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GEOLOGIC CHARACTERIZATION OF NATURAL AGGREGATE

A Field Geologist's Guide to
Natural Aggregate Resource Assessment

by

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ABSTRACT

This report is intended to help the field geologist engaged in geologic reconnaissance to determine the aggregate (crushed stone and sand and gravel) potential of an area. The report guides the geologist to observations in the field, summarizes relations between the geologic properties of rocks and sand and gravel and their likely performance as an aggregate, and provides geologists with information about the specific physical and chemical properties that are important to aggregate quality.

The physical and chemical properties of aggregate result from the geologic origin and mineralogy of the potential source and its subsequent weathering or alteration. Many of the properties of aggregate relate to grain size, texture, mineralogy, pore space, and weathering products, all characteristics that can be observed and described by traditional geologic methods. Knowledge of which physical or chemical qualities determine the suitability of aggregate enables geologists to characterize potential aggregate sources.

It should be noted that in reporting aggregate production, the aggregate industry does not strictly adhere to a common petrological classification to describe the source rocks for crushed stone. For example, a "limestone" may refer to a limestone, a dolomite, or a marble that does not take a polish. The term "marble" may refer to a true metamorphic marble or to a limestone or dolomite that takes a polish. Coarse-grained, dark-colored mafic intrusive rocks may be identified as "traprock" or "black granite" by the aggregate industry. The term "traprock" is also used to describe any fine-grained, dark-colored extrusive igneous rock such as basalt and andesite. These differences in nomenclature need to be considered when the geologist prepares reports that will be used by the aggregate industry.

The key to mapping potential sources of aggregate is an understanding of the geology of the region: focussing on the surficial geology and Quaternary geologic history for deposits of sand and gravel, and a general study of stratigraphy, origin, and structural history of the region for sources of crushed stone. Geologic maps serve as a primary source of information for determining the location of potential sources of aggregate. The mapped distribution of surficial deposits restricts the area in which sand and gravel deposits are likely to occur. The distribution of bedrock units suitable for crushed stone shown on geologic maps helps identify the general areas where the target stone type is at or near the surface, and for identifying the source rocks of sand and gravel particles.

Of the sedimentary rocks, hard dense limestone and dolomite generally make good sources of crushed stone. However, some limestone and dolomite may be soft, absorptive, and friable, which results in poor quality aggregate. Chert and flint may be used as crushed stone; however, they are hard to crush and may cause adverse chemical reactions when used as concrete aggregate. Conglomerate, breccia, and sandstone, are locally used for crushing. Of these rocks, sandstone, when hard and dense, is most commonly used for crushed stone and is a major source of aggregate in some areas.

Igneous rocks commonly are hard, tough, and dense, and make an excellent source of crushed stone. However, certain extrusive rocks are too porous to make good aggregate and other highly siliceous igneous rocks tend to chemically react with alkali when used as aggregate in cement concrete. Fractures along cleavage in some coarse grained igneous rocks can result in crushing strengths too low for aggregate use. For the same reasons some lava flow rocks may be unsuitable for aggregate if they contain flow-banded, strongly jointed, vesicular, or brecciated members. Pyroclastic volcanic materials such as ash and tuff may be unsuitable unless they have become indurated by heating (welding) or compacted and cemented during burial.

Metamorphic rocks comprise a very broad range of rock types. Their suitability for use as aggregate depends on the parent rock, the degree and type of metamorphism, and the subsequent alteration and weathering.

Most gravel is found in glaciated regions, in alluvial basins, as fluvial deposits near rivers and streams, or as marine deposits. The suitability of sand and gravel for use as aggregate depends properties including grain-size distribution, particle shape, surface features of clasts, lithologies of clasts, and the weathering of the clasts.

A variety of properties can be described to characterize aggregate. Many of these are physical properties that can be measured using standardized tests. Chemical properties of aggregate are important in the manufacture of concrete or bituminous mixes because some aggregates contain minerals that chemically react with or otherwise affect the mixes. Excessive amounts of contaminants may cause decreased strength and durability of aggregate, may affect the quality of the bond between the cement and the aggregate, may cause an unsightly appearance, and may inhibit the hydration of the cement. Weathering of bedrock or gravel clasts lessens the strength of aggregate, increases the overall cost of separating the good from the bad rock, and influences the blasting and extractive techniques employed. Maps of potential sources of aggregate should include descriptions of these properties as well as delineate the areal extent and thickness of the potential aggregate source.

INTRODUCTION

This report is intended to help the field geologist engaged in geologic reconnaissance to determine the aggregate potential of an area. For purposes of this report aggregate is defined as crushed stone and sand and gravel. The report bridges the gap between the geologist and the aggregate specialist by acquainting the geologist with some technical aspects of the aggregate industry. This report guides the geologist to observations in the field and summarizes relations between the geologic properties of rocks and sand and gravel and their likely performance as an aggregate. This document assumes that geologists who assess aggregate resources are competent mappers but lack expertise in the aggregate industry. The intended reader is the geologic mapper, the mineral resource appraiser, and the prospecting geologist. This document provides such geologists with information about the specific physical and chemical properties that are important to aggregate quality.

The physical and chemical properties of aggregate result from the geologic origin and mineralogy of the potential source and its subsequent weathering or alteration. Many of the properties of aggregate relate to grain size, texture, mineralogy, pore space, and weathering products, all characteristics that can be observed and described by traditional geologic methods. Knowledge of which physical or chemical qualities determine the suitability of aggregate enables geologists to characterize potential aggregate sources.

The largest single use of natural aggregates is in construction, and much of that aggregate is used in portland-cement concrete or bituminous mixes. The specifications for natural aggregate in portland-cement concrete or bituminous mixes are generally more rigorous and specific than for other construction-related uses. If aggregate can meet the specifications for these uses, it will satisfy almost any other use. Therefore, the specifications required for portland cement and bituminous mixes, and the geologic observations that help describe them, are emphasized in this report. Aggregate characteristics can be divided into three groups: (1) physical properties, (2) chemical properties, and (3) contaminants. Major physical properties that affect the use of aggregate with portland-cement concrete or bituminous concrete are: gradation of particle sizes; particle shape; particle-surface texture; porosity; pore structure; specific gravity; thermal properties; and susceptibility to volume changes. Chemical properties of aggregate that adversely affect the strength and durability of portland-cement concrete or bituminous mixes include oxidation of certain minerals, short-term reactions such as efflorescence, and longer-term reactions such as the alkali-silica reaction. The presence of certain contaminants can prevent the cement from hydrating or bitumen from adhering to the aggregate.

To help ensure that aggregates will satisfactorily meet engineering specifications, aggregate commonly is subjected to standardized tests. Common tests and measurements (geologic observations) can be made in the field or laboratory by an experienced geologist to help evaluate the quality of potential aggregate sources. These include: 1) resonance when struck with a hammer; 2) friability or pulverulence when squeezed between the fingers; 3) ease of fracturing; 4) nature of fracture surfaces and fracture fillings; 5) odor on fresh fracture; 6) color and variations in color; 7) internal structure such as porosity, granularity, seams, and veinlets; 8) reaction to water, such as absorption of droplets on fresh fractures, expulsion of air or slaking, softening, or swelling when immersed, and capillary suction against the tongue; and 9) reaction to acid (Mielenz, 1994). These rather simple and inexpensive tests (observations) can be used to estimate more specific *physical* and *chemical* properties important to determining aggregate quality and determining if deleterious *contaminants* are present.

There is a variety of reasons to conduct more extensive engineering tests, including to determine compliance with specification requirements (commonly set by purchaser), to ensure thorough quality controls, to assure that the customer is receiving the same material that is being produced at the plant site, and to obtain measurements of the physical properties used by the engineer in design of pavements, foundations, portland cement concrete, bituminous mixes, etc. (Marek 1991). These tests commonly expose aggregate to conditions that simulate the conditions under which the aggregate will be used. The tests are expensive and time consuming and are generally only used for detailed resource appraisals and in exploration.

The most common guidelines that outline testing procedures and specifications for natural aggregates are those described by the American Society for Testing and Materials (ASTM). The construction industry often relies on the results of previous ASTM tests of materials and the service records of these materials in actual use to estimate the quality of similar materials. Selected ASTM procedures for testing aggregate are shown in Appendix A. The approach to assessing aggregate described by this paper closely follows ASTM Standard 295-90, *Standard Guide for Petrographic Examination of Aggregate for Concrete*. This paper relates that standard to geologic parameters, practices and terminology.

TYPES OF POTENTIAL AGGREGATE DEPOSITS

Naturally-occurring aggregate deposits, whether sand and gravel or source rock for crushed stone, are formed by a variety of geologic processes. Volcanoes, earthquakes, glaciers, rivers and streams, and marine processes have each contributed to the formation of the materials we use as aggregate. Consequently, the key to locating suitable deposits and assessing the potential for new aggregate sources is understanding the geologic processes that form them and the geologic settings in which they occur. The field geologist is well suited for this task.

Crushed Stone

Crushed stone is "The product resulting from the artificial crushing of rock, boulders, or large cobblestones, substantially all faces of which have resulted from the crushing operation" (Langer, 1988 as paraphrased from American Society for Testing and Materials, 1994). More crushed stone is produced in the United States than any other mineral, mainly for uses in the construction industry, and as noted by Tepordei (1993), "Despite the relative low value of its basic products, the crushed stone industry is a major contributor to and an indicator of the economic well-being of the Nation".

In addition to the size and shape of the particles, crushed stone is classified according to the type of rock from which it was produced. Bedrock is broadly classified on the basis of its origin into three main groups: sedimentary, igneous, and metamorphic. Crushed stone is produced from each of the three rock groups as summarized below. More detailed discussions of the rock types are contained in Tepordei (1993), Dunn (1991), and ASTM Standard C294 (American Society for Testing and Materials, 1994).

It should be noted that, in reporting aggregate production, the aggregate industry does not strictly adhere to a common petrological classification to describe the source rocks for crushed stone. For example, a "limestone" may refer to a limestone, a dolomite, or a marble that does not take a polish. On the other hand, the term "marble" may refer to a true metamorphic marble or to a limestone or dolomite that takes a polish. Similarly, the coarse-grained, dark-colored mafic intrusive rock called gabbro may be identified as "traprock" or "black granite" by the aggregate industry; however, the term "traprock" is also used to describe any fine-grained, dark-colored extrusive igneous rock such as basalt and andesite. These differences in nomenclature need to be considered when the geologist prepares reports that will be used by the aggregate industry.

Sedimentary Rocks

Table 1 shows the most common types of sedimentary rocks and which of those rock types often are good sources for crushed stone. Of the chemically or biochemically deposited sedimentary rocks, hard dense limestones and dolomites, composed of carbonates, generally make good sources of crushed stone and make up approximately 71 percent of crushed stone production (Tepordei, 1993). However, some limestone and dolomite may be soft, absorptive, and friable, which results in poor quality aggregate. Chert and flint are composed of silica that has been precipitated from water by organisms such as sponges, radiolarians, and diatoms. Chert and flint may be used as crushed stone; however, they are hard to crush and may cause adverse chemical reactions with alkali when used as concrete aggregate.

Clastic sedimentary rocks, including conglomerate, breccia, and sandstone, are locally used for crushing. Of these rocks, sandstone, when hard and dense, is most commonly used for crushed stone and is a major source of aggregate in some areas. Even so, sandstone makes up less than 3 percent of the total U.S. production (Tepordei, 1993).

SEDIMENTARY ROCKS

Source material (unconsolidated)	Equivalent rock (consolidated)
Clastic Rocks	
Angular coarse fragments	Breccia*
Gravel	Conglomerate*
Sand	Quartzite*, sandstone*, with varieties according to cement (siliceous†, calcareous, clayey, ferruginous) Constituents other than quartz (arkose*, graywacke*, tuff*)
Silt and clay	Argillite, siltstone, claystone, shale
Chemical and Biochemical	
Calcareous	
Shells, coral, crinoids	Limestone*, chalk
$CaCO_3$ precipitated	Oolitic limestone
$CaMg(CO_3)$ precipitated	Dolomite*, dolomitic limestone*
Siliceous precipitate or fossils	Flint*†, chert*†, diatomite

* Rocks commonly used as aggregate
† May be reactive with alkali in portland-cement paste

Table 1. Common sedimentary rocks used for crushed stone (modified after Smith and Collis, 1993).

Igneous Rocks

Table 2 shows the primary petrologic igneous rock types based on mineral composition, grain size, and texture. The aggregate industry identifies igneous rocks based primarily on grain-size and color: light-colored, coarse-grained (intrusive) rocks are termed *granite* which may also include light-colored, coarse-grained metamorphic gneisses as well; as previously mentioned, dark-colored, fine-grained (extrusive) rocks are called *traprock*; light-colored, fine-grained volcanic rocks like rhyolite and trachyte may be termed either *traprock* or *granite* by different producers; and dark-colored, coarse-grained igneous rocks like gabbro may be referred to as *black granite* or *traprock*. Volcanic cinders and scoria are also used as sources for crushed stone, but together they make up only about 0.2 percent of the total crushed stone production (Tepordei, 1993).

Igneous rocks commonly are hard, tough, and dense, and make an excellent source of crushed stone. However, certain extrusive rocks are too porous to make good aggregate and other highly siliceous igneous rocks tend to chemically react with alkali when used as aggregate in cement concrete. Fractures along cleavage in some coarse grained igneous rocks can result in crushing strengths too low for aggregate use. For the same reasons some lava flow rocks may be unsuitable for aggregate if they contain flow-banded, strongly jointed, vesicular, or brecciated members. Pyroclastic volcanic materials such as ash and tuff may be unsuitable unless they have become indurated by heating (welding) or compacted and cemented during burial.

Metamorphic Rocks

Table 3 shows a variety of common metamorphic rock types and the parent rocks from which they were derived. Except for rocks formed by predominately thermal activity (skarn), most regionally metamorphosed rocks show planar foliation caused by crystallization of parallel phyllosilicate minerals (micas). This foliation produces planes of weakness which are undesirable in aggregate, but only highly-foliated schist appears to have little or no use as aggregate. Marble accounts for 0.34 percent of the total crushed stone production and slate for 0.14 percent (Tepordei, 1993); however, rocks identified by the producers as marble may include some limestones and dolomites that take a polish. Metamorphic quartzite physically resembles sedimentary silica-cemented quartz sandstone and the two are not separated in reported production figures. Similarly, to aggregate producers, gneiss resembles coarse-grained igneous rocks. Consequently, reported production figures include a substantial amount of gneiss under the granite category.

Sand and Gravel

Sand and gravel deposits are accumulations of durable rock fragments and mineral particle. Such deposits result from the disintegration of bedrock and the subsequent transport, abrasion, and deposition of the weathered fragments. Ice and water are the principal geologic

IGNEOUS ROCKS

ACIDIC (SICILIC)	*INTERMEDIATE*	*BASIC* (MAFIC)
Coarse-grained (plutonic) rocks (grain size larger than about 5 mm) May be brittle from presence of large crystals		
Granite	**Syenite**	**Gabbro**
Granodiorite	**Diorite**	**Peridotite**
Quartz monzonite	**Quartz diorite**	**Dunite**
Medium-grained (hypabyssal) rocks (grain size between 5 and 1 mm); crystals commonly intergrown Commonly good aggregate		
Granophyre	**Porphyry**	**Diabase**
	Porhyrite	
Fine-grained (extrusive) rocks (grain size less than 1 mm, i.e. below the range of the unaided eye) Some rocks may be brittle and splintery; some may be alkali-silica reactive; otherwise good aggregate		
Rhyolite†	**Trachyte**	**Basalt**
	Dacite†	**Andesite†**
Glassy (extrusive) rocks Some rocks may be brittle and splintery; some may be alkali-silica reactive		
Pumice		**Scoria**
Obsidian†		
Continuous variation in properties and composition		
Light color **Low relative density (2.6)** **High silica percentage (66% +) potassium feldspar**		**Dark color** **High relative density (2.9)** **High ferro-magnesian minerals and plagioclase feldspar**

† May be reactive with alkali in portland-cement paste

Table 2. Common petrologic igneous rock types arranged according to general mineral composition and grain size (modified after Smith and Collis, 1993).

agents that affect the distribution of deposits of sand and gravel. Consequently, most gravel is found in glaciated regions, in alluvial basins, or as fluvial deposits near rivers and streams. Windblown deposits are too fine grained materials to be an important source of natural aggregate except possibly as blending sands. Unlike sources of crushed stone, which may be any age, sand and gravel deposits are mostly Quaternary in age, although some Tertiary sand and gravel is mined as aggregate.

Glacial Deposits

Much of the sand and gravel in the northern latitudes or high altitudes of the United States are the products of either continental or alpine glaciation. Glaciofluvial deposits occur in a wide variety of topographic settings. Streams flowing within or on top of the ice deposited material that presently underlies sinuous ridges called eskers or ice-channel fillings. Where the materials are deposited adjacent to the ice as mounds or terraces, they are kames or kame terraces. These deposits collectively are ice-contact deposits, and tend to be coarse-grained, poorly sorted material. The field geologist recognizes these valuable resources of sand and gravel by their unique landforms.

Granular materials carried away from the melting ice before being deposited are outwash deposits. Outwash tends to have fewer very coarse particles, and is better sorted. The processes involved with glacial erosion and deposition are extremely complex and dynamic. Hourly, daily, seasonal, and longer term temperature and climatic changes affect the generation of meltwater. Because of this, the grain-size distribution of glaciofluvial deposits varies greatly, both areally and with depth.

Alluvial Fans

In the arid western part of the United States, large valley basins are filled with thick unconsolidated alluvium. Alluvial fans are most common in, and characteristic of, regions with arid and semiarid climate, although some fans occur in more humid environments as well. In arid regions fan material is derived from erosion of the adjacent mountains, then transported by infrequent but torrential floods (typical of desert environments) down a steep-gradient streams towards the basins. Once reaching the flat, lowland areas the sudden decrease in gradient combined with infiltration of water rapidly diminishes carrying power which causes the streams to deposit their sediment load as alluvial fans. Generally the deposited material is coarsest adjacent to the mountains and becomes progressively finer toward the center of the basins. In time, the fans formed by adjacent streams may coalesce to form continuous, thick bajada deposits.

METAMORPHIC ROCKS

METAMORPHIC ENVIRONMENT (temperature and pressure conditions)		
Original rock	**Low grade Shallow burial**	**Medium and high grade Deep burial**
	Foliated platy rocks (effects of pressure paramount)	
Argillite, siltstone, claystone, shale	Slate	Phyllite, schist, gneiss*
Clayey sandstone	Graywacke	Quartz-mica schist, fine-grained gneiss
Clayey limestone	Slaty marble*	Calcareous schist
Granite	Sheared granite	Granite-gneiss*, quartz-mica schist
Basalt	Green (chlorite) schist	Amphibolite, hornblende gneiss*
	Nonfoliated, massive rocks (effects of temperature paramount)	
Any parent rock		Hornfels* (some recrystallization but original features may be present)
Quartzose sandstone	Quartzitic sandstone*	Quartzite*
Limestone and dolomite	Marble*	

* Metamorphic rocks commonly used as aggregate

Table 3. Common metamorphic rock types and the parent rocks from which they are derived (modified after Smith and Collis (1993).

Stream Channel and Terrace Deposits

Sand and gravel deposits are widely distributed throughout the United States as stream channel and terrace deposits, ranging from a few meters to tens of meters thick. This type of deposit is a primary source of aggregate material in much of the United States. The potential usefulness of any specific deposit is highly dependent on the type and composition of the bedrock source(s) of the clasts and the size and sorting of these clasts in the deposit.

Terraces and beaches found on mountainsides in the arid western U.S., especially in the Basin and Range province, contain sand and gravel deposits similar in many respects to stream channel and terrace deposits. During glacial periods mountain streams and meltwater from mountain glaciers sustained numerous freshwater lakes. Terraces and beaches formed around the margins of these lakes. Some of these deposits may be suitable for aggregate and should be considered in aggregate assessments.

Marine Deposits

Deposits of sand, silt, and clay form along shorelines (beaches) and submarine bars where sediments transported by streams are deposited and reworked by wave and current action. Rivers that flow across coastal plains may form large deltas, but the sediments are mostly sand, silt, and clay which are not suitable for coarse aggregate. However, where vigorous streams draining nearby mountains empty into the sea, deltaic deposits may contain a gravel component (Dunn, 1991). Although marine deposits currently provide a very small proportion of sand and gravel production, they could become more significant as other sources are depleted, and if economic, regulatory, and environmental concerns can be adequately addressed.

AGGREGATE ASSESSMENTS

The two primary sources of aggregate material are bedrock and deposits of sand and gravel. In areas where these traditional aggregate sources are scarce, other less common materials, such as volcanic cinders, shells, and caliche, are used as aggregate. Blast furnace slag, mine tailings, and other waste products are also locally used for aggregate, and there is a trend for recycling existing concrete and asphalt as aggegate (Langer and Glanzman, 1993). Whether these rather exotic alternative aggregate sources need to be considered is largely dependent on the goals of the individual assessment. This part of the report is primarily concerned with assessing potential sources of bedrock and deposits of sand and gravel.

Regional assessments (smaller than 1:50,000 map scale) and preliminary site investigations (1:50,000 map scale or larger) require the same basic types of information, but the level of detail between the two commonly differs, especially in the amount and kind of field observations. For example, regional assessments rely heavily on published data, supplemented by reconnaissance field observations to describe the nature of the regional deposits, and on geometric models of typical deposits to estimate volume.

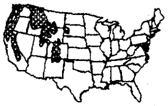
Site investigations use detailed field studies to determine physical and chemical characteristics of potential aggregate, spatial variability, and thickness measurements based on measured sections, well logs, and geophysical data to determine the geometry of the potential source for volume estimates. Regardless of the level of detail, an assessment of natural aggregate potential involves determining the location, quality, and the volume of the potential aggregate.

Locating Potential Aggregate Sources

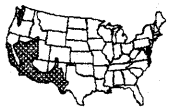
The preparation of a map showing the distribution of potential aggregate sources is essential for resource assessments. The key to mapping potential sources of aggregate is an understanding of the geology of the region: focussing on the surficial geology and Pleistocene and Holocene geologic history for deposits of sand and gravel, and a general study of stratigraphy, origin, and structural history of the region for sources of crushed stone. Knowledge of the types of aggregate sources likely to be present in a geographic region is an excellent starting point for delineating potential sources in the assessment area. For the United States, for example, to concisely describe the occurrence of natural aggregate sources, it is necessary to divide the country into specific regions (fig. 1). Each division reflects the type and availability of bedrock in a region and reflects the origin, general distribution, and abundance of sand and gravel in a region. Because the occurrence of bedrock suitable for use as crushed stone, and the origin and occurrence of sand and gravel deposits are related to physiography, the divisions selected for this report are based in general on physiography. Expanded descriptions of each region are contained in Appendix B.

Geologic maps serve as a primary source of information for determining the location of potential sources of aggregate (Dunn, 1991). Varnes (1974) describes techniques to translate information on geologic maps into interpretive products. The mapped distribution of surficial deposits restricts the area in which sand and gravel deposits are likely to occur. The distribution of bedrock units suitable for crushed stone, such as granite, limestone, dolomite, and basalt, shown on geologic maps is sufficient for identifying the general areas where the target stone type is at or near the surface (Bottge and others, 1965; Timmons, 1994), and for identifying the source rocks of sand and gravel particles. Nevertheless, available geologic maps may be too general to allow the user to confidently select potential resources, and additional field work may be necessary.

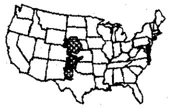
Aerial photos and other types of remote sensing data provide an excellent means for preparing reconnaissance geologic maps when none exist or existing maps are too generalized (Ray, 1960; Schwochow and others, 1974). Aerial photographs are especially useful for identifying landforms associated with sand and gravel deposits and sources of crushed stone,



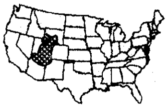
Western Mountain Ranges - Mountainous areas underlain with bedrock generally suitable for use as crushed stone. Sand and gravel commonly restricted to stream and terrace deposits and limited glaciofluvial deposit



Alluvial Basins - Mountain ranges underlain with bedrock generally suitable for use as crushed stone. Large alluvial basins filled with extensive deposits of poorly sorted sand and gravel.



High Plains - Gently-sloping plain underlain with unconsolidated or semiconsolidated bedrock unsuitable for use as crushed stone. Sand and gravel of variable quality commonly restricted to upstream sections of major river and terrace deposits.



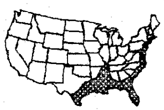
Colorado Plateau and Wyoming Basin - Flat plateau underlain with bedrock generally unsuitable or marginally suitable for use as crushed stone. Sand and gravel of variable quality commonly restricted to stream and terrace deposits.

Columbia Plateau - Flat plateau underlain with bedrock generally suitable for use as crushed stone. Sand and gravel of variable quality commonly restricted to stream and terrace deposits.

Piedmont Blue Ridge Region - Areas of thick saprolite underlain with bedrock generally suitable for use as crushed stone. Sand and gravel commonly restricted to stream and terrace deposits.

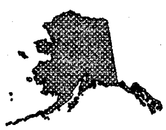
Nonglaciated Central Region - Areas of residuum underlain with bedrock of variable suitability for use as crushed stone. Sand and gravel of variable quality commonly restricted to stream and terrace deposits.

Glaciated Central Region - Areas underlain with bedrock of variable suitability for use as crushed stone. Thickness of overburden limits accessibility of bedrock in large areas. Sand and gravel commonly is available as glaciofluvial deposits and as stream and terrace deposits.



Atlantic and Gulf Coastal Plain - Gently-sloping plain underlain with thick unconsolidated sediments generally unsuitable for use as crushed stone. Consolidated bedrock generally is inaccessible. Sand and gravel is of variable quality and is limited in occurrence, commonly being restricted to upstream sections of major rivers and terrace deposits.

Glaciated Northeastern and Superior Uplands - Areas underlain with bedrock generally suitable for use as crushed stone. Sand and gravel commonly is available as glaciofluvial deposits and as stream and terrace deposits.



Alaska - Physiographically complex area of mountains, plateaus, and coastal plains underlain by igneous, meatmorphic, and sedimentary rocks of varying suitability for use as crushed stone. Sand and gravel commonly is available as glaciofluvial deposits and as stream and terrace deposits.

Hawaiian Islands - Volcanic islands underlain with bedrock generally suitable for use as crushed stone. Sand and gravel is of variable quality and is limited in occurrence, commonly being restricted to stream, terrace, and beach deposits.

Figure 1. Aggregate regions of the United States.

although detailed topographic maps can also be used effectively. Topographic maps also show the location of existing pits and quarries, providing clues to where aggregate is known to exist.

Quality of Potential Aggregate Sources

The preliminary map of the distribution of potential natural aggregate sources serves as the template for evaluating the probable quality of the aggregate resources. Following evaluations, symbols may be put on the map to show various levels of quality, including areas that are unacceptable.

National specifications exist for aggregate, however, specific requirements are determined by the users of the material, including federal, state, county, and city governments. Aggregate used in road building and concrete construction are subject to very rigorous specifications, but these specifications, as well as the specifications for other applications, can vary from area to area; U. S. Department of Interior (1981), Mielenz (1994), Barksdale (1991), and American Society for Testing and Materials (1994) describe many of the tests and factors that must be considered for concrete aggregate (See Appendix A).

Many of the ASTM quality tests (Appendix A) used by aggregate producers require considerable time and/or specialized equipment to conduct. For assessment purposes, however, good estimates of the quality of potential aggregate sources can be obtained by relatively routine geologic field observations (or published descriptions) of the physical properties, sources of contamination, mineralogy, and weathering characteristics of the potential deposit. Each potential aggregate source should be characterized as thoroughly as possible according to the factors in Tables 4-7 described below.

A variety of properties can be described to characterize aggregate. Many of these properties can be measured using standardized tests. Table 4 identifies and describes commonly measured physical properties of aggregate, and their relationships to performance in portland cement or asphaltic concrete. Excessive amounts of contaminants may cause decreased strength and durability, may affect the quality of the bond between the cement and the aggregate, may cause an unsightly appearance, and may inhibit the hydration of the cement. Contaminants commonly can be reduced to acceptable levels during processing by washing and screening. Specific sources of contamination are shown in Table 5, and should be evaluated for every potential natural aggregate source.

Chemical properties of aggregate are important in the manufacture of concrete or bituminous mixes. Ideally, aggregate is an inert filler and should not change chemically in place. However, some aggregates contain minerals that chemically react with or otherwise affect the concrete or bituminous mixes. In concrete, these chemical processes are reactions between the aggregate and cement or oxidation of constituents. In bituminous mixes, chemical factors may influence oxidation of asphalt or the stripping of bituminous film from aggregates.

Minerals that can cause adverse chemical reactions in aggregate used in bituminous and concrete mixes are shown in Tables 6a and 6b.

Weathering of bedrock or gravel clasts lessens the strength of aggregate, increases the overall cost of separating the good (sound) from the bad (unsound) rock, and influences the blasting and extractive techniques employed (Fookes, 1991). In general, igneous and metamorphic rocks, which were formed under high temperature and pressure, weather more quickly in the near surface environment. Sedimentary rocks weather more slowly because they were formed under conditions much like those existing at the earth's surface. The suitability of a natural aggregate source as related to the degree of weathering of the bedrock is shown in Table 7.

Sand and Gravel Deposits

Regional studies that include general information regarding the quality of aggregate should include:

Predominant lithologies
Particle-size distribution
Color
Weathering
Presence of deleterious constituents, including chemical reactants.

Grain-size distribution of deposits of sand and gravel can be quite variable, both areally and with depth. To assist characterizing grain-size distribution, one can visualize how a deposit might be mined. For example, to reduce processing costs, a relatively thick layer of gravel that overlies a thick sand deposit would probably be excavated separately and, consequently, the sand and the gravel units should be described separately. A coarse-grained esker in a sandy outwash plain also would be mined (and described) separately. In contrast, if a deposit, either areally or in section, was characterized by interfingering sand and gravel beds or pockets of particles of contrasting grain sizes, the operator would mine the materials collectively, and process them later. This type of deposit can be described as a single unit, although the characteristics of the particles in the pockets and lenses should also be evaluated. Detailed information about the quality of the gravel can be included on the map or in the report for preliminary site studies. Most quality information can be determined by careful visual examination, scratch and acid tests, and hitting the sample with a hammer.

PHYSICAL PROPERTIES

DEFINITION	GENERAL AFFECTS AND AFFECTS ON USE IN PORTLAND CEMENT CONCRETE OR BITUMINOUS MIXES
Particle size - Particle grain-size distribution as determined by mechanical screening or, in the field by screening with portable sieves or by visual estimates	Concrete aggregate should contain a broad range of grain sizes throughout the sand-and-gravel range of sizes. Gap grading (aggregates with certain grain sizes missing) can be used and may be necessary in some applications. Grading of aggregates for bituminous mixes varies depending on pavement design. In most cases grading can be improved by processing.
Particle shape - Particle shape is described as round, irregular, angular, flaky, elongate, or elongate and flaky ***Round*** - Fully water-worn or completely shaped by attrition ***Irregular*** - Is naturally irregular, or partly shaped by attrition and having rounded edges ***Angular*** - Has well defined edges formed at the intersection of roughly planar faces ***Flaky*** - Has one dimension significantly smaller than the other two dimensions ***Elongated*** - Has one dimension significantly larger than the other two ***Flaky and elongate*** - Has three significantly different dimensions, i.e. length significantly larger than width and width significantly larger than thickness. (Smith & Collis, 1993.)	The shape characteristics of both coarse aggregate and sand can have marked effects on the workability of fresh concrete and on the strength properties of hardened concrete. These effects tend to be beneficial when where the predominant particle shape is equidimensional, and are detrimental when the predominant shape is flaky and/or elongated (Smith and Collis, 1993; U.S. Department of Interior, 1981). Intergranular contact provides the strength in bituminous mixes, making angular particles generally desirable for these mixes. Excessive flat or elongate particles may be harmful. Aggregate for bituminous mixes should be reasonably free of flat or elongate particles. Smooth surfaces on aggregates may be easy to coat with bitumen, but they offer little assistance to hold the aggregate in place. ASTM specifications call for a specified minimum amount of particles with fractured faces to be used in bituminous mixes.
Particle surface texture - degree of roughness or irregularity of the surface of an aggregate particle. ***Glassy*** - Conchoidal fracture ***Smooth*** - Water-worn or smooth from fracture of laminated or very finely-grained rock ***Granular*** - Surface fractures show more or less uniform size rounded grains ***Rough*** - Surface fractures show fine- or medium-grained rock containing no easily visible crystalline constituents ***Crystalline*** - Contain easily visible crystalline constituents ***Honeycombed*** - Visible pores and cavities (Smith & Collis, 1993).	Particle surface texture primarily affects the bond between the aggregate and cement paste in hardened concrete. Concrete flexural strengths and compressive strengths decrease with increasing particle smoothness. Recent advances in cement concrete technology have made it possible to produce very high strength concrete with aggregate having a relatively smooth surface texture (Smith and Collis, 1993).
Porosity - Porosity is the percentage of the total volume of aggregate occupied by pore spaces	An approximate correlation exists between aggregate quality and rock porosity. Porosity affects the strength and elastic characteristics of aggregate, and may affect permeability, absorption, and durability. Rock with a water absorption of 2% or less will usually produce good aggregate, whereas otherwise suitable rocks with a water absorption that exceeds 4% may not (Smith & Collis). For some applications surface pores contribute to a rough surface texture. When used in portland cement concrete, aggregate with surface pores can absorb water that can be released at a later time thus improving the curing conditions (Barksdale, 1991).

Pore structure - Pore structure is the size, shape, and volume of the spaces within an aggregate particle. Pores can be impermeable (isolated, enclosed cavities) or permeable (interconnected and connecting to the surface of the particle)	Large volumes of permeable pores are not desirable in aggregate for most applications. Large pore volumes allow aggregate to absorb large volumes of water or salt solutions, thus reducing soundness. For bituminous mixtures a large volume of pores also increases the absorption of binder, thus increasing the cost of paving mixture (Barksdale, 1991).
Grades of fracturing ***Massive*** - Fracture spacing > 3 ft ***Moderately fractured*** - Fracture spacing 8 in. to 3 ft ***Very fractured*** - Fracture spacing 4 in. to 8 in. ***Extremely fractured*** - Fracture spacing 2 in. to 4 in. ***Crushed*** - Fracture spacing < 2 in. (Dunn, 1991).	Fractures are natural pathways for groundwater movement and subsequent weathering or alteration Rocks with considerable fracturing tend to make poor aggregate (Dunn, 1991). Fracturing in bedrock can affect blasting and mining operations.
Strength ***Strong*** - Makes metallic sound, and breaks with difficulty, when struck with hammer ***Moderately strong*** - Makes dull sound, and breaks with moderate hammer blow ***Weak*** - Cuts easily with knife ***Very weak*** - Breaks with finger pressure. (Dunn, 1991).	Rock or gravel clasts with weak strengths tend to make poor aggregate. Weak particles commonly perform poorly in use and break down during handling.
Specific gravity - Ratio of the mass of a given volume of aggregate to the mass of an equal volume of water	Specific gravity may be a useful general indicator of the suitability of an aggregate. Very low specific gravity frequently indicates aggregate that is porous, weak, or absorptive; high specific gravity generally indicates high-quality aggregate. Specific gravity of aggregate is of significance when design or structural considerations require that concrete have a maximum or minimum weight.
Volume change - wetting and drying - Change in the volume of aggregate as the moisture content of the aggregate changes over time.	Aggregate should exhibit little or no volume change with wetting and drying. Swelling or shrinkage produces disruptive forces that can crack concrete or cause popouts in the mixture (Barksdale, 1991).
Coefficient of thermal expansion - Change in the volume of aggregate produced by a variation in temperature.	Aggregate should have a coefficient of thermal expansion that is approximately equal in all directions, and all minerals in the aggregate should have the same coefficients of thermal expansion (Barksdale, 1991). If concrete contains ingredients that expand at different rates and to different degrees of severity, internal stresses may crack the concrete (Rexford, 1950).
Thermal conductivity - Ability of an aggregate to conduct heat.	Aggregate with low thermal conductivities are desirable to prevent the penetration of frost through pavement (Barksdale, 1991).

Table 4. Commonly measured physical properties of aggregate, and their relationships to performance in portland cement or asphaltic concrete.

CONTAMINANTS

CONTAMINANT	Affects on Use in Portland Cement Concrete or Bituminous Mixes
Structurally soft or weak particles	Soft or weak particles, in significant amounts, can affect the integrity of portland-cement or bituminous concrete. In small proportions they probably are not detrimental except that they may result in "pop-outs" when exposed to freeze-thaw action (Smith and Collis, 1993). Micaceous minerals are soft, have a perfect cleavage parallel to one plane, and have low compressive and flexural strength. Aggregates with minerals with a fibrous structure such as satin-spar, and fibrous varieties of amphiboles and serpentines, may be soft
Fine-grained materials that occur as surface coatings, lumps, or disseminated throughout the aggregate	Fine-grained materials increase water content of cement, may be misrepresented in grain-size when conducting sieve analyses, and decrease aggregate-matrix bond (Smith and Collis, 1993). In addition, where present as lumps, fine-grained materials can affect soundness
Organic materials	Some organic matter, including sugar, fuel oil, and humus can retard or prevent the hydration of cement and hardening of concrete when present even in trace amounts. Other forms of organic matter, such as coal and lignite are regarded as undesirable, mainly because they are weak and unsound, and because they cause unsightly stains on the surface of concrete (Smith and Collis, 1993). Some organic impurities have been shown to entrain large amounts of air in concrete which may reduce the unit weight and compressive strength of concrete, and may interfere with proper air-entraining agents (Swenson and Chaly, 1956)
Chlorides	Chlorides, usually sodium chloride, occur in marine and some coastal sources of aggregate, and in some inland sedimentary sources. Presence of chloride in cement concrete may cause corrosion of imbedded steel reinforcing bar or mesh in reinforced concrete
Chemical contaminates	Any of the materials listed Table 6 showing chemical properties are considered deleterious material.
Soluble particles	Solution of soluble materials is seldom a serious problem in aggregates. However, some rock or sand and gravel contain sufficient quantities of water soluble substances (such as gypsum), as coatings or seam fillings, to cause difficulties when used as concrete aggregate (McLaughlin and others, 1960)

Table 5. Contaminants that may affect portland cement concrete or bituminous mixes.

CHEMICAL PROPERTIES

REACTION	AFFECTS ON USE IN PORTLAND CEMENT CONCRETE OR BITUMINOUS MIXES
Alkali-reactive silica	See Table 6b - Alkali from cement in concrete pore-water solution can react with aggregate that contains certain silica minerals, forming a gel around the aggregate. The gel imbibes water, causes expansion of the aggregate, and subsequently of the concrete (Dolar-Mantuani, 1983; Mather and Mather, 1991).
Alkali-reactive carbonate	Reaction is similar to the alkali-silica reaction although no visible gel is formed. Rocks potentially susceptible to alkali-carbonate reaction are dolomitic limestones in which the dolomite constitutes 40-60 percent of the total carbonate fraction of the rock, in which there is a 10-20 percent clay fraction, and in which small dolomite crystals is scattered throughout a matrix of extremely fine grained calcite and clay (Hadley, 1961; Mather and Mather, 1991; Ozol, 1994).
Electrochemical properties	Adhesion of bitumen to aggregate is related to the type of binder and type of stone. If aggregate and bitumen are improperly matched, the bitumen will strip from the aggregate. Bitumen is slightly negatively charged and adheres better to positively charged rocks such as basic igneous and metamorphic rocks, limestone, and dolomite. Cationic agents are added to bitumen when negatively-charged aggregates such as siliceous rocks. Many aggregates such as basalt, porphyries, and siliceous limestones have mixed charges (Hoiberg, 1965).
Metallics	Some metal compounds, such as lead or zinc oxides, can seriously affect the setting rate of concrete. Some pyrite is able to oxidize, and together with creating an unsightly appearance, may cause expansion problems (Smith and Collis, 1993).
Periclase	Periclase (magnesium oxide) hydrates in portland cement paste that causes increased volume. Periclase may not hydrate until long after the concrete has hardened and can no longer accommodate the stress induced by volume increase (Dolar-Mantuani, 1983).
Sulfides	Pyrite, marcasite, and pyrrhotite are frequent accessory constituents of many potential sources of aggregate. If sufficient oxygen is available, all three minerals may oxidize and cause stains and loss of concrete strength. In addition, oxidation may generate soluble sulfate compounds that react with the cement matrix and cause volume increases and associated popouts or cracks (U.S. Department of Interior, 1981).
Sulphates	When present in sufficient quantities, or when in wet or damp locations, sulphates can react with cement compounds resulting in excessive expansion and ultimately disruption of hardened concrete. Gypsum ($CaSO_4 \cdot 2H_2 0$) is deleterious because it can effect the setting time of concrete. Magnesium and sodium sulphates are readily soluble, and therefore aggressively react with concrete. Calcium sulphate is less soluble, and is capable of slow, although progressive reactions.
Zeolites	Natrolite and heulandite, two zeolites rich in sodium, can exchange the sodium for calcium from the cement paste, and increase the alkalis in the cement paste. Laumontite and leonhardite may undergo volume change during wetting and drying.

Table 6a. Chemical properties of aggregate important in the manufacture of portland cement concrete or bituminous mixes.

REACTIVE MATERIAL	OCCURRENCE
Opal	Deposited at low temperatures from silica-bearing waters. Formed as deposits of thermal springs, in cracks and cavities of igneous rocks, in mineral veins, in hydrothermally altered rocks, and in some shales, sandstones, and carbonate rocks. May form entire rock mass, but more commonly occurs in accumulations in voids, fractures, or encrustations. Chert may contain opal, or any combinations of opal and other silica minerals. May form as coatings on gravels and sand, as a cement in sands, and as secondary weathered product of some rocks such as granite.
Chalcedony	Cryptocrystalline to microcrystalline variety of silica with a fibrous structure that can be viewed under polarizing microscope. Chalcedony most commonly occurs in chert but also occurs in cherty limestone and dolostone, shale, phyllite, slate, and volcanic rock (Mielenz, 1978).
Crypto crystalline to microcrystalline quartz	Principal constituent of most varieties of chert. Chert most often occurs as nodules, lenses, or beds in limestone and dolomite, and less often as layers in a bedded deposit. It may also contain inclusions of disseminated clayey material, and calcite or dolomite remnants of the host rock. Cryptocrystalline to microcrystalline quartz also fills veins and vugs in a variety of rock types, and may be a cement in some sedimentary rocks. Thus normally nonreactive rocks such as sandstone, basalt, granite, and other rock types may be reactive if coated or impregnated with opal, chalcedony, or cryptocrystalline to microcrystalline quartz.
Tridymite and cristobalite	Minor constituents in shallow intrusive volcanic rocks with glassy or partially glassy groundmass. Rare in aggregate except where volcanic rocks are abundant. Rocks include cryptocrystalline rhyolite, latite, dacite, some andesite, and rocks of similar composition but with microcrystalline structure. Reactivity is affected by composition and texture of groundmass and is enhanced by large internal specific surface that develops when volatile constituents of rocks expand during eruption (Dolar-Mantuani, 1983).
Volcanic glasses	Occur as rocks such as obsidian, perlite, or pumice, or as a portion of the groundmass of some volcanic rocks. Microstructure is very similar to opal, and are very unstable and potentially reactive.
Macro-crystalline quartz	Some macrocrystalline quartz is alkali-reactive, especiallyquartz that has a deformed crystal lattice from having been intensely fractured, strained, or shocked, quartz with surface irregularities, and quartz with pores and inclusions. These minearal tend to be slowly to very slowly reactive. The poorly ordered silica at the grain boundaries may be responsible for the reactive nature of strained quartz (Smith and Collis, 1993; Dolar-Mantuani, 1983). Most common in metamorphic rocks, but also occurs in some igneous rocks that have been subjected to high stresses. May occur as detrital material in clastic sediments. Undeformed macrocrystalline quartz generally is not expansively alkali-reactive (Dolar-Mantuani, 1983).

Table 6b. The occurrence of alkali-silica reactive minerals and rocks.

Descriptions for gravels at individual sites should include:

- Predominant lithologies
- Particle-size distribution
- Particle shape
- Particle surface texture
- Internal structure of particles, including observations of pore space and fractures
- Grain packing and cementation
- Mineral composition
- Significant heterogeneities
- Hydrothermal alteration
- Weathering
- Coatings or incrustations
- Presence of deleterious constituents, including chemical reactants.

Particle counts of gravel clasts should be made to determine the lithologies of the gravel clasts. Sample size of each size fraction should comprise at least 150 particles (Mielenz, 1994). Each lithologic type should be listed as a percentage of the total pebble count, and general observations that describe the relative degrees of physical and chemical quality should be made for each lithologic type. Using criteria described in Table 8, physical quality should be described as satisfactory, fair, or poor; chemical quality should be described as innocuous or deleterious. An example of a hypothetical pebble count is shown in Table 9. The results of geologically characterizing a potential aggregate source can then be used to estimate or predict general engineering properties that are more meaningful to the aggregate industry such as physical soundness, hardness, strength, and toughness (Table 10).

Potential Sources of Crushed Stone

Usually the performance of a potential source of crushed stone can be judged by considering a few elementary features. Descriptions should include:

- Predominant lithologies
- Color
- Layering characteristics (schistosity, bedding, or banding)
- Location and spacing of fractures and parting planes
- Hydrothermal alteration
- Weathering
- Presence of deleterious constituents, including chemical reactants.

Descriptions of rock and core samples for site studies should contain information from examination of hand specimens, polished sections, thin sections, or core samples, and should include:

- Predominant lithologies, and their percentage of the total rock mass
- Grain (crystal) size, texture, and variation
- Layering characteristics (schistosity, bedding, or banding)
- Location and spacing of fractures and parting planes
- Alteration
- Weathering
- Porosity
- Presence of deleterious constituents, including chemical reactants.

Descriptions of core samples should also include length of core recovered; core loss and location; and type or types of breakage.

FRESH	No visible sign of rock weathering.	Aggregate properties not influenced by weathering. Mineral constituents are fresh and sound.
FAINTLY WEATHERED	Discoloration on major discontinuity surfaces.	Aggregate properties not significantly influenced by weathered minerals. Mineral constituents sound.
SLIGHTLY WEATHERED	Discoloration indicates weathering of rock and discontinuity surfaces. All rock material may be discolored by weathering and may be somewhat weaker than fresh rock.	Aggregate properties may be significantly influenced by weathered minerals. Strength and abrasion characteristics may be weakened. Some altered mineral constituents and microcracks.
MODERATELY WEATHERED	Less than half the rock is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present as a continuous framework or as corestones.	Aggregate properties significantly influenced by weathered minerals. Soundness characteristics markedly affected. Altered mineral constituents common; many microcracks.
HIGHLY WEATHERED	More than half the rock is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present as a continuous framework or as corestones.	Generally not suitable for aggregate.
COMPLETELY WEATHERED	All rock is decomposed and/or disintegrated to a soil. The original mass structure is still largely in tact.	Not suitable for aggregate.
RESIDUAL SOIL	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil still has not been significantly transported.	Not suitable for aggregate.

Table 7. Weathering of bedrock or gravel clasts and its relevance to the performance of aggregate (modified after Fookes, 1980).

PHYSICAL QUALITY

TERM	DEFINITION
Satisfactory	Particles are hard to firm, relatively free from fractures, and not chiplike; capillary absorption is very small or absent; and the surface texture is relatively rough.
Fair	Particles exhibit one or two of the following qualities: firm to friable; moderately fractured; capillary absorption small to moderate; flat or chiplike; surface relatively smooth and impermeable; very low compressibility; coefficient of thermal expansion approaching zero or being negative in one or more directions.
Poor	Particles exhibit one or more of the following qualities: friable to pulverant; slake when wetted and dried; highly fractured; capillary absorption moderate to high; marked volume change with wetting and drying; combine three or more qualities under "fair".

CHEMICAL QUALITY

TERM	DEFINITION
Innocuous	Particles contain no constituents which dissolve or react chemically to a significant extent with constituents of the atmosphere, water, or hydrating portland cement while enclosed in concrete or mortar under ordinary conditions.
Deleterious	Particles contain one or more constituents in significant proportion which are known to react chemically under conditions ordinarily prevailing in portland cement concrete or mortar in such a manner as to produce significant volume change, interfere with the normal course of hydration of portland cement, or supply substances which might produce harmful effects upon concrete or mortar.

Table 8. Terms used to describe relative degrees of physical and chemical quality of natural aggregate (from Woods and others, 1960).

CONSTITUENTS	Amount as percent of particles in fractions indicated		Degrees of Quality	
	1 1/2 - 3/8 in	3/8 - 3/16 in	Physical	Chemical
Granite and granitic gneiss	65.7	78.0	Satisfactory	Innocuous
Weathered granite and granitic gneiss	11.8	10.8	Fair	Innocuous
Deeply weathered granite and granitic gneiss	5.4	3.3	Poor	Innocuous
Rhyolite	0.7	0.6	Satisfactory	Deleterious*
Dacite porphyry	0.6	0.2	Satisfactory	Innocuous
Basalt	0.7	0.3	Satisfactory	Innocuous
Pumicite	0.3	---	Fair	Deleterious*
Biotite and sillimanite schist	0.8	---	Satisfactory	Innocuous
Quartz and quartzite	8.9	4.7	Satisfactory	Innocuous
Sandstone	2.8	1.5	Satisfactory	Innocuous
Weathered sandstone	0.3	---	Fair	Innocuous
Hard siltstone	1.3	0.2	Satisfactory	Innocuous
Porous ferruginous siltstone	---	0.1	Poor	Innocuous
Chalcedonic chert	0.6	0.3	Satisfactory	Deleterious*
Fissile shale	0.1	---	Poor	Innocuous

* Deleterious with high-alkali cements

Table 9. Results of hypothetical pebble count and evaluation of a potential gravel aggregate source.

PHYSICAL SOUNDNESS - the ability of an aggregate to resist weathering, particularly freezing-thawing and wetting-drying cycles.	Generally aggregates that contain weak, cleavable, absorptive, or swelling particles are not suitably sound. Examples are shales, sandstones, limestones, clayey rocks, some very coarse crystalline rocks, and porous cherts (Gillott, 1980; Neville, 1973). Weathered rock types such as weathered igneous rocks where secondary clay minerals are produced, can also be unsound (Fookes, 1980). However, because the physical properties of the rocks, not their composition, controls frost susceptibility, not all these types of rocks have durability problems. The most important physical property of rock particles affecting weathering resistance (particularly freezing--thawing) is the size, abundance, and continuity of pores, channels, and fractures (McLaughlin and others, 1960). These provide conduits for the passage of water, which in turn accelerate the weathering process. It is generally accepted that there is an approximate correlation between quality (soundness) and rock porosity. A rough working rule is that rock with a water absorption value of less than 2 percent will usually produce quality aggregate, whereas those with values greater than 4 percent generally will not (Smith and Collis, 1993). Specifications for soundness are similar for aggregates to be used in concrete or bituminous mixes.
HARDNESS, STRENGTH, AND TOUGHNESS - Hardness (resistance to load), strength (resistance to abrasion), and toughness (resistance to impact) of aggregates determine their ability to resist mechanical breakdown.	Hardness, strength, and toughness are generally controlled by the individual mineral constituents of rock particles, the strength with which these minerals are locked or cemented together, and the abundance of fractures. Particles consisting of minerals with a low degree of hardness are considered to be soft; those which are easily broken down, due to weak bonding or cementation or to fracturing, are considered to be weak (McLaughlin and others, 1960). Soft or weak particles are deleterious in aggregates because they perform poorly in use and because they break down during handling, thus affecting the grading of the aggregates. Mechanical breakdown of aggregates due to the action of mixers, mechanical equipment, and (or) traffic, or breakdown due to weathering is referred to as aggregate degradation. Degradation can occur due to compressive failure of grains at points of contact, as well as to abrasive action of grains on each other. Degradation generally is of greater significance in bituminous pavements than in concrete pavements. A good average aggregate has a crushing strength several times greater than that of the concrete (Fookes, 1980).

Table 10. Terms used by aggregate industry to describe the engineering properties of natural aggregate.

Descriptions should include the relative degrees of physical and chemical quality (Table 8), which requires subjective estimates of what the rock will look like if crushed to gravel-size clasts. The results of the characterization should be translated into engineering properties that are useful to the aggregate industry (Table 10).

Quantity of Potential Aggregate Sources

Calculating the reserves of a sand and gravel deposit or a source of crushed stone involves determining the three-dimensional extent (volume) and variability (yield of usable material) of the deposit. For most regional assessments, the quantity estimates of aggregate resources should be considered inferred reserves. Inferred reserves are those for which quantitative estimates are based largely on broad geologic knowledge of the geologic character of the deposits and for which there are few, if any, samples (Blondel and Lasky, 1956). The estimates commonly are based on assumed continuity or repetition supported by geologic evidence such as comparison with deposits of similar type.

Maps of potential sources of aggregate should delineate the areal extent of the sand and gravel deposit, the general distribution of grain sizes of the deposit, both areally and vertically, and the thickness of the deposit. Grain size of surface materials can be shown as map units, texture overprints or colors, or as descriptive text. Grain-size distribution of subsurface materials can be shown as stack-map units (Kempton and Cartwright, 1984), descriptive text, or as logs accompanying the map.

Regional studies conducted under short deadlines and with limited field reconnaissance present problems in estimating the amount of potential sand and gravel aggregate resources present. Thickness commonly may be included as part of descriptive texts or logs accompanying existing geologic maps, although detailed descriptions of potential deposits may be lacking from the literature or, at best, limited to a few specific sites. Under these conditions, the use of models of "typical" deposits in the regions in terms of overall geometry and the horizontal and vertical variability of particle sizes provides one method of subjectively estimating deposit volumes (Bliss, 1993).

Maps of potential sources of crushed stone aggregate should delineate the areal extent of lithologic units and, where possible, the thickness of the units. The structural attitude of layered units should be noted so that the volume of the units can be calculated from the map data. Regional studies should include general information regarding the quality of potential aggregate.

For site evaluations, estimating the volume of a sand and gravel or bedrock deposit is a complex process that involves determining the configuration of the deposit. Outcrop observations, drilling, coring, augering, and trenching are routine methods for determining the thickness of the deposit and overburden, as well as the vertical variation in the deposit required for accurate reserve estimates. Visual estimates of grain-size classes separated by on-site sieving of auger and outcrop samples is a convenient method (Moore, 1995). Seismic, ground-based resistivity, ground-penetrating radar, and electromagnetic measurements are especially useful supplements for extrapolating the lateral extent and vertical variation of the deposit between drill holes, pits, and trenches (Odum and Miller, 1988; Dunn, 1991). Detailed geologic cross sections and isopach maps derived from the various data provide the primary information necessary for calculating reserves. For site maps thickness commonly is shown with isopachs or as logs accompanying the map. Dunn (1991) describes the geologic information required to calculate reserves, the methods for calculating various types of reserve information, and the critical nature of the reserve information in evaluating the economic risk of subsequent permitting and production processes.

REFERENCES

American Society for Testing and Materials, 1994, Annual book of ASTM standards, Section 4, Volume 04.02, Concrete and mineral aggregates: Philadelphia, Pa., 878 p.

Barksdale, R.D., ed., 1991, The aggregate handbook: National Stone Association, 16 chapters numbered separately.

Bliss, J.D., 1993, Modeling sand and gravel deposits--initial strategy and preliminary examples: U.S. Geological Survey Open-File Report 93-200, 31p.

Blondel, F., and Lasky, S.G., 1956, Mineral reserves and mineral resources: Economic Geology, p. 686-697.

Bottge, R.G., McDivitt, J.F., and McCarl, H.N., 1965, Prospecting for natural aggregates, Part 2: Rock Products, v. 68, no. 6, p. 93-95.

Dolar-Mantuani, Ludmila, 1983, Handbook of concrete aggregates, a petrographic and technological evaluation: Park Ridge, N.J., Noyes Publications, 345 p.

Dunn, J.R., 1991, Chapter 4 - Geology and Exploration, *in* Barksdale, R.D., ed., The Aggregate Handbook: Washington, D.C., National Stone Association, p. 4-2 - 4-45.

Fookes, P.G., 1980, An introduction to the influence of natural aggregates on the performance and durability of concrete: The Quarterly Journal of Engineering Geology, v. 13, no. 4, p. 207-229.

Fookes, P.G., 1991, Geomaterials: The Quarterly Journal of Engineering Geology, v. 24, no.1, p. 3-16.

Gillott, J.E., 1980, Properties of aggregates affecting concrete in North America: The quarterly journal of engineering geology, v. 13, no. 4, p. 289-303.

Hadley, D.W., 1961 , Alkali reactivity of carbonate rocks: Skokie, Ill., Portland Cement Association, Resource Department Bulletin 139, 14 p.

Hoiberg, A.J., 1965, editor, Bituminous Materials: Asphalts, Tars, and Pitches, Volume II: Asphalts, John Wiley & Sons, New York, New York.

Kempton, J.P., and Cartwright, K., 1984, Three-dimensional geologic mapping: A basis for hydrogeologic and land-use evaluations, in Keaton, J.R., ed., Engineering geology mapping symposium: Bulletin of the Association of Engineering Geologists, v. 21, n. 3, p. 317-336.

Langer, W.H., 1988, Natural aggregates of the conterminous United States: U. S. Geological Survey Bulletin 1594, 33 p.

Langer, W.H., and Glanzman, V.M., 1993, Natural aggregate -- Building America's future: U.S. Geological Survey Circular 1110, 39 p.

Marek, C.R., 1991, Chapter 3 - Basic Properties of Aggregate, *in* Barksdale, R.D., ed., The Aggregate Handbook: Washington, D.C., National Stone Association, p. 3-1 - 3-81.

Mather, K., and Mather, B., 1991, Aggregates, *in*, Kiersch, G.A., ed., The heritage of engineering geology; The first hundred years, Centennial Special Volume 3: Geological Society of America, Boulder, CO, p. 323-332.

McLaughlin, J.P., Woods, K.B., Mielenz, R.C., and Rockwood, N.C., 1960, Distribution, production, and engineering characteristics of aggregates, section 16, in Woods, K.B., Berry, D.S., and Goetz, W.H., eds., Highway engineering handbook: New York, McGraw-Hill Book Company, Inc., p. 16-1 to 16-53.

Mielenz, R.C., 1978, Petrographic examination (Mineral aggregates): ASTM STP 169B-1978, p. 539-572.

Mielenz, R.C., 1994, Petrographic evaluation of concrete aggregates, *in* American Society of Testing and Materials, Concrete and concrete-making materials: ASTM STP 169C, p. 341-364.

Moore, D.M., 1995, Sand and gravel assessment, Nambe Pueblo, northern New Mexico, U.S. Geological Survey administrative report, 39 p.

Neville, A.M., 1973, Properties of concrete: New York, John Wiley and Sons, 686 p.

Odum, J.K., and Miller, C.H., 1988, Geomorphic, seismic, and geotechnical evaluation of sand and gravel deposits in the Sheridan, Wyoming, area: U.S. Geological Survey Bulletin 1845, 32 p.

Ozol, M.A., 1994, Alkali-carbonate rock reaction, ASTM STP 169C, p. 372-387.

Ray, R.G., 1960, Aerial photographs in geologic interpretation and mapping: U.S. Geological Survey Professional Paper 373, 230 p.

Rexford, E.P., 1950, Concrete aggregates for large structures: Transactions, American Institute of Mining Engineering, v. 187, p. 395-402.

Schwochow, S.D., Shroba, R.R., and Wicklein, P.C., 1974, Sand, gravel, and quarry aggregate resources, Colorado Front Range counties: Colorado Geological Survey, Department of Natural Resources Special Publication 5-A, 43 p.

Smith, M.R., and Collis, L., eds., 1993, Aggregates -- Sand, gravel and crushed rock aggregates for construction purposes: London, Geological Society Engineering Geology Special Publication No. 9, The Geological Society, 339 p.

Swenson, E.G., and Chaly, V., 1956, Basis for classifying deleterious characteristics of concrete aggregate materials: Journal of the American Concrete Institute, v. 27, no. 9, p. 987-1002.

Tepordei, V.V., 1993, Crushed stone - 1991: U.S. Bureau of Mines Annual Report, 43 p.

Timmons, B.J., 1994, Prospecting for natural aggregates; An update: Rock Products. v. 97, no. 8, p. 43-45.

U. S. Department of Interior, 1981, Concrete manual: Water and Power Resources Service Technical Publication, 627 p.

Varnes, D.J., 1974, The logic of geologic maps, with reference to their interpretation and use for engineering purposes: U.S. Geological Survey Professional Paper 837, 48 p.

Appendix A: ASTM Tests - Common laboratory tests to determine physical, chemical, and engineering properties of aggregate.

ASTM Designation	Description
C 294 Standard descriptive nomenclature for constituents of natural mineral aggregates	This nomenclature briefly describes some of the more common, or more important, natural materials of which natural aggregate are composed.
C 295 Petrographic examination of aggregates for concrete	This guide outlines procedures for petrographic examination of gravel, crushed stone, rock core, and bedrock outcrops.
C 136 Sieve analysis of fine and coarse aggregates	A weighed sample of aggregate is separated through a series of sieves of progressively smaller openings for determination of particle-size distribution.
C 123 Lightweight pieces in aggregate	A heavy liquid is used to separate light-weight particles from the aggregate.
C 127 Specific gravity and adsorption of coarse aggregate	A sample of aggregate is immersed in water to fill the pores, the water dried from the surface of the particles, and the sample weighed. The sample is then weighted while submerged in water. Finally the sample is oven dried and weighed.
C 289 Potential alkali-silica reactivity of aggregates (chemical method)	Chemical determination of the potential reaction of an aggregate with alkalis in portland cement concrete.
C 227 Potential alkali reactivity of cement-aggregate combinations (mortar-bar method)	Aggregate is mixed with cement and water to form a bar. The bar is stored under specific moisture and temperature conditions and is measured at specific intervals over a period of months and years.
C 1260 Potential alkali reactivity of aggregates (mortar-bar method)	Aggregate is mixed with cement and water to form a bar. The bar is stored immersed in a solution of sodium hydroxide (NaOH) at a controlled temperature. The bar is measured after 14 days, and specific intervals thereafter.
C586 Potential alkali reactivity of carbonate rocks for concrete aggregates (rock cylinder method)	Determines the expansive characteristics of carbonate rocks while immersed in a solution of sodium hydroxide (NaOH).
C 131 Resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles Machine	The Los Angeles test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding. The sample is rotated in a steel drum containing a specified number of steel spheres. As the drum rotates, a shelf picks up the aggregate and the spheres and drops them to the opposite side of the drum, creating an impact-crushing effect. After the prescribed number of revolutions, the contents are sieved to measure degradation as a percent loss.
C 535 Resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles Machine	
C 88 Soundness of aggregates by use of sodium sulfate or magnesium sulfate	Test involves alternate cycles of immersion in saturated solutions of sodium or magnesium sulfate and drying to precipitate salt in permeable pore spaces. The internal force derived from rehydration of salt simulates the expansion of water on freezing.

Appendix B: Physiographic/geographic divisions of the United States and their generalized natural aggregate potential.

Generally, each region has similar occurrences of aggregate within its boundaries, but is fairly distinct from other regions. However, there are also significant differences within regions, specifically concerning physical and chemical characteristics of the aggregates. Where possible, these differences are discussed in the text.

Western Mountain Ranges

The Western Mountain Ranges occupy parts of western Washington and Oregon, large parts of Idaho, eastern Montana, western Wyoming, central Colorado, northern and eastern California, and small parts of South Dakota and New Mexico. The region includes Sierra Nevadas in California and Nevada, Coast Ranges and Cascade Mountains in Oregon and Washington, northern Rocky Mountains in Idaho and Montana, Bighorn Mountains in Wyoming, Wasatch and Uinta Mountains in Utah, Black Hills in South Dakota, and Southern Rocky Mountains in Wyoming, Colorado, and New Mexico. The general physiography is tall, massive mountains alternating with relatively narrow, steep-sided valleys. The summits and slopes of the mountains consist of bare or thinly covered bedrock only a few meters thick. Cover is thicker along the base of the slopes. The narrow valleys are underlain with relatively thin, coarse, bouldery alluvium. Larger valleys may have higher terraces.

Most of the region is underlain with granitic and metamorphic rocks, flanked by consolidated sedimentary rocks including some limestones. The same bedrock is also a source for glacial, stream-channel, or terrace deposits.

Alluvial Basins

The Alluvial Basins consist of two areas: the main area occupies most of Nevada, western Utah, large parts of California, Arizona, and New Mexico, and small parts of Idaho, Colorado, and Texas; a smaller part occupies the Puget Sound and Willamette Valley of Washington and Oregon. The region has alternating basins or valleys and mountain ranges. The summits of the mountains commonly consist of bare or thinly covered bedrock only a few meters thick. The mountain ranges are commonly underlain with granitic, metamorphic, and consolidated sedimentary rocks. The basins are generally filled with thick (several hundred to several thousand meters) unconsolidated fluvial material with alluvial fans along the margins. Although the region commonly has abundant supplies of sand and gravel, some areas, such as a large area surrounding the Salton Sea in southern California, are deficient in sand and gravel.

Columbia Plateau

The Columbia Plateau region occupies parts of southeastern Washington, eastern Oregon, southern Idaho, northeastern California, and northern Nevada. The region is underlain with a thick sequence of extensive lava flows separated by soil zones and interbedded sediments. These lavas are mantled in places by alluvial, glacial, and windblown deposits. The northern part of this region commonly is underlain with basalts. The southern part is underlain with basaltic and acidic rocks.

Sand and gravel, partly formed by present streams, and partly of glacial origin is well distributed throughout much of the Washington part of the region. However, in places, enormous floods that occurred during Pleistocene time, stripped the surface soils, leaving bare scablands or cutting deep valleys such as Grand Coulee. In the rest of the region sand and gravel is rather limited, commonly being restricted to river and stream terraces.

Colorado Plateau and Wyoming Basin

The Colorado Plateau and Wyoming Basin region occupies parts of Wyoming, eastern Utah, western Colorado, northern Arizona, and northwest New Mexico. The region consists of high plateaus with deeply incised canyons, mountains, deserts, and badlands. The region is underlain with flat to gently dipping sedimentary rocks. Erosion has produced extensive, prominent cliffs that commonly are capped with resistant sandstones. There are large expanses of exposed bedrock or areas of thin rocky soil. Surficial deposits are of relatively minor importance in the region.

This region is generally underlain with poorly consolidated to consolidated sandstones, shales, and limestones, with the sandstones and shales being most prevalent and most extensive. In places the rock units contain significant amounts of gypsum or halite.

Thin deposits of alluvium or glacial deposits occur along parts of the valleys of major streams especially adjacent to the mountain ranges in the northern and eastern parts of the region. In the remainder of the region sand and gravel is generally limited to stream or river terraces.

High Plains

The High Plains region extends from South Dakota in the north through Nebraska, Wyoming, Colorado, Kansas, Oklahoma, to New Mexico and Texas in the south. The High Plains are a remnant of a great alluvial plain built by streams that flowed east from the Rocky Mountains. Stream erosion has removed a large portion of the plain, however, in large areas the original depositional surface of the plain is almost unmodified, and forms a flat, gently eastward-sloping tableland. Significant topographic features include sand dunes, which are especially prevalent in central and northern Nebraska; wide valleys of braided streams that flow from the Rocky Mountains eastward across the plain; and numerous circular depressions called playas, that intermittently contain water after heavy rains.

The region is underlain by thick, semiconsolidated bedrock that ranges from silt to sand and gravel, with sand being most abundant, and clay occurring in only a few areas. Gravels occur haphazardly throughout the region, usually in small deposits. The major source of aggregates is alluvial deposits of major rivers and their tributaries.

Nonglaciated Central Region

The Nonglaciated Central region extends from the Rocky Mountains on the west to the Appalachian Mountains on the east. The part of the region in eastern Colorado and northeastern New Mexico is separated from the remainder of the region by the High Plains. The nonglaciated region also includes the "Driftless " area in Wisconsin, Minnesota, Iowa, and Illinois. The region is topographically complex and includes central lowlands and plains as well as hilly and mountainous areas.

Most of the northern part of the region (in Montana, North Dakota, South Dakota, Wyoming, and Nebraska) and the part of the region flanking the Rocky Mountains is underlain with sedimentary rocks that consist mostly of sandstones, shales, and conglomerates. Most of the region in the south-central and eastern United States is underlain with limestones and dolomites. Sand and gravel deposits occur as alluvial or terrace deposits.

Glaciated Central Region

The Glaciated Central region extends from the northern part of the Great Plains in Montana to the Catskill Mountains in New York, and south to the limit of Pleistocene glaciation. The eastern part of the region (New York and Pennsylvania) is characterized by rolling hills and low rounded mountains. The western part of the region is flat to gently rolling. The entire region is underlain with consolidated sedimentary rocks which in turn are overlain with glacial deposits. The sedimentary rocks consist primarily of sandstone, shale, limestone, and dolomite and are most prevalent in southern Minnesota and Wisconsin, Iowa, northern Illinois, Missouri, Indiana and western Ohio, and are less prevalent in Pennsylvania and New York. The parts of the region in Montana, North Dakota, South Dakota, and most of Nebraska generally lack limestones or dolomites.

Piedmont-Blue Ridge Region

The Piedmont Blue Ridge region extends from Pennsylvania in the north, southward through Maryland, Virginia, North Carolina, South Carolina, Tennessee, Georgia and Alabama. The Piedmont part of the region consists of low, rounded hills and long, rolling northeast-southwest trending ridges situated between the Coastal Plain to the east and the Blue Ridge to the west. The Blue Ridge is mountainous, and contains the highest peaks east of the Mississippi. The mountains are bordered by low-gradient streams flowing in relatively narrow valleys. The entire region is underlain by igneous, metasedimentary, and metaigneous bedrock (granite, gneiss, schist, quartzite, slate, marble, and phyllite). Near the surface the rocks are weathered to saprolite, a clay-rich, unconsolidated material developed in place primarily from the chemical weathering. The valleys are underlain with relatively thin, moderately-sorted alluvium with sand and gravel deposits occurring as alluvial or terrace deposits.

Glaciated Northeastern and Superior Uplands

The Glaciated Northeastern and Superior Uplands region occupies two separate areas. The Northeast Upland includes nearly all of New England, the Adirondack Mountains, and the Lake Champlain valley. The Superior Uplands encompasses most of the northern parts of Minnesota and Wisconsin adjacent to the western end of Lake Superior. The entire region is characterized by rolling hills and low mountains. Although some of the higher mountains have large expanses of exposed rock, most igneous and metasedimentary bedrock of the region is overlain by unconsolidated deposits laid down by ice sheets that covered the area during the Pleistocene, and by gravel, sand, silt, and clay laid down by meltwater streams and in lakes that formed during the melting of the ice.

The thickness of the unconsolidated deposits range from a few meters to more than 100 m in some of the valleys. The most extensive glacial deposit is till. In most of the valleys and other low areas, the till is covered by glacial outwash consisting of interlayered sand and gravel. The major sources of sand and gravel are glaciofluvial deposits and stream channel and river terrace deposits.

Atlantic and Gulf Coastal Plain

The Atlantic and Gulf Coastal Plain region extends along the Atlantic Coast from Cape Cod, Massachusetts south to Florida, and along the Gulf Coast from Florida to the Rio Grande, Texas. The topography of the region ranges from extensive, flat, coastal swamps and marshes to rolling uplands near the inner margin of the region. The region is underlain with extensive deposits of sand, silt, clay, and gravel that vary in thickness. Depending on location, they are either of marine or fluvial origin.

Consolidated bedrock generally is inaccessible in the Coastal Plain region, except near the inner margin, and in southeastern Florida, which is underlain by semiconsolidated limestones.

The predominant surficial material of the coastal plain is sand. Near the inner edge of the Coastal Plain are deposits of sand and gravel. Present-day streams cutting through these deposits transport gravels downstream as much as 80 km. These terrace and stream gravels are limited in occurrence. Coarse materials are so limited in this region that shells are commonly substituted for gravel in coastal areas. The quality of the gravels vary in accordance with the types of rocks from which they originated.

Hawaiian Islands

The Hawaiian Islands are the tops of volcanoes that rise from the ocean floor. Each island was formed by lava that issued from one or more eruptive centers. The islands have a hilly appearance resulting from erosion that has carved valleys into the volcanoes and built relatively narrow plains along parts of the coastal areas.

Each of the Hawaiian Islands is underlain with lava flows. Andesitic and basaltic lava flows are commonly used as a source of crushed stone. In addition, clinker from the tops of lava flows and cinders from cinder cones are used as stone aggregate.

In some areas, alluvium of older and modern terraces and alluvial fans contain poorly sorted sand and gravel of variable quality. In coastal areas a thin layer of alluvium consisting of coral and shell fragments, volcanic debris, and clay form discontinuous beach deposits. Alluvium, terrace deposits, and beach deposits may all be used as aggregate if they meet the required specifications.

Alaska

Alaska is underlain by a diverse assemblage of rocks. The principal mountain ranges have cores of igneous and metamorphic rocks. These are overlain and flanked by sedimentary and volcanic rocks. The sedimentary rocks include carbonates, sandstones, and shales.

Approximately half of Alaska, including the mountain ranges and adjacent parts of the lowlands, was covered by glaciers during the Pleistocene. Glaciofluvial deposits in these areas commonly contain sand and gravel. In the Intermontane Plateaus, sand and gravel commonly occurs in river channels and floodplains, terrace deposits, and placer-mine tailings. The Arctic Coastal Plain consists of silt, sand, and gravel, with the northeastern part having moderate to high potential for sand and gravel. The Arctic Coastal Plain, as well as most of the Rocky Mountain System and part of the Intermontane Plateaus are areas of continuous permafrost. Here, and to a lesser degree elsewhere in Alaska, much of the aggregate is frozen and requires drilling and blasting.