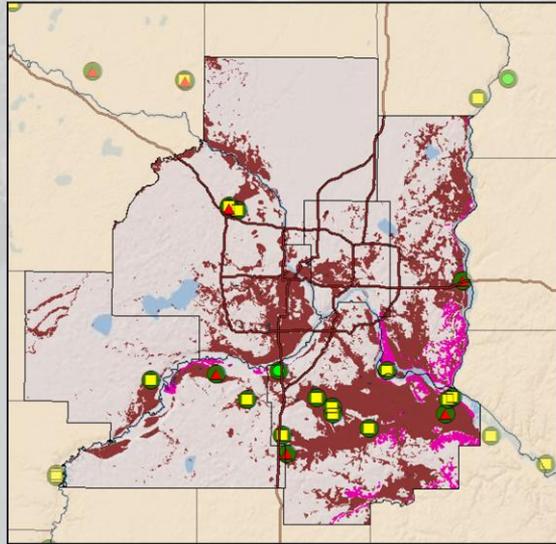
Potential sources
of limestone

Potential sources
of sand and gravel

Max alkali-silica
reaction expansion,
in percent,
after 14 days

- 0-0.15
- >0.15 – 0.25
- ▲ >0.25 – 0.674

● With use of fly ash



The Minnesota Department of Transportation (MDOT) Office of Materials & Road Research tested several aggregate sources for the potential alkali-silica reaction (ASR). Results from the 14-day expansion test are shown in this map. The smaller symbols indicate test results on aggregate. The larger, green circle indicates the 14-day test result when fly ash is used in the concrete mixture. All aggregates in the mapped area had test results of less than 0.15 percent expansion when used in concrete with fly ash. By understanding the quality of the aggregate in an area, the sources of aggregate can be matched to the application.

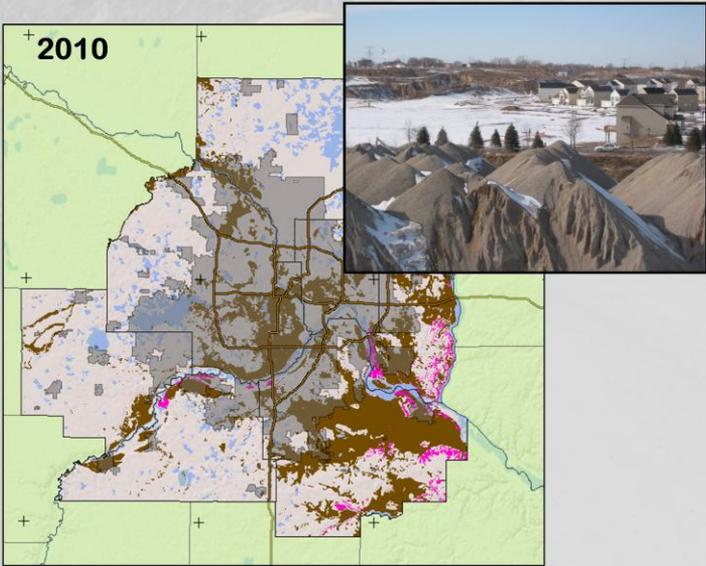
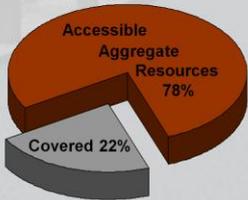
Data from Minnesota Department of Transportation, (2009).

Societal Issues – Encroachment Minneapolis/St. Paul, Minnesota

Potential sources
of limestone

Potential sources
of sand and gravel

Built-up
areas

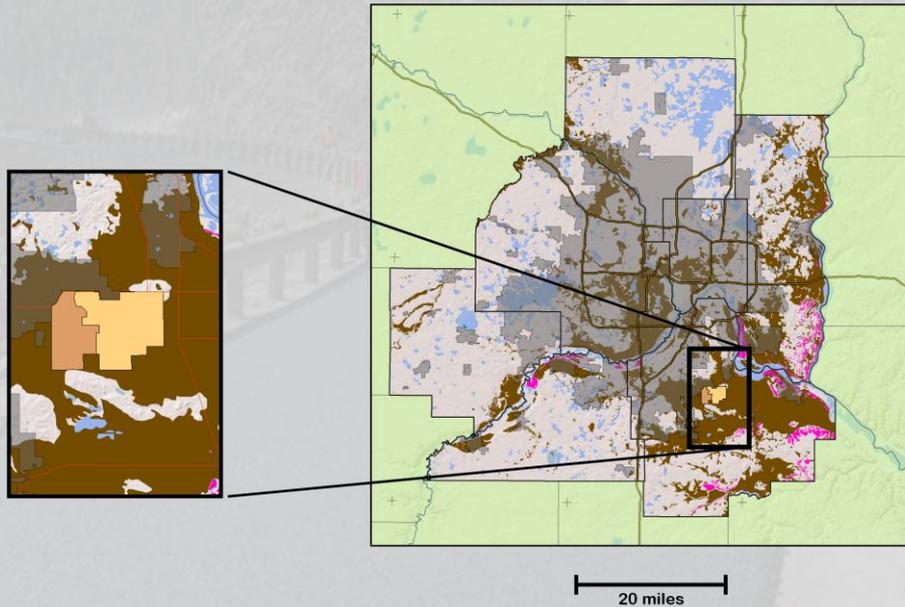


Photograph from the U.S. Geological Survey.



Nearly one-quarter of the potential sources of aggregate in the Minneapolis/St. Paul area have been covered by development, and are no longer available for use.

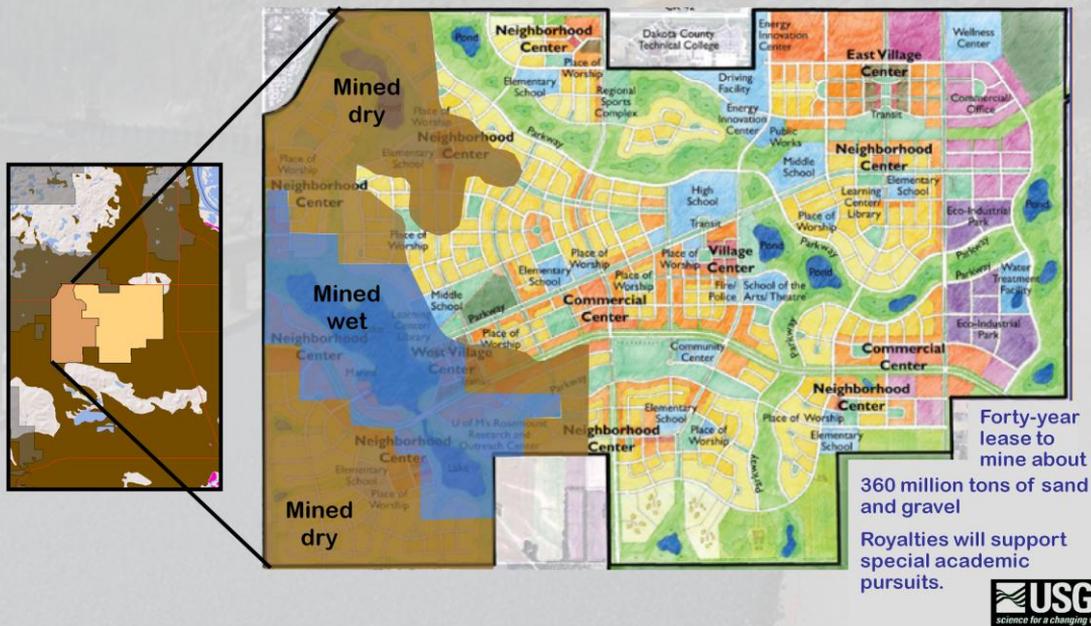
Encroachment



A new development is planned in the southeastern metropolitan area.

UMore Park

Protecting aggregate from encroachment



The plan allows for gravel extraction on approximately 1,722 acres on the western edge of the UMore Park property. A 40-year lease agreement has been signed whereby a local aggregate producer will conduct phased gravel mining at UMore Park, with gravel mining limited to a total of 160 acres at any given time. The lease agreement generates royalties for the University that will be designated for long-term support of special academic pursuits not adequately funded by other sources. Following local approvals, mining activities will tentatively commence in late 2011.

Summary Issues

- A large supply of aggregate will be needed to repair the Nation's transportation infrastructure.
- Aggregate is widespread but does not occur everywhere.
- Aggregate may not meet quality requirements for specific uses.
- Aggregate development may be prohibited by encroachment.



There is an indisputable need for an uninterrupted, large supply of aggregate for the restoration and rehabilitation of the infrastructure. Aggregate needs to be mined as close as possible to the projects that use it.

Natural aggregate is widespread through the conterminous United States, but is not universally available for consumptive use. Some areas are devoid of gravel, and potential sources of crushed stone may be covered with sufficient overburden to make surface mining impractical. The aggregate may not meet the strict quality requirements for its intended use. Encroachment by conflicting land uses and environmental restrictions may limit access to potential aggregate resources.

Summary

Solutions (from case studies)

- Geologic knowledge of deposits can help understand:
 - Occurrence or absence of potential aggregate resources
 - Characteristics of aggregate resources.
- Project design can include:
 - Use of local marginal material (anhydrite, cinders) for appropriate applications such as base course and high quality material for applications such as wearing surfaces
 - Use of local unconventional material such as clinker or cinder (as light-weight aggregate) in high-specification uses
 - Use of high-specification material imported from outside the state
 - Use of aggregates blended from different source areas
 - Use of recycled aggregate.
- Efficient transport (back-haul and multi-modal transport) can help minimize costs of aggregate transport.
- Including the consideration of aggregate resources in plans of growth and development can help protect local aggregate supplies.



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