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Standard Descriptive Nomenclature for Constituents of Concrete Aggregates[1]

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This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This descriptive nomenclature provides brief descriptions of some of the more commonly occurring, or more important, natural and artificial materials of which mineral aggregates are composed. The descriptions provide a basis for understanding these terms as applied to concrete aggregates. When appropriate, brief observations regarding the potential effects of using the natural and artificial materials in concrete are discussed.

NOTE 1—These descriptions characterize minerals and rocks as they occur in nature and blast-furnace slag or lightweight aggregates that are prepared by the alteration of the structure and composition of natural material. Information about lightweight aggregates are given in Specifications C 330, C 331, and C 332.

1.2 This standard does not include descriptions of constituents of aggregates used in radiation shielding concrete. See Descriptive Nonmenclature C 638.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 125 Terminology Relating to Concrete and Concrete Aggregates
C 227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method)
C 289 Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)
C 330 Specification for Lightweight Aggregates for Structural Concrete
C 331 Specification for Lightweight Aggregates for Concrete Masonry Units
C 332 Specification for Lightweight Aggregates for Insulating Concrete
C 638 Descriptive Nonmenclature of Constituents of Aggregates for Radiation-Shielding Concrete

3. Significance and Use

3.1 This descriptive nomenclature provides information on terms commonly applied to concrete aggregates. This standard is intended to assist in understanding the meaning and significance of the terms.

3.2 Many of the materials described frequently occur in particles that do not display all the characteristics given in the descriptions, and most of the described rocks grade from varieties meeting one description to varieties meeting another with all intermediate stages being found.

3.3 The accurate identification of rocks and minerals can, in many cases, be made only by a qualified geologist, mineralogist, or petrographer using the apparatus and procedures of these sciences. Reference to these descriptions may, however, serve to indicate or prevent gross errors in identification. Identification of the constituent materials in an aggregate may assist in characterizing its engineering properties, but identification alone cannot provide the sole basis for predicting behavior of aggregates in service. Aggregates of any type or combination of types may perform well or poorly in service depending upon the exposure to which the concrete is subjected, the physical and chemical properties of the matrix in which they are embedded, their physical condition at the time they are used, and other factors. Constituents that may occur only in minor amounts in the aggregate may or may not decisively influence its performance. Information about concrete aggregate performance in concrete has been published by ASTM.[3]

CONSTITUENTS OF NATURAL MINERAL AGGREGATES

4. Classes and Types

4.1 The materials found as constituents of natural mineral aggregates are minerals and rocks.

4.2 Minerals are naturally occurring inorganic substances of more or less definite chemical composition and usually of a specific crystalline structure. The physical nature of the rock-forming minerals and aspects of crystal chemistry determine the important physical and chemical properties of natural

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Klieger, P., and Lamond, J. F., editors, Significance of Tests and Properties of Concrete and Concrete-Making Materials, ASTM STP 169C, 1994.

mineral aggregates. Certain assemblages of rock-forming minerals possess desirable qualities for use as aggregates in cementitious materials.

4.2.1 Minerals are characterized by their crystallographic, physical, and optical properties and their chemical composition. The crystallographic properties of minerals may be determined by x-ray diffraction and optical properties (**1-6**). The physical properties of minerals include but are not limited to crystal habit, cleavage, parting, fracture, hardness, specific gravity, luster, color, streak, magnetism, luminescence, and pyroelectricity (**7**). The optical properties of minerals include but are not limited to refractive index, birefringence, optic sign, pleochroism, and sign of elongation (**2-5**). Methods to determine the chemical composition of minerals include but are not limited to optical properties (**5**), flame photometry (**7**,**8**), chemical spot tests (**9**,**10**), various staining techniques (**11**), x-ray fluorescence, and electron microscopy (**12-14**).

4.2.2 Different minerals may have the same chemical composition but different crystallographic and physical properties. Such sets of minerals are known as polymorphs. Distinguishing between some polymorphs can be important for determining the suitability of aggregates for use in cementitious materials.

4.3 Rocks are classified according to origin into three major divisions: igneous, sedimentary, and metamorphic. These three major groups are subdivided into types according to mineral and chemical composition, texture, and internal structure. Most rocks are composed of several minerals but some are composed of only one mineral. Certain examples of the rock quartzite are composed exclusively of the mineral quartz, and certain limestones are composed exclusively of the mineral calcite. Individual sand grains frequently are composed of particles of rock, but they may be composed of a single mineral, particularly in the finer sizes.

4.3.1 Igneous rocks form from molten matter either at or below the earth's surface.

4.3.2 Sedimentary rocks form near the earth's surface by the accumulation and consolidation of the products of weathering and erosion of existing rocks, or by direct chemical precipitation. Sedimentary rocks may form from pre-existing igneous, metamorphic, or sedimentary rocks.

4.3.3 Metamorphic rocks form from pre-existing igneous, sedimentary, or metamorphic rocks by the action of heat or pressure or both.

5. Silica Minerals

5.1 *Quartz*—a very common hard mineral composed of silica (SiO_2). It will scratch glass and is not scratched by a knife. When pure it is colorless with a glassy (vitreous) luster and a shell-like (conchoidal) fracture. It lacks a visible cleavage (the ability to break in definite directions along even planes) and, when present in massive rocks such as granite, it usually has no characteristic shape. It is resistant to weathering and is therefore an important constituent of many sand and gravel deposits and many sandstones. It is also abundant in many light-colored igneous and metamorphic rocks. Some strained, or intensely fractured (granulated), and microcrystalline quartz may be potentially deleteriously reactive with the alkalies in the hydraulic cement paste.

5.2 *Opal*—a hydrous form of silica ($SiO_2 \cdot nH_2O$) which occurs without characteristic external form or internal crystalline arrangement as determined by ordinary visible light methods. When X-ray diffraction methods are used, opal may show some evidences of internal crystalline arrangement. Opal has a variable water content, generally ranging from 3 to 9 %. The specific gravity and hardness are always less than those of quartz. The color is variable and the luster is resinous to glassy. It is usually found in sedimentary rocks, especially some cherts, and is the principal constituent of diatomite. It is also found as a secondary material filling cavities and fissures in igneous rocks and may occur as a coating on gravel and sand. The recognition of opal in aggregates is important because it is potentially deleteriously reactive with the alkalies in hydraulic cement paste or with the alkalies from other sources, such as aggregates containing zeolites, and ground water.

5.3 *Chalcedony*—chalcedony has been considered both as a distinct mineral and a variety of quartz. It is frequently composed of a mixture of microscopic fibers of quartz with a large number of submicroscopic pores filled with water and air. The properties of chalcedony are intermediate between those of opal and quartz, from which it can sometimes be distinguished only by laboratory tests. It frequently occurs as a constituent of the rock chert and is potentially deleteriously reactive with the alkalies in hydraulic cement paste.

5.4 *Tridymite and cristobalite*—high temperature crystalline forms of silica (SiO_2) sometimes found in volcanic rocks. They are metastable at ordinary temperatures and pressures. They are rare minerals in aggregates except in areas where volcanic rocks are abundant. A type of cristobalite is a common constituent of opal. Tridymite and cristobalite are potentially deleteriously reactive with the alkalies in hydraulic cement paste.

6. Feldspars

6.1 The minerals of the feldspar group are the most abundant rock-forming minerals in the crust of the earth. They are important constituents of all three major rock groups, igneous, sedimentary, and metamorphic. Since all feldspars have good cleavages in two directions, particles of feldspar usually show several smooth surfaces. Frequently, the smooth cleavage surfaces show fine parallel lines. All feldspars are slightly less hard than, and can be scratched by, quartz and will, when fresh, easily scratch a penny. The various members of the group are differentiated by chemical composition and crystallographic properties. The feldspars *orthoclase, sanidine*, and *microcline* are potassium aluminum silicates, and are frequently referred to as *potassium feldspars*. The *plagioclase* feldspars include those that are sodium aluminum silicates and calcium aluminum silicates, or both sodium and calcium aluminum silicates. This group, frequently referred to as the "soda-lime" group, includes a continuous series, of varying chemical composition and optical properties, from *albite*, the sodium aluminum feldspar, to *anorthite*, the calcium aluminum feldspar, with intermediate members of the series designated *oligoclase, andesine, labradorite*, and *bytownite*. Potassium feldspars and sodium-rich plagioclase feldspars occur typically in igneous rocks such as granites and rhyolites, whereas, plagioclase feldspars of higher calcium content are found in igneous rocks of lower silica content such as diorite, gabbro, andesite, and basalt.

7. Ferromagnesian Minerals

7.1 Many igneous and metamorphic rocks contain dark green to black minerals that are generally silicates of iron or magnesium, or of both. They include the minerals of the amphibole, pyroxene, and olivine groups. The most common amphibole mineral is hornblende; the most common pyroxene mineral is augite; and the most common olivine mineral is forsterite. Dark mica, such as biotite and phlogopite, are also considered ferromagnesian minerals. The amphibole and pyroxene minerals are brown to green to black and generally occur as prismatic units. Olivine is usually olive green, glassy in appearance, and usually altered. Biotite has excellent cleavage and can be easily cleaved into thin flakes and plates. These minerals can be found as components of a variety of rocks, and in sands and gravels. Olivine is found only in dark igneous rocks where quartz is not present, and in sands and gravels close to the olivine source.

8. Micaceous Minerals

8.1 Micaceous minerals have perfect cleavage in one direction and can be easily split into thin flakes. The mica minerals of the muscovite group are colorless to light green; of the biotite group, dark brown to black or dark green; of the lepidolite group, white to pink and red or yellow; and of the chlorite group, shades of green. Another mica, phlogopite, is similar to biotite, commonly has a pearl-like luster and bronze color, and less commonly is brownish red, green, or yellow. The mica minerals are common and occur in igneous, sedimentary, and metamorphic rocks, and are common as minor to trace components in many sands and gravels. The muscovite, biotite, lepidolite, and phlogopite minerals cleave into flakes and plates that are elastic; the chlorite minerals, by comparison, form inelastic flakes and plates. Vermiculite (a mica-like mineral) forms by the alteration of other micas and is brown and has a bronze luster.

8.2 Because micaceous materials have a high surface area, they can influence the properties of freshly mixed and hardened concrete. Aggregates with a high mica content can reduce workability and increase the water demand of the concrete (15). The shape and perfect cleavage of micaceous minerals may result in a poor bond to the cementitious paste (16).

9. Clay Minerals

9.1 The term "clay" refers to natural material composed of particles in a specific size range less than 2 μm (0.002 mm). Mineralogically, clay refers to a group of layered silicate minerals including the clay-micas (illites), the kaolin group, very finely divided chlorites, and the swelling clays—smectite including montmorillonites. Members of several groups, particularly micas, chlorites, and vermiculites, occur both in the clay-size range and in larger sizes. Some clays are made up of alternating layers of two or more clay groups. Random, regular, or both types of interlayering are known. If smectite is a significant constituent in such mixtures, then fairly large volume changes may occur with wetting and drying.

9.2 Clay minerals are hydrous aluminum, magnesium, and iron silicates that may contain calcium, magnesium, potassium, sodium, and other exchangeable cations. They are formed by alteration and weathering of other silicates and volcanic glass. The clay minerals are major constituents of clays and shales. They are found disseminated in carbonate rocks as seams and pockets and in altered and weathered igneous and metamorphic rocks. Clays may also be found as matrix, void fillings, and cementing material in sandstones and other sedimentary rocks.

9.3 Most aggregate particles composed of, or containing, large proportions of clay minerals are soft and, because of the large internal surface area of the constituents, they are porous. Some of these aggregates will disintegrate when wetted. Rocks in which the cementing matrix is principally clay, such as clay-bonded sandstones, and rocks in which swelling clay minerals (smectite) are present as a continuous phase or matrix, such as in some altered volcanics, may slake in water or may disintegrate in the concrete mixer. Rocks of this type are unsuitable for use as aggregates. Rocks having these properties less well developed will abrade considerably during mixing, releasing clay, and raising the water requirement of the concrete containing them. When such rocks are present in hardened concrete, the concrete will manifest greater volume change on wetting and drying than similar concrete containing non-swelling aggregate.

10. Zeolites

10.1 The zeolite minerals are a large group of hydrated aluminum silicates of the alkali and alkaline earth elements which are soft and usually white or light colored. They are formed as a secondary filling in cavities or fissures in igneous rocks, or within the rock itself as a product of hydrothermal alteration of original minerals, especially feldspars. Some zeolites, particularly *heulandite, natrolite*, and *laumontite*, reportedly produce deleterious effects in concrete, the first two having been reported to raise the alkali content in concrete by releasing alkalies through cation exchange and thus increasing alkali reactivity when alkali-reactive aggregate constituents are present. Laumontite and its partially dehydrated variety *leonhardite* are notable for their substantial volume change with wetting and drying. Both are found in rocks such as quartz diorites and some sandstones.

11. Carbonate Minerals

11.1 The most common carbonate mineral is *calcite* (calcium carbonate, $CaCO_3$). The mineral *dolomite* consists of calcium carbonate and magnesium carbonate ($CaCO_3 \cdot MgCO_3$ or $CaMg(CO_3)_2$) in equivalent molecular amounts, which are 54.27 and 45.73 by mass %, respectively. Both calcite and dolomite are relatively soft, the hardness of calcite being 3 and that of dolomite 3½ to 4 on the Mohs scale, and are readily scratched by a knife blade. They have rhombohedral cleavage, which results in their breaking into fragments with smooth parallelogram shaped sides. Calcite is soluble with vigorous effervescence in cold dilute hydrochloric acid; dolomite is soluble with slow effervescence in cold dilute hydrochloric acid and with vigorous effervescence if the acid or the sample is heated or if the sample is pulverized.

12. Sulfate Minerals

12.1 Carbonate rocks and shales may contain sulfates as impurities. The most abundant sulfate mineral is *gypsum* (hydrous calcium sulfate; $CaSO_4 \cdot 2H_2O$); *anhydrite* (anhydrous calcium sulfate, $CaSO_4$) is less common. Gypsum is usually white or colorless and characterized by a perfect cleavage along one plane and by its softness, representing hardness of 2 on the Mohs scale; it is readily scratched by the fingernail. Gypsum may form a whitish pulverulent or crystalline coating on sand and gravel. It is slightly soluble in water.

12.2 Anhydrite resembles dolomite in hand specimen but has three cleavages at right angles; it is less soluble in hydrochloric acid than dolomite, does not effervesce and is slightly soluble in water. Anhydrite is harder than gypsum. Gypsum and anhydrite occurring in aggregates can cause sulfate attack in concrete and mortar.

13. Iron Sulfide Minerals

13.1 The sulfides of iron, *pyrite, marcasite*, and *pyrrhotite* are frequently found in natural aggregates. Pyrite is found in igneous, sedimentary, and metamorphic rocks; marcasite is much less common and is found mainly in sedimentary rocks; pyrrhotite is less common but may be found in many types of igneous and metamorphic rocks. Pyrite is brass yellow, and pyrrhotite bronze brown, and both have a metallic luster. Marcasite is also metallic but lighter in color and finely divided iron sulfides are soot black. Pyrite is often found in cubic crystals. Marcasite readily oxidizes with the liberation of sulfuric acid and formation of iron oxides, hydroxides, and, to a much smaller extent, sulfates; pyrite and pyrrhotite do so less readily. Marcasite and certain forms of pyrite and pyrrhotite are reactive in mortar and concrete, producing a brown stain accompanied by a volume increase that has been reported as one source of popouts in concrete. Reactive forms of iron sulfides may be recognized by immersion in saturated lime water (calcium hydroxide solution); upon exposure to air the reactive varieties produce a brown coating within a few minutes.

14. Iron Oxide Minerals, Anhydrous and Hydrous

14.1 There are two common iron oxide minerals: (*1*) Black, magnetic: *magnetite* (Fe_3O_4), and (*2*) red or reddish when powdered: *hematite* (Fe_2O_3); and one common hydrous oxide mineral, brown or yellowish: *goethite* ($FeO(OH)$). Another common iron-bearing mineral is black, weakly magnetic, *ilmenite* ($FeTiO_3$). Magnetite and ilmenite are important accessory minerals in many dark igneous rocks and are common detrital minerals in sediments. Hematite is frequently found as an accessory mineral in reddish rocks. Limonite, the brown weathering product of iron-bearing minerals, is a field name for several varieties of hydrous iron oxide minerals including goethite; it frequently contains adsorbed water, and various impurities such as colloidal or crystalline silica, clay minerals, and organic matter. The presence of substantial amounts of soft iron-oxide minerals in concrete aggregate can color concrete various shades of yellow or brown. Very minor amounts of iron minerals color many rocks, such as ferruginous sandstones, shales, clay-ironstones, and granites. Magnetite, ilmenite, and hematite ores are used as heavy aggregates.

DESCRIPTIONS OF IGNEOUS ROCKS

15. General

15.1 Igneous rocks are those formed by cooling from a molten rock mass (magma). They may be divided into two classes: (*1*) plutonic, or intrusive, that have cooled slowly within the earth; and (*2*) volcanic, or extrusive, that formed from quickly cooled lavas. Plutonic rocks have grain sizes greater than approximately 1 mm, and are classified as coarse- or medium-grained. Volcanic rocks have grain sizes less than approximately 1 mm, and are classified as fine-grained. Volcanic rocks frequently contain glass. Both plutonic and volcanic rocks may consist of porphyries, that are characterized by the presence of large mineral grains in a fine-grained or glassy groundmass. This is the result of sharp changes in rate of cooling or other physico-chemical conditions during solidification of the melt.

15.2 Igneous rocks are usually classified and named on the basis of their texture, internal structure, and their mineral composition which in turn depends to a large extent on their chemical composition. Rocks in the plutonic class generally have chemical equivalents in the volcanic class.

16. Plutonic Rocks

16.1 *Granite*—granite is a medium- to coarse-grained, light-colored rock characterized by the presence of potassium feldspar with lesser amounts of plagioclase feldspars and quartz. The characteristic potassium feldspars are orthoclase or microcline, or both; the common plagioclase feldspars are albite and oligoclase. Feldspars are more abundant than quartz. Dark-colored mica (biotite) is usually present, and light-colored mica (muscovite) is frequently present. Other dark-colored ferromagnesian minerals, especially hornblende, may be present in amounts less than those of the light-colored constituents. *Quartz-monzonite* and *granodiorite* are rocks similar to granite, but they contain more plagioclase feldspar than potassium feldspar.

16.2 *Syenite*—syenite is a medium- to coarse-grained, light-colored rock composed essentially of alkali feldspars, namely microcline, orthoclase, or albite. Quartz is generally absent. Dark ferromagnesian minerals such as hornblende, biotite, or pyroxene are usually present.

16.3 *Diorite*—diorite is a medium- to coarse-grained rock composed essentially of plagioclase feldspar and one or more ferromagnesian minerals such as hornblende, biotite, or pyroxene. The plagioclase is intermediate in composition, usually of the variety andesine, and is more abundant than the ferromagnesian minerals. Diorite usually is darker in color than granite or syenite and lighter than gabbro. If quartz is present, the rock is called *quartz diorite.*

16.4 *Gabbro*—gabbro is a medium- to coarse-grained, dark-colored rock consisting essentially of ferromagnesian minerals and plagioclase feldspar. The ferromagnesian minerals may be pyroxenes, amphiboles, or both. The plagioclase is one of the calcium-rich varieties, namely labradorite, bytownite, or anorthite. Ferromagnesian minerals are usually more abundant than feldspar. *Diabase* (in European usage *dolerite*) is a rock of similar composition to gabbro and basalt but is intermediate in mode of origin, usually occurring in smaller intrusions than gabbro, and having a medium to fine-grained texture. The terms "trap" or "trap rock" are collective terms for dark-colored, medium- to fine-grained igneous rocks especially diabase and basalt.

16.5 *Peridotite*—peridotite is composed of olivine and pyroxene. Rocks composed almost entirely of pyroxene are known as *pyroxenites*, and those composed of olivine as *dunites.* Rocks of these types are relatively rare but their metamorphosed equivalent, serpentinite, is more common.

16.6 *Pegmatite*—extremely coarse-grained varieties of igneous rocks are known as pegmatites. These are *usually* light-colored and are most frequently equivalent to granite or syenite in mineral composition.

17. Fine-Grained and Glassy Extrusive Igneous Rocks

17.1 *Volcanic Rock*—volcanic or extrusive rocks are the fine-grained equivalents of the coarse-and-medium-grained plutonic rocks. Equivalent types have similar chemical compositions and may contain the same minerals. Volcanic rocks commonly are so fine-grained that the individual mineral grains usually are not visible to the naked eye. Porphyritic textures are common, and the rocks may be partially or wholly glassy or non-crystalline. The glassy portion of a partially glassy rock usually has a higher silica content than the crystalline portion. Some volcanic or extrusive rocks may not be distinguishable in texture and structure from plutonic or intrusive rocks that originated at shallow depth.

17.2 *Glassy Volcanic Rocks*—These rocks are of particular significance because they contain, or may contain, high silica glass that is alkali-reactive, and secondary minerals that are alkali-reactive or release alkalies into concrete. The high silica glasses, generally classed as those containing more than 55 % silica, are known to be alkali-reactive, whereas the low-silica glasses are not. Among igneous rocks that contain, or may contain, high silica glass are: obsidian, pumice, trachyte, rhyolite, scoria, dacite, basalt, andesite, and perlite. Aggregates containing these rocks include crushed parent rock where the aggregate is constituted totally of the rock, or as varying percentages in gravels and sands. Glassy rocks, particularly the more siliceous ones, are potentially deleteriously reactive with the alkalies in hydraulic cement paste.

17.3 *Volcanic Glass*—igneous rocks composed wholly of glass are named on the basis of their texture and internal structure. A dense dark natural glass of high silica content is called *obsidian*, while lighter colored finely vesicular glassy froth filled with elongated, tubular bubbles is called *pumice.* Dark-colored coarsely vesicular types containing more or less spherical bubbles are called *scoria.* Pumices are usually silica-rich (corresponding to rhyolites or dacites), whereas scorias usually are more basic (corresponding to basalts). A high-silica glassy lava with an onion-like structure and a pearly luster, containing 2 to 5 % water, is called *perlite.* When heated quickly to the softening temperature, perlite puffs to become an artificial pumice. Glass with up to 10 % water and with a dull resinous luster is called *pitchstone*.

17.4 *Felsite*—light-colored, very fine-grained igneous rocks are collectively known as felsites. The felsite group includes *rhyolite, dacite, andesite*, and *trachyte*, which are the equivalents of granite, quartz diorite, diorite, and syenite, respectively. These rocks are usually light colored but they may be gray, green, dark red, or black. When they are microcrystalline or contain natural glass, rhyolites, dacites, and andesites are potentially deleteriously reactive with the alkalies in hydraulic cement paste.

17.5 *Basalt*—fine-grained extrusive equivalent of gabbro and diabase. When basalt contains natural glass, the glass is generally lower in silica content than that of the lighter-colored extrusive rocks and hence is not deleteriously reactive with the alkalies in hydraulic cement paste; however, exceptions have been noted in the literature with respect to the alkali reactivity of basaltic glasses.

17.6 Vesicles and other voids in volcanic rocks may contain alkali-reactive forms of silica such as opal, cristobalite, tridymite, and various varieties of microcrystalline quartz. Additionally, zeolitic minerals can release alkalies and thus increase the alkalies in the paste.

DESCRIPTIONS OF SEDIMENTARY ROCKS

18. General

18.1 Sedimentary rocks are stratified rocks usually laid down under water, although they can also be formed by wind and glacial action. Sediments may be composed of particles of preexisting rocks derived by mechanical agencies or they may be of chemical or organic origin. The sediments are usually indurated by cementation or compaction during geologic time, although the degree of consolidation may vary widely.

18.2 *Gravel, sand, silt*, and *clay* form the group of unconsolidated sediments. Although the distinction between these four members is made on the basis of their particle size, a general trend in the composition occurs. Gravel and, to a lesser degree, coarse sands usually consist of rock fragments; fine sands and silt consist predominantly of mineral grains; and clay exclusively of mineral grains, largely of the group of clay minerals. All types of rocks and minerals may be represented in unconsolidated sediments.

19. Conglomerates, Sandstones, and Quartzites

19.1 These rocks consist of particles of *sand* or *gravel*, or both, with or without interstitial and cementing material. If the particles include a considerable proportion of gravel, the rock is a *conglomerate*. If the particles are in the sand sizes, that is, less than 2 mm but more than 0.06 mm in major diameter, the rock is a *sandstone* or a *quartzite.* If the rock breaks around the sand grains, it is a sandstone; if the grains are largely quartz and the rock breaks through the grains, it is quartzite. Conglomerates, and sandstones are sedimentary rocks but quartzites may be sedimentary (*orthoquartzites*) or metamorphic (*metaquartzites*). The cementing or interstitial materials of sandstones may be quartz, opal, calcite, dolomite, clay, iron oxides, or other materials. These may influence the quality of a sandstone as concrete aggregate. If the nature of the cementing material is known, the rock name may include a reference to it, such as *opal-bonded sandstone* or *ferruginous conglomerate.* Opal-containing rocks may be potentially deleteriously reactive with alkalies in the hydraulic cement paste.

19.2 *Graywackes and subgraywackes*—gray to greenish gray sandstones containing angular quartz and feldspar grains, and sand-sized rock fragments in an abundant matrix resembling claystone, shale, argillite, or slate. Graywackes grade into subgraywackes, the most common sandstones of the geologic column.

19.3 *Arkose*—coarse-grained sandstone derived from granite, containing conspicuous amounts of feldspar.

20. Claystones, Shales, Argillites, and Siltstones

20.1 These very fine-grained rocks are composed of, or derived by erosion of sedimentary *silts* and *clays*, or of any type of rock that contained clay. When relatively soft and massive, they are known as *claystones*, or *siltstones*, depending on the size of the majority of the particles of which they are composed. Siltstones consist predominantly of silt-sized particles (0.0625 to 0.002 mm in diameter) and are intermediate rocks between claystones and sandstones. When the claystones are harder and platy or fissile, they are known as *shales*. Claystones and shales may be gray, black, reddish, or green and may contain some carbonate minerals (calcareous shales). A massive, firmly indurated fine-grained argillaceous rock consisting of quartz, feldspar, and micaceous minerals is known as *argillite*. Argillites do not slake in water as some shales do. As an aid in distinguishing these fine-grained sediments from fine-grained, foliated metamorphic rocks such as slates and phyllites, it may be noted that the cleavage surfaces of shales are generally dull and earthy while those of slates are more lustrous. Phyllite has a glossier luster resembling a silky sheen. Clay ironstone concretions are generally nodular particles consisting of mixtures of clay minerals and iron oxides. They are commonly hard and range in color from red-brown to purplish brown to orange-brown to orange to yellow. They are commonly concentric and may contain soft cores of clay minerals.

20.2 Clay ironstones may cause popouts in concrete subject to freezing and thawing while saturated with water. Aggregates containing abundant shale may be detrimental to concrete because they can produce high shrinkage, but not all shales are harmful. Some shales and siltstones may cause popouts and scaling in concrete subject to freezing and thawing while saturated with water (**15**,**17**). Some argillites, siltstones, and shales are alkali-silica reactive and may cause popouts (**18**,**19**).

20.3 Although aggregates which are volumetrically unstable in wetting and drying are not confined to any class of rock, they do share some common characteristics. If there is a matrix or continuous phase, it is usually physically weak and consists of material of high specific surface, frequently including clay. However, no general relation has been demonstrated between clay content or type of clay and large volume change upon wetting and drying. Volumetrically unstable aggregates do not have mineral grains of high modulus interlocked in a continuous rigid structure capable of resisting volume change.

20.4 Aggregates having high elastic modulus and low volume change from the wet to the dry condition contribute to the volume stability of concrete by restraining the volume change of the cement paste. In a relatively few cases, aggregates have been demonstrated to contribute to unsatisfactory performance of concrete because they have relatively large volume change from the wet to the dry condition combined with relatively low modulus of elasticity. On drying, such aggregates shrink away from the surrounding cement paste and consequently fail to restrain its volume change with change in moisture content.

21. Carbonate Rocks

21.1 *Limestones*, the most widespread of carbonate rocks. They range from pure limestones consisting of the mineral calcite to pure *dolomites* (dolostones) consisting of the mineral dolomite. Usually they contain both minerals in various proportions. If 50 to 90 % is the mineral dolomite, the rock is called *calcitic dolomite*. The term "magnesium limestone" is sometimes applied to dolomitic limestones and calcitic dolomites but it is ambiguous and its use should be avoided. Most carbonate rocks contain some noncarbonate impurities such as quartz, chert, clay minerals, organic matter, gypsum, and sulfides. Carbonate rocks containing 10 to 50 % sand are *arenaceous* (or *sandy*) *limestones* (or *dolomites*); those containing 10 to 50 % clay are *argillaceous* (or *clayey* or *shaly*) *limestones* (or *dolomites*). *Marl* is a clayey limestone which is fine-grained and commonly soft. Chalk is fine-textured, very soft, porous, and somewhat friable limestone, composed chiefly of particles of microorganisms. Micrite is very fine-textured chemically precipitated carbonate or a mechanical ooze of carbonate particles, usually 0.001 to 0.003 mm in size. The term "limerock" is not recommended.

21.2 The reaction of the dolomite in certain carbonate rocks with alkalies in portland cement paste has been found to be associated with deleterious expansion of concrete containing such rocks as coarse aggregate. Carbonate rocks capable of such reaction possess a characteristic texture and composition. The characteristic microscopic texture is that in which relatively large crystals of dolomite (rhombs) are scattered in a finer-grained matrix of micritic calcite and clay. The characteristic composition is that in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid-insoluble residue contains a significant amount of clay. Except in certain areas, such rocks are of relatively infrequent occurrence and seldom make up a significant proportion of the material present in a deposit of rock being considered for use in making aggregate for concrete.

22. Chert

22.1 *Chert*—the general term for a group of variously colored, very fine-grained (aphanitic), siliceous rocks composed of microcrystalline or cryptocrystalline quartz, chalcedony, or opal, either singly or in combinations of varying proportions. Identification of the form or forms of silica requires careful determination of optical properties, absolute specific gravity, loss on ignition, or a combination of these characteristics. Dense cherts are very tough, with a waxy to greasy luster, and are usually gray, brown, white, or red, and less frequently, green, black or blue. Porous varieties are usually lighter in color, frequently off-white, or stained yellowish, brownish, or reddish, firm to very weak, and grade to tripoli. Ferruginous, dense, red, and in some cases, dense, yellow, brown, or green chert is sometimes called *jasper.* Dense black or gray chert is sometimes called *flint.* A very dense, even textured, light gray to white chert, composed mostly of microcrystalline to cryptocrystalline quartz, is called *novaculite.* Chert is hard (scratches glass, but is not scratched by a knife blade) and has a conchoidal (shell-like) fracture in the dense varieties, and a more splintery fracture in the porous varieties. Chert occurs most frequently as nodules, lenses, or interstitial material, in limestone and dolomite formations, as extensively bedded deposits, and as components of sand and gravel. Most cherts have been found to be alkali-silica reactive to some degree when tested with high-alkali cement, or in the quick chemical test (Test Method C 289). In the absence of information to the contrary, all chert should be regarded as potentially deleteriously reactive with the alkalies in hydraulic cement paste. The degree of alkali-silica reactivity, and whether a given chert will produce a deleterious degree of expansion in concrete, are complex functions of several factors. The degree of the alkali-silica reactivity and whether a given chert will produce a deleterious degree of expansion in concrete are complex functions of several factors. Among them are: the mineralogic composition and internal structure of the chert; the amount of the chert as a proportion of the aggregates; the particle-size distribution; the alkali content of the cement; and the cement content of the concrete. However, opaline cherts may produce deleterious expansion of mortar or concrete when present in very small proportions (less than 5 % by mass of the aggregate). Cherts that are porous may be susceptible to freezing and thawing deterioration in concrete and may cause popouts or cracking of the concrete surface above the chert particle.

DESCRIPTIONS OF METAMORPHIC ROCKS

23. General

23.1 Metamorphic rocks form from igneous, sedimentary, or pre-existing metamorphic rocks in response to changes in chemical and physical conditions occurring within the earth's crust after formation of the original rock. The changes may be textural, structural, or mineralogic and may be accompanied by changes in chemical composition. The rocks are dense and may be massive but are more frequently foliated (laminated or layered) and tend to break into platy particles. Rocks formed from argillaceous rocks by dynamic metamorphism usually split easily along one plane independent of original bedding; this feature is designated "platy cleavage." The mineral composition is very variable depending in part on the degree of metamorphism and in part on the composition of the original rock.

23.2 Most of the metamorphic rocks may derive either from igneous or sedimentary rocks but a few, such as marbles and slates, originate only from sediments.

23.3 Phyllites, slates, metaquartzites, gneisses, schists, mylonite, and other rocks containing low temperature silica and silicate minerals and highly strained or microcrystalline quartz are potentially deleteriously reactive with alkalies in the hydraulic cement paste.

24. Metamorphic Rocks

24.1 *Marble*—a recrystallized medium- to coarse-grained carbonate rock composed of calcite or dolomite, or calcite and dolomite. The original impurities are present in the form of new minerals, such as micas, amphiboles, pyroxenes, and graphite.

24.2 *Metaquartzite*—a granular rock consisting essentially of recrystallized quartz. Its strength and resistance to weathering derive from the interlocking of the quartz grains.

24.3 *Slate*—a fine-grained metamorphic rock that is distinctly laminated and tends to split into thin parallel layers. The mineral composition usually cannot be determined with the unaided eye.

24.4 *Phyllite*—a fine-grained thinly layered rock. Minerals, such as micas and chlorite, are noticeable and impart a silky sheen to the surface of schistosity. Phyllites are intermediate between slates and schists in grain size and mineral composition. They derive from argillaceous sedimentary rocks or fine-grained extrusive igneous rocks, such as felsites.

24.5 *Schist*—a highly layered rock tending to split into nearly parallel planes (schistose) in which the grain is coarse enough to permit identification of the principal minerals. Schists are subdivided into varieties on the basis of the most prominent mineral present in addition to quartz or to quartz and feldspars; for instance, *mica schist. Greenschist* is a green schistose rock whose color is due to abundance of one or more of the green minerals, chlorite or amphibole, and is commonly derived from altered volcanic rock.

24.6 *Amphibolite*—a medium- to coarse-grained dark-colored rock composed mainly of hornblende and plagioclase feldspar. Its schistosity, which is due to parallel alignment of hornblende grains, is commonly less obvious than in typical schists.

24.7 *Hornfels*—equigranular, massive, and usually tough rock produced by complete recrystallization of sedimentary, igneous, or metamorphic rocks through thermal metamorphism sometimes with the addition of components of molten rock. Their mineral compositions vary widely.

24.8 *Gneiss*—one of the most common metamorphic rocks, usually formed from igneous or sedimentary rocks by a higher degree of metamorphism than the schists. It is characterized by a layered or foliated structure resulting from approximately parallel lenses and bands of platy minerals, usually micas, or prisms, usually amphiboles, and of granular minerals, usually quartz and feldspars. All intermediate varieties between gneiss and schist, and between gneiss and granite are often found in the same areas in which well-defined gneisses occur.

24.9 *Serpentinite*—a relatively soft, light to dark green to almost black rock formed usually from silica-poor igneous rocks, such as pyroxenites, peridotites, and dunites. It may contain some of the original pyroxene or olivine but is largely composed of softer hydrous ferromagnesian minerals of the serpentine group. Very soft talc-like material is often present in serpentinite.

CONSTITUENTS OF ARTIFICIAL AGGREGATES

25. General

25.1 Artificial aggregates are aggregates resulting from reconstitution of natural materials, other than by physical processes, such as crushing and screening, or from physical or mechanical processing of pre-existing artificial materials to produce aggregates for new work. Examples of reconstitution processes are: (1) heat treatment, such as heating, sintering, calcination, or partial or complete fusion of volcanic rocks, clay, shale, or slate, with resulting mechanical disruption, vitrification, recrystallization, bloating, or combinations of these phenomena in production of lightweight aggregates, and (2) formation of new materials as a consequence of industrial processes, such as slag produced simultaneously with iron in a blast furnace. An example of mechanical processing of pre-existing artificial material is the recovery of hardened concrete from constructions to produce aggregate.

26. Artificial Aggregate

26.1 *Cinders (industrial)*—the agglomerated residue from combustion of coal or coke in an industrial furnace. Specifications may place limitations on content of combustible residues, sulfides, and sulfate. Undesirable sulfur compounds can be reduced by leaching during storage in stockpiles.

26.1.1 Industrial cinders are highly porous and variable in firmness, friability, particle shape, and surface texture. The matrix is a mixture of siliceous glass and finely divided residues of original silt, fine sand, and calcined clay minerals. Particles of unburned coal and coke may be present. Original laminations of sandstone or siltstone occurring in the coal will be represented by compact particles within the product. Such particles and unburned coal and coke may produce unsoundness in concrete.

26.2 *Blast-furnace slag*—the nonmetallic product, consisting essentially of silicates and aluminosilicates of calcium and other bases, that is developed in a molten condition simultaneously with iron in a blast furnace (as described in Terminology C 125). The glass phase of normal blast-furnace slag is not deleteriously reactive with alkalies in concrete.

NOTE 2—Steel furnace slag, unlike blast furnace slag, should not be used as aggregate for hydraulic cement concrete.

26.2.1 *Air-Cooled Blast-Furnace Slag*—the material resulting from solidification of molten blast-furnace slag under atmospheric conditions. Subsequent cooling may be accelerated by application of water to the solidified surface. Such slags are more or less crystallized, the crystals ranging from submicroscopic to several millimetres in size. More than 20 compounds have been identified in air-cooled slag but even well crystallized slag rarely contains more than five compounds. The most typical crystalline constituent is melilite, a compound of variable composition between akermanite ($2CaO \cdot MgO \cdot 2SiO_2$) and gehlenite ($2CaO \cdot Al_2O_3 \cdot SiO_2$). Calcium sulfide (CaS) is almost always present in small proportion.

26.2.1.1 Potentially deleterious constituents include iron sulfides that may produce unsightly staining of concrete or may result in formation of gypsum (calcium sulfate dihydrate, $CaSO_4 \cdot 2H_2O$) by weathering. Use of very old slag with high alumina cement may cause ettringite formation and concrete expansion. Rare chemical anomalies may cause inversion of β-dicalcium silicate to γ-dicalcium silicate with accompanying 10 % increase in volume, resulting in “dusting” or “blowing” of slag. Such inversion while cooling the slag allows removal of the disintegrated material by screening during the production of aggregate. Slower inversion may produce weak and friable particles that are unsuitable as constituents of concrete aggregate; this is determinable by appropriate tests.

26.2.2 *Granulated Blast-Furnace Slag*—the glassy, granular material formed when molten blast-furnace slag is rapidly chilled as by immersion in water. In the jet process, the steam of molten slag is disrupted by a high-pressure water jet and the water/slag mixture is separated by screening. Dry-granulated slag is produced by a mechanical device that breaks the stream of molten slag by impact into small particles which then are quenched by water and air.

26.2.3 *Lightweight Blast-Furnace Slag*—the foamed product formed when molten slag is expanded by applying a limited amount of water, typically less than that required for granulation, so that a relatively dry, cellular, lumpy product results. Aggregate is produced by crushing and screening the clinker. (see 26.2.2).

26.3 *Expanded Shale, Clay, and Slate*—aggregates produced by heating prepared materials of these types to a range of temperature between incipient and complete fusion with accompanying expansion (bloating) that occurs with formation and expansion of entrapped gases. The aggregate may be prepared by prior crushing and screening of the raw materials and fired with or without admixtures, with iron oxides, or carbonaceous materials, crushing and screening of the fired product, or by processing of pellets produced by any of several methods. Other processes involve production of light-weight aggregate by burning of mixtures of coal and shale, clays, or other materials in moving grates exposed to heated gas flow.

26.3.1 Expansion and vesiculation of clays, shales, and slates occurs during firing in the range from about 1650°C (3000°F) to 1700°C (3100°F), but the results obtained for a particular material depend upon the rate of heating, the temperature attained in the feed, the composition of the kiln atmosphere, residency in the kiln, and other factors. Expansion and vesiculation requires *(1)* presence of one or more substances that release gas after fusion has developed sufficient molten material to prevent its escape, and *(2)* the molten material be of sufficient viscosity to retain the expanding gas. The viscosity of the melt is determined to a large extent by the bulk chemical composition of the raw material as defined by proportions of SiO_2 and Al_2O_3 and the total of calcium, magnesium, ferrous iron, ferric iron, and alkalies. Increasing alumina content tends to increase refractory quality of the feed and decreases vesiculation.

26.3.2 Gas is released by several processes. The most significant reaction apparently is partial reduction of ferric oxide with release of oxygen. The ferric oxide is furnished by limonite or hematite in the raw feed or by decomposition of original iron-bearing minerals, most notably clays, micas, and clay-like minerals.

26.3.3 The internal structure or fabric of the clay, shale, or slate is significant in the expansion process. Most beneficial is a dense, relatively impervious fabric that resists shrinkage during heating and retards release of vapors and gases before fusion effects a seal in the particles. The fabric is especially important in firing of carbonaceous clays and shales inasmuch as a porous, open fabric permits ready burning out of the carbon, whereas a dense fabric retards oxidation by the kiln atmosphere and retains CO and CO_2 produced by reaction with interstitial water or with water or oxygen released by hydrated compounds or hydroxylated silicates.

26.3.4 The most promising sources of lightweight aggregate are shales and clays containing illite, beidellite, members of the montmorillonite (smectite) clays, and vermiculitechlorite. These minerals approximate the composition that has been found to yield a melt of optimum viscosity. Compared to members of the kaolin group, they contain lesser proportions of alumina and moderate proportions of alkalies and alkaline earths, which serve as fluxes in the firing process.

26.3.5 The matrix of expanded clays, shales, and slates is composed of an intimate intermingling of siliceous glass and residues of granular minerals. Decomposition of calcium and magnesium carbonates produces free lime, free magnesia, or both compounds, which may cause expansion or popouts in concrete constructions or products unless the aggregate is water- or steam-cured prior to use. Laminations or seams of sandstone or siltstone that were constituents of the geologic formation at the source will occur as individual particles or as portions of vesiculated particles in the aggregate. They may display efflorescence and may include free lime or magnesia when originally carbonaceous. The glass phase of expanded clays, shales, and slates may be alkali reactive but expansion of concrete from this cause has not been observed because any siliceous gels that are generated are accommodated within the abundant air-filled cavities that characterize the expanded particles.

26.4 *Diatomite (sintered)*—lightweight aggregate produced by crushing and screening of diatomaceous earth or shales, spraying with oil, and firing in a rotary kiln. The main constituents are opaline skeletons of diatoms together with variable proportions of siliceous glass produced by the firing process. Other constituents are fine sand, silt, clay, and finely divided volcanic glass.

26.4.1 Some sintered diatomites used as aggregate for concrete produce significant expansion with both low- and high-alkali cements.

26.5 *Vermiculite (exfoliated)*—a micaceous mineral caused to expand and exfoliate by rapid heating as a result of release of combined water. The final volume of the particles can be as much as 30 times the original size. However, the degree of expansion, elasticity, brittleness, and fragility of the particles varies widely, depending upon mineralogic composition of the vermiculite, crystal size, purity, and conditions of firing.

26.5.1 Bodies of vermiculite ore may grade at the margins to hydrobiotite and biotite mica and become intermingled with varying proportions of granular or other non-micaceous minerals.

26.6 *Perlite (expanded)*—rhyolitic volcanic glass having a relatively high water content and a perlitic structure that has been heated sufficiently to cause it to break into small, expanded particles. The product usually is produced only in fine aggregate sizes and used in products for insulating purposes.

26.6.1 Expanded perlite varies in particle shape, surface texture, friability, and content of dense volcanic rock particles and individual crystals. Typical expanded perlite is potentially alkali reactive although significant expansion may not occur because of porosity of the particles. Laboratory tests show that certain perlites produce significant expansion of mortar stored and tested in accordance with Test Method C 227 with either low- or high-alkali cements. Such volume change will not necessarily cause structural distress if appropriately accommodated in the design of structures or products.

26.7 Recycled concrete-hardened hydraulic-cement concrete that has been processed for use as concrete aggregate. Extensive evaluations in several countries have shown that use of recycled concrete as aggregate in new concrete is feasible and may become routine. Approval of an available source of concrete for recycling as aggregate should include two stages, namely, *(1)* planning the examination of the constructions to be demolished and *(2)* selection of procedures that should be included in evaluation of the aggregate that can be obtained economically for the intended new work. The following relationships are of especial significance:

26.7.1 The potential compressive strength of concrete containing recycled concrete as aggregate is controlled largely by the compressive strength of the concrete to be recycled, provided the fine aggregate is crushed rock or natural sand of suitable quality.

26.7.2 A substantial reduction in potential compressive strength may result when the conventional fine aggregate is replaced in whole or in part by fine aggregate derived from the recycled concrete. Hansen[4] concludes that all material smaller than 2 mm in recycled concrete should be screened and wasted.

26.7.3 Use of recycled concrete decreases workability of fresh concrete at given water content, increases water requirements for given consistency, increases drying shrinkage at given water content, and reduces modulus of elasticity at given water-cement ratio. The effects are greatest when the recycled concrete is used as both coarse and fine aggregate.

26.7.4 Freezing and thawing resistance of the new concrete relates to many factors, including the properties of the recycled concrete in terms of compressive strength, parameters of the air-void system, and frost resistance of the aggregate included in the recycled concrete as well as the parameters of the air-void system and other qualities of the cementitious matrix of the new concrete.

26.7.5 Chemical admixtures, air-entraining admixtures, and mineral admixtures included in the recycled concrete will not modify significantly the properties of the fresh or hardened, new concrete, except insofar as they modify the conditions enumerated in 26.7.1-26.7.4. High concentrations of water-soluble chloride ion in the recycled concrete may contribute to accelerated corrosion of steel embedments in the new concrete.

26.7.6 Prospective sources of recycled concrete may be unsound or have been rendered unsound in service, such as presence of physically unsound or chemically reactive aggregate, deterioration by aggressive chemical attack or leaching, damage by fire or service at high temperature, and so on.

26.7.7 Significance of contaminants in the recycled concrete should be analyzed in relation to the anticipated service, such

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[4] Hansen, T. C., "Recycled Concrete and Recycled Aggregate," Materials and Structures, International Union of Testing and Research Laboratories for Materials and Structures (RILEM), vol. 19, 1986, pp. 201–246.

as presence of noxious, toxic, or radioactive substances; presence of bituminous materials that may impair air entrainment; appreciable concentrations of organic materials that my produce excessive air entrainment; inclusion of metallic embedments that may cause rust staining or blistering of surfaces; and excessive fragments of glass, including bottle glass, that are expected to produce harmful effects of alkali-silica reaction.

27. Keywords

27.1 aggregates; artificial aggregates; carbonates; clays; concrete; feldspars; ferromagnesian minerals; igneous rocks; iron oxides; iron sulfides; metamorphic rocks; micas; minerals; nomenclature; recycled concrete; rocks; sedimentary rocks; silica; sulfates; zeolites

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