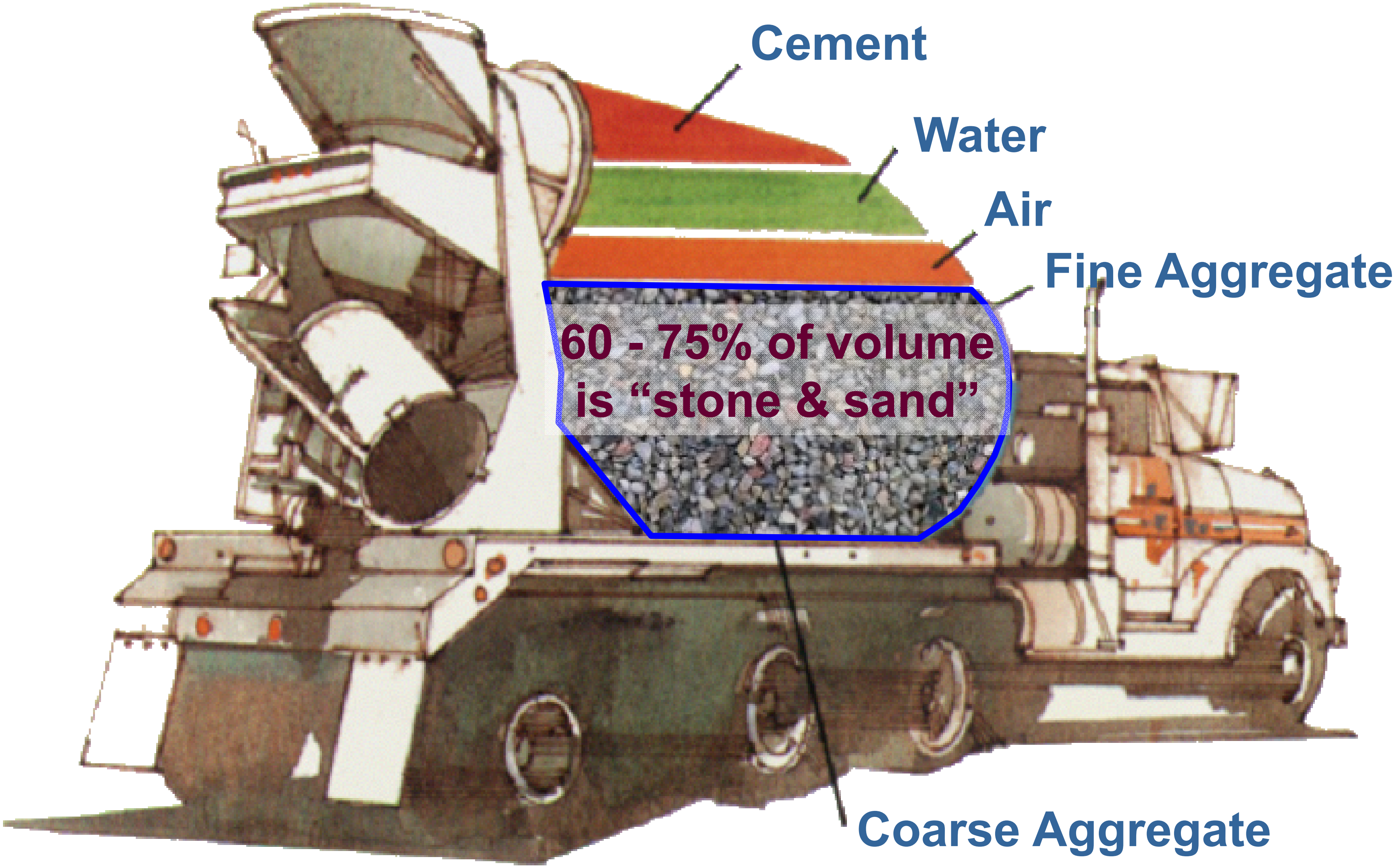
PCA

Concrete Technology and Codes

Aggregate Geology and Classification

Aggregate Geology and Classification

- Brief concrete overview
- Aggregate mineralogy and geology
- Aggregate production
- Physical properties of aggregates



Cement
Water
Air
Fine Aggregate
60 - 75% of volume
is “stone & sand”
Coarse Aggregate

ACI 221R Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete

Aggregates, the major constituent of concrete, influence the properties and performance of both freshly mixed and hardened concrete. In addition to serving as an inexpensive filler, they impart certain positive benefits that are described in this guide. When they perform below expectation, unsatisfactory concrete may result. Their important role is frequently over-looked because of their relatively low cost as compared to that of cementitious materials.

Aggregate in Concrete

Coarse Aggregate

(stone or gravel)

> 5 mm (0.2 in.)

Largest particles may range from 0.5 mm (⅜ in.) to 37.5 mm (1½ in.) or more

Fine Aggregate

(sand)

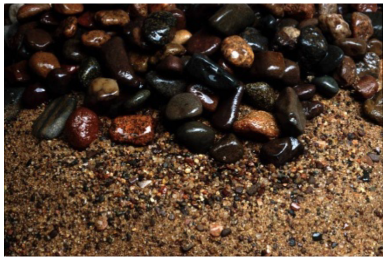
< 5 mm (0.2 in.)

Influence of Aggregate on Fresh Concrete Properties

Aggregate Property	Concrete Property
Particle size distribution (grading) Particle shape Particle texture Presence of fine material (silt & clay)	Workability Water demand Paste content 
Organic impurities  	Setting behavior 

Influence of Aggregate on

Hardened Concrete Properties

Aggregate Property	Concrete Property
Size and shape Strength Stiffness Organic impurities 	Mechanical behaviour Strength Modulus of elasticity Shrinkage 
Coefficient of thermal expansion	Coefficient of thermal expansion
Thermal conductivity	Thermal conductivity
Specific heat	Specific heat
Thermal diffusivity	Thermal diffusivity

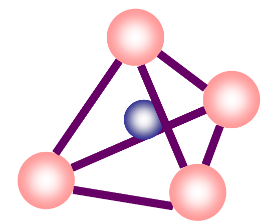
Influence of Aggregate on
Hardened Concrete Properties

Aggregate Property	Concrete Property
Soundness Frost resistance Particle size	Resistance to freezing and thawing
Presence of alkali-reactive minerals	Resistance to alkali-aggregate reaction
Density Porosity Volume stability Mineral composition	Abrasion resistance Frictional properties (pavements) Aesthetics Economics 

Aggregate Geology

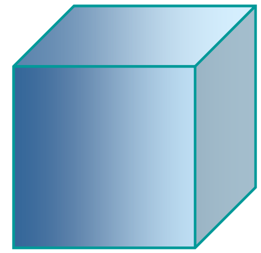
Aggregate Geology

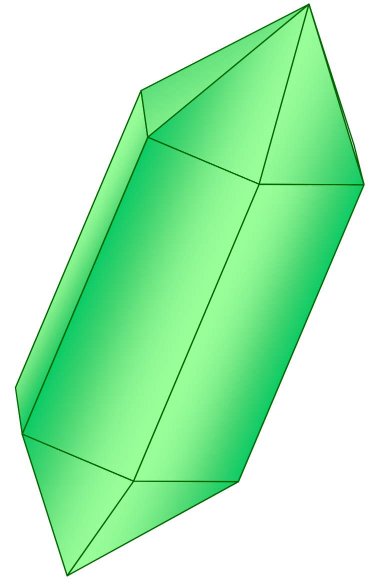
- "Mineral"– solid crystalline substance, formed by natural, and usually inorganic, processes
  - Homogeneous physical properties
  - Distinctive chemical composition
  - Distinct crystal structure



- "Rock"– natural assemblage of one or more minerals

Mineral Classification

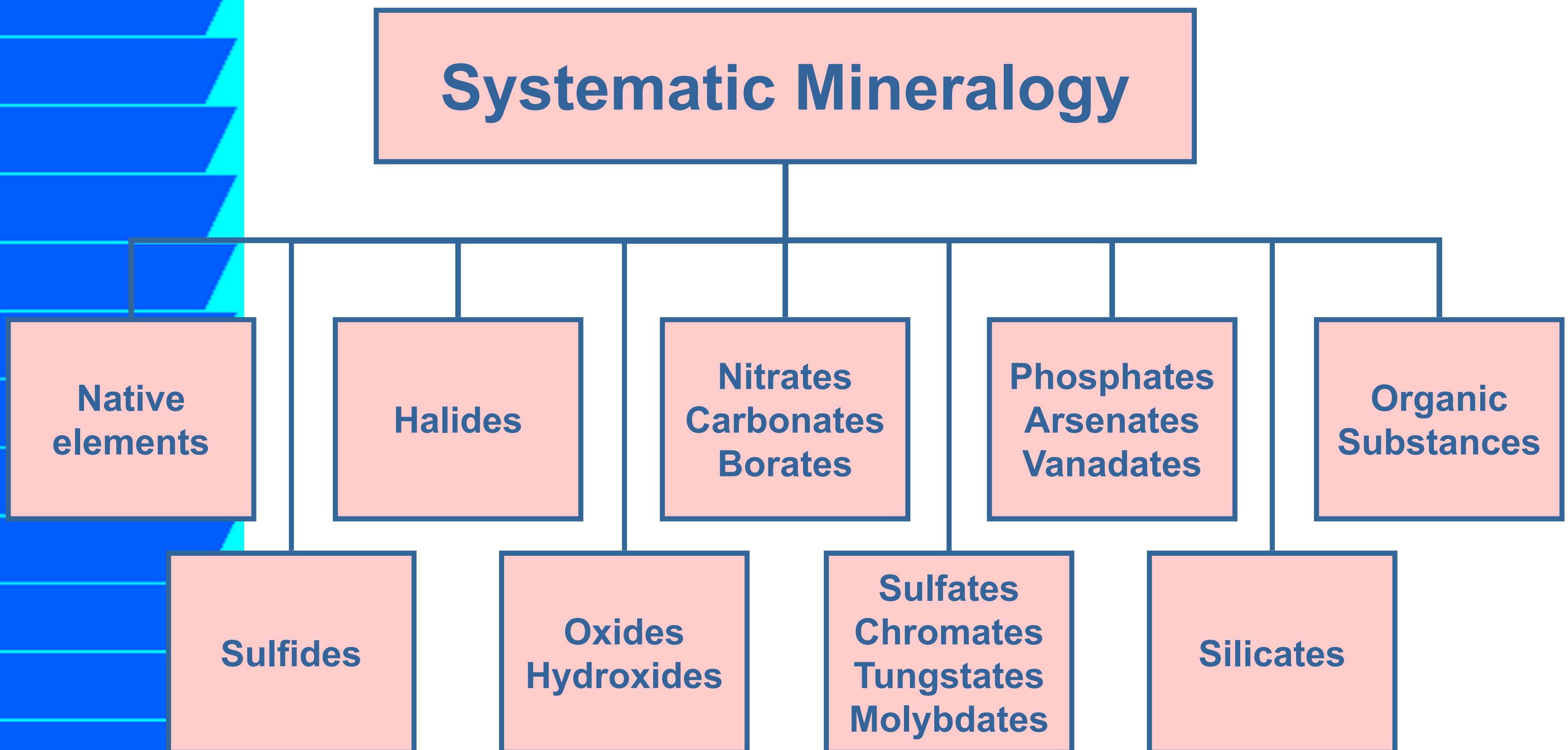




- Crystallography
- Physical properties
  - Crystal habit
  - Cleavage
  - Hardness
  - Color
  - Density
  - Optical properties
  - Electrical properties
  - Magnetic properties
- Chemical composition

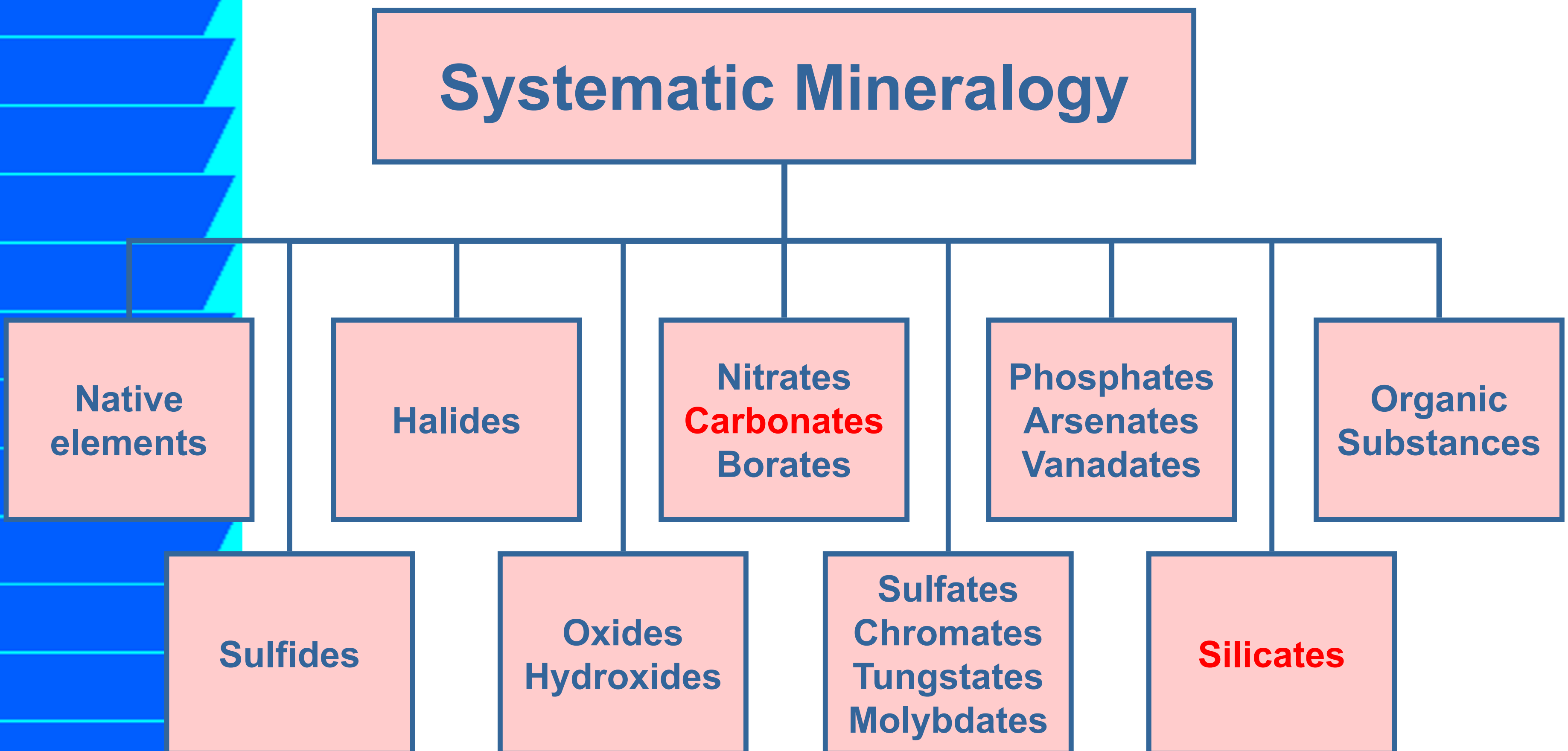
Mineral Classification

by Chemical Composition



Mineral Classification

by Chemical Composition



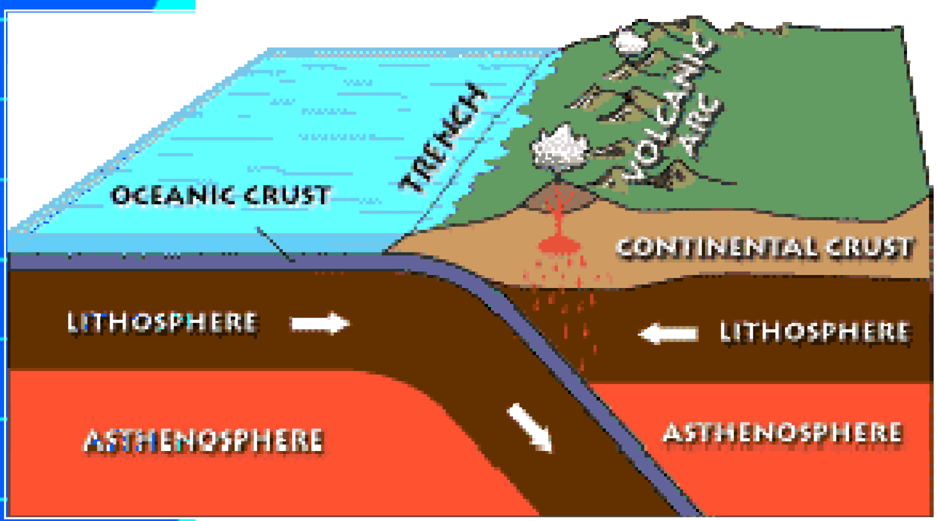
Rock Classification

Rocks classified by mode of formation

- Igneous
- Sedimentary
- Metamorphic

Igneous Rocks

Formed by solidification and crystallization of cooling magma (intrusive) or lava (extrusive)



Igneous Rocks

- Intrusive igneous rocks
  - form slowly
  - have a coarse-grained texture
- Extrusive igneous rocks
  - solidify more rapidly
  - have a fine-grained texture

Igneous Rocks

Intrusive	Extrusive	Major Minerals	Minor Minerals
Granite	Rhyolite	Quartz, K-feldspar, Na-feldspar	Muscovite, biotite, amphibole
Syenite	Trachyte	K-feldspar, Na-feldspar	Quartz, muscovite, biotite, amphibole
Granodiorite	Dacite	Quartz, Na-feldspar, amphibole	K-feldspar, Ca-feldspar, biotite
Diorite	Andesite	Na-feldspar, Ca-feldspar, amphibole	Pyroxene, biotite
Gabbro/ Diabase	Basalt	Ca-feldspar, pyroxene, olivine	Na-feldspar, amphibole

Sedimentary Rocks

- Detrital sedimentary rocks
- Chemical sedimentary rocks

Sedimentary Rocks

Detrital sedimentary rocks

- Formed by deposition and lithification of rock and mineral fragments
- Deposition results from weathering and transport of existing rocks
- Lithification occurs through compaction and/or cementation
- Classified mainly by particle size

Sedimentary Rocks

Particle Name	Size (mm)
Boulder	> 256
Cobbles	64–256
Pebble	4–64
Granule	2–4
Sand	0.062–2
Silt	0.004–0.062
Clay	< 0.004

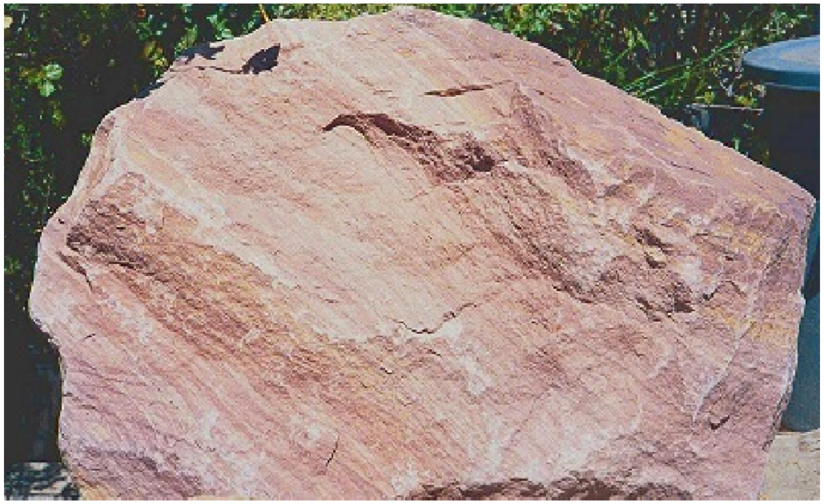
Sedimentary Rocks

Particle Name	Size (mm)	Sediment Name	Detrital Rock
Boulder	> 256	Gravel	Conglomerate (rounded particles) Breccia (angular particles)
Cobbles	64–256		
Pebble	4–64		
Granule	2–4		
Sand	0.062–2	Sand	Sandstone
Silt	0.004–0.062	Mud	Siltstone Claystone Argillite Shale } Mudstone
Clay	< 0.004		

Sedimentary Rocks

Sandstones classified by:

- Particle sorting
- Particle shape
- Particle mineralogy
- Cementing material
  - calcite
  - silica
  - iron oxide



Sedimentary Rocks

- Detrital sedimentary rocks
- Chemical sedimentary rocks
  - Inorganic
  - Organic

Sedimentary Rocks

Chemical sedimentary rocks

<u>Inorganic</u>

Precipitation of dissolved material from solution (calm lakes and seas)

- limestone– travertine, oolitic limestone
- dolostone
- chert
- rock salt (halite)
- rock gypsum

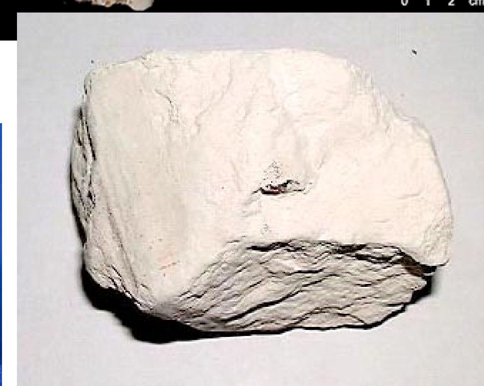
Sedimentary Rocks

Chemical sedimentary rocks

<u>Organic</u>

“Biochemical sediment” formed by skeletons of marine organisms

- coquina
- chalk
- coral reefs
- chert



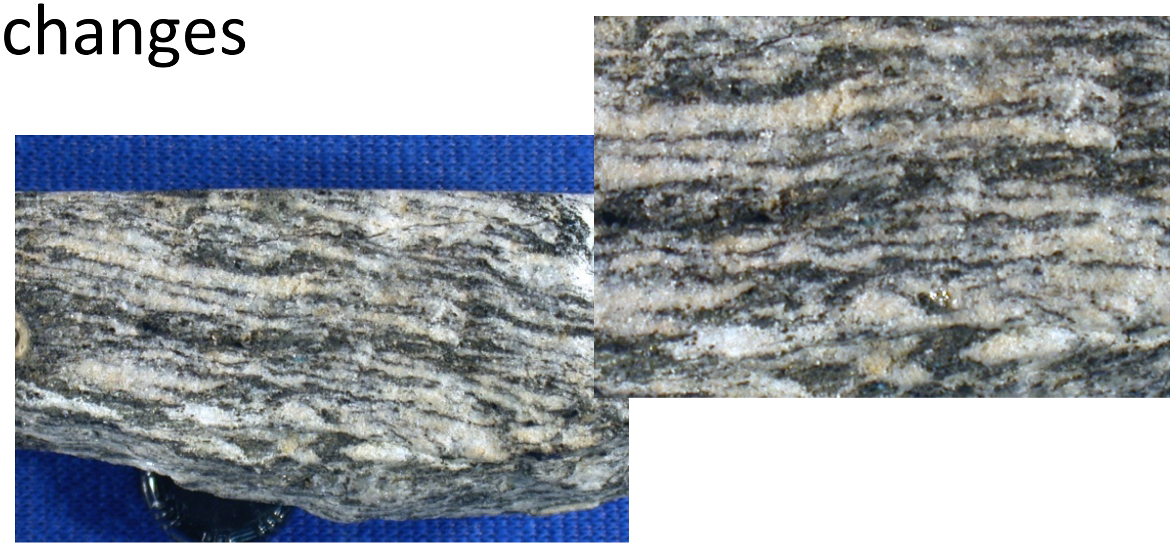
- Coal

peat

anthracite

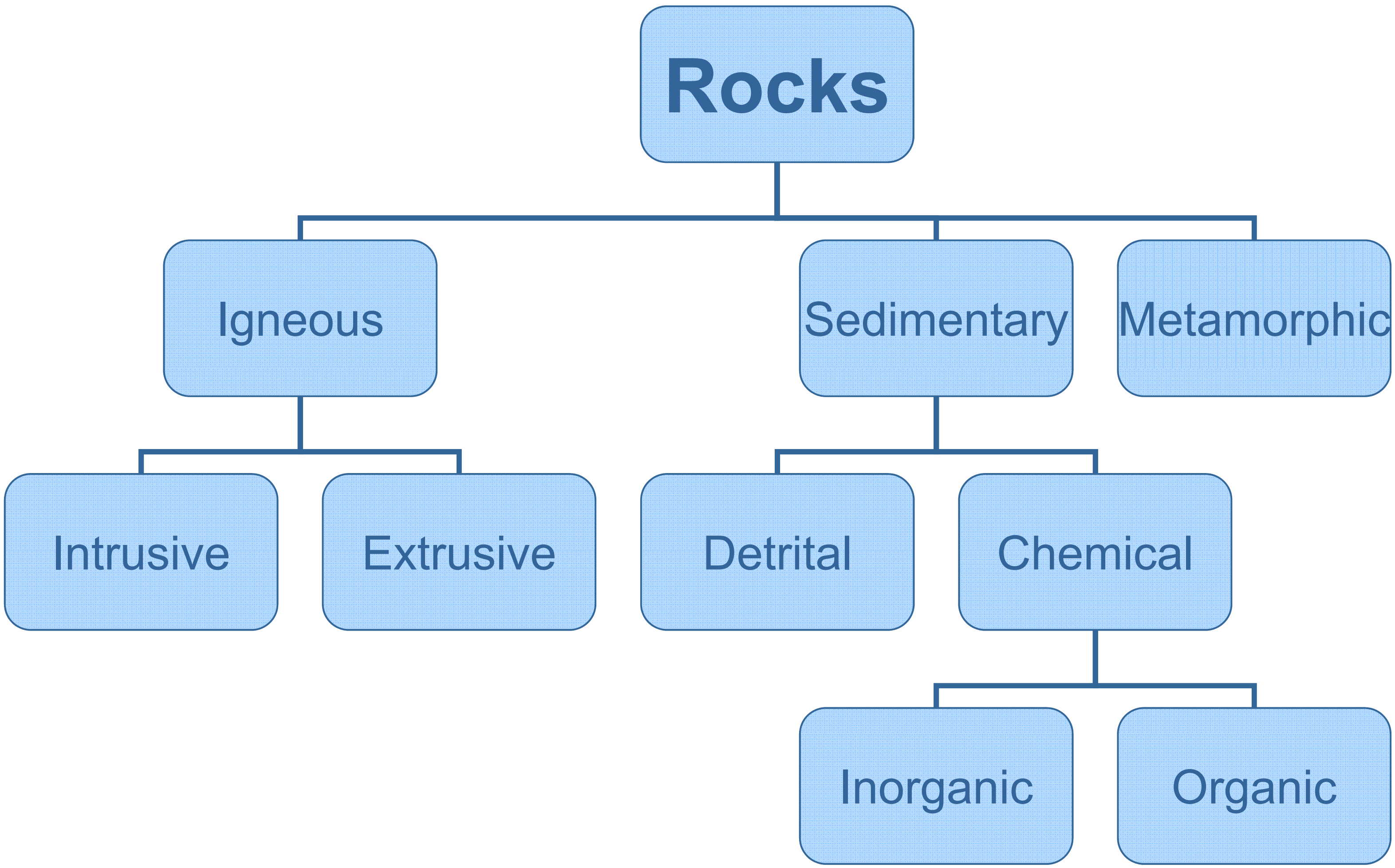
Metamorphic Rocks

- Formed by transformation of preexisting rocks exposed to immense heat and/or pressure
- Original rock undergoes mineralogical and textural changes

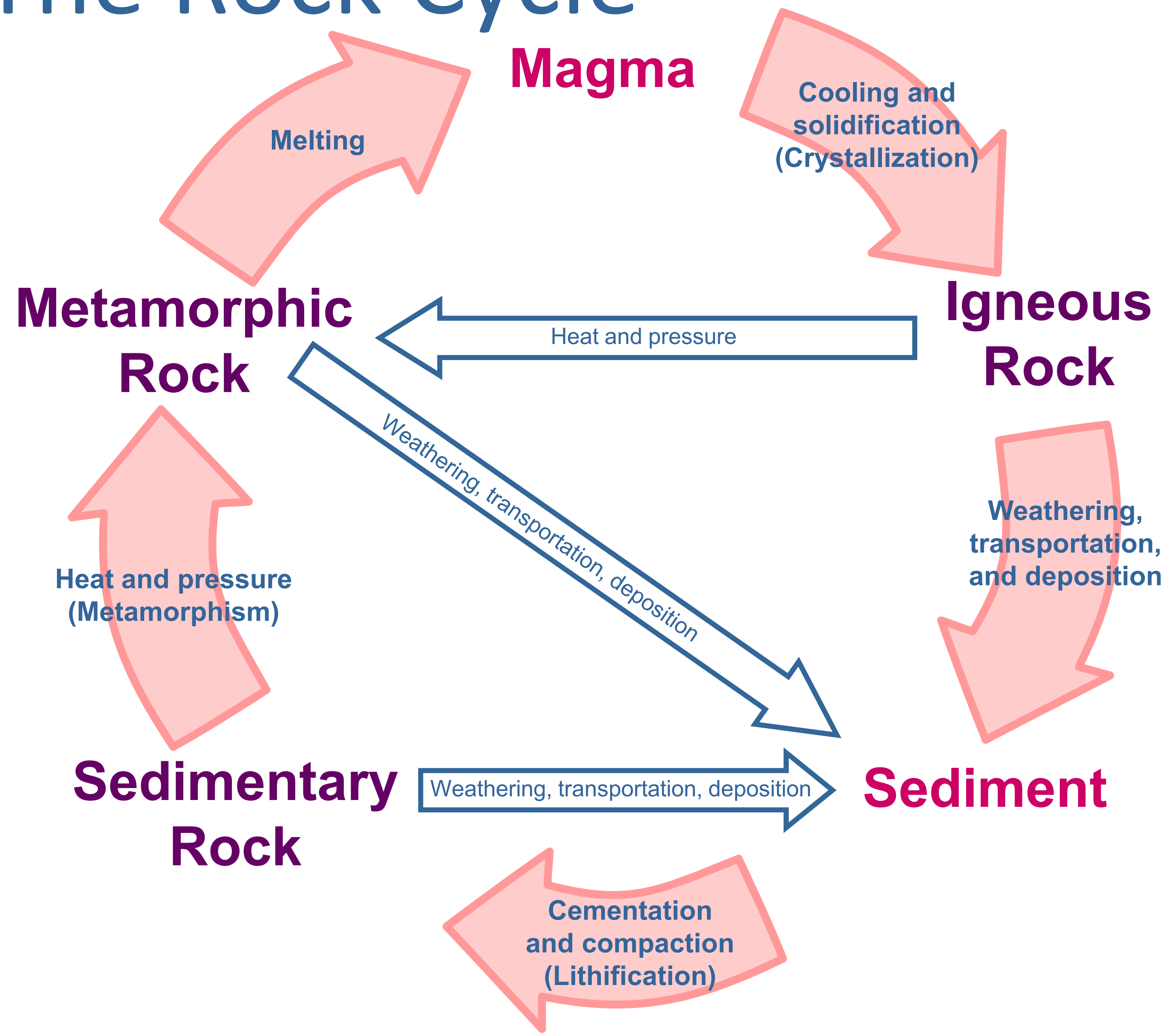


Granite → Gneiss

Rock Classification



The Rock Cycle

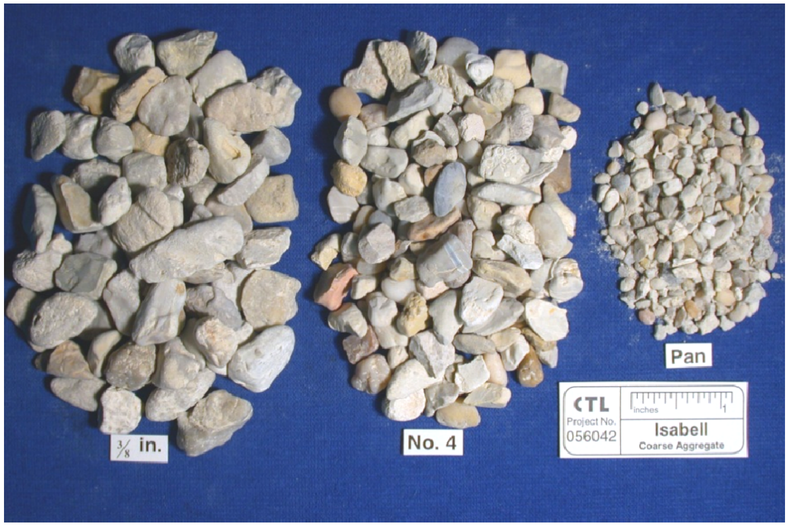


"Rocks" for Use in Concrete

- ASTM C294: Standard Descriptive Nomenclature for Constituents of Concrete Aggregates
- Common, naturally occurring rock types
  - granite, diorite, gabbro
  - fine-grained volcanic rocks
  - basalt (traprock)
  - conglomerate, sandstone, (ortho)quartzite, arkose
  - graywacke
  - siltstone, claystone, shale
  - limestone
  - chert
  - marble
  - (meta)quartzite
  - gneiss
  - slate, phyllite, schist

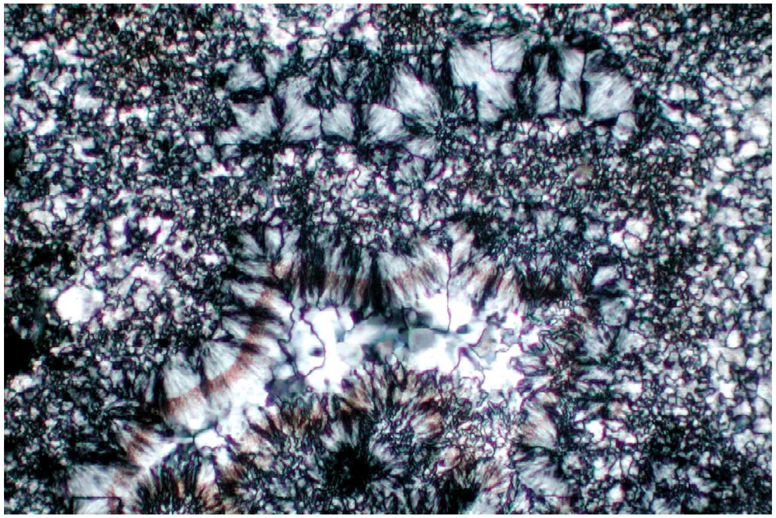
“Rocks” for Use in Concrete

- ASTM C295: Standard Guide for Petrographic Examination of Aggregates for Concrete
- X-ray diffraction
- X-ray fluorescence

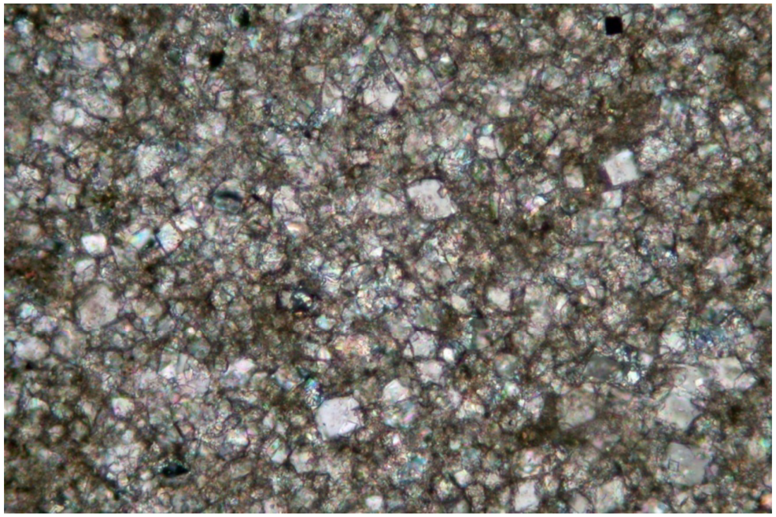


Potentially Deleterious Constituents

- Chalcedonic chert (ASR)



- Argillaceous dolomitic limestone (ACR)



Aggregate Production

Aggregate Production

- Natural sand and gravel
- Crushed rock

Aggregate Production

- Natural sand and gravel
  - usually dug or dredged from pits, rivers, lakes or seabeds
  - often require minimal processing
  - tend to be smooth and rounded

Aggregate Production

- Crushed rock
  - typically produced by crushing quarried rock or cobbles and boulders
  - tend to be sharp and angular

Aggregate Production
Crushed Rock

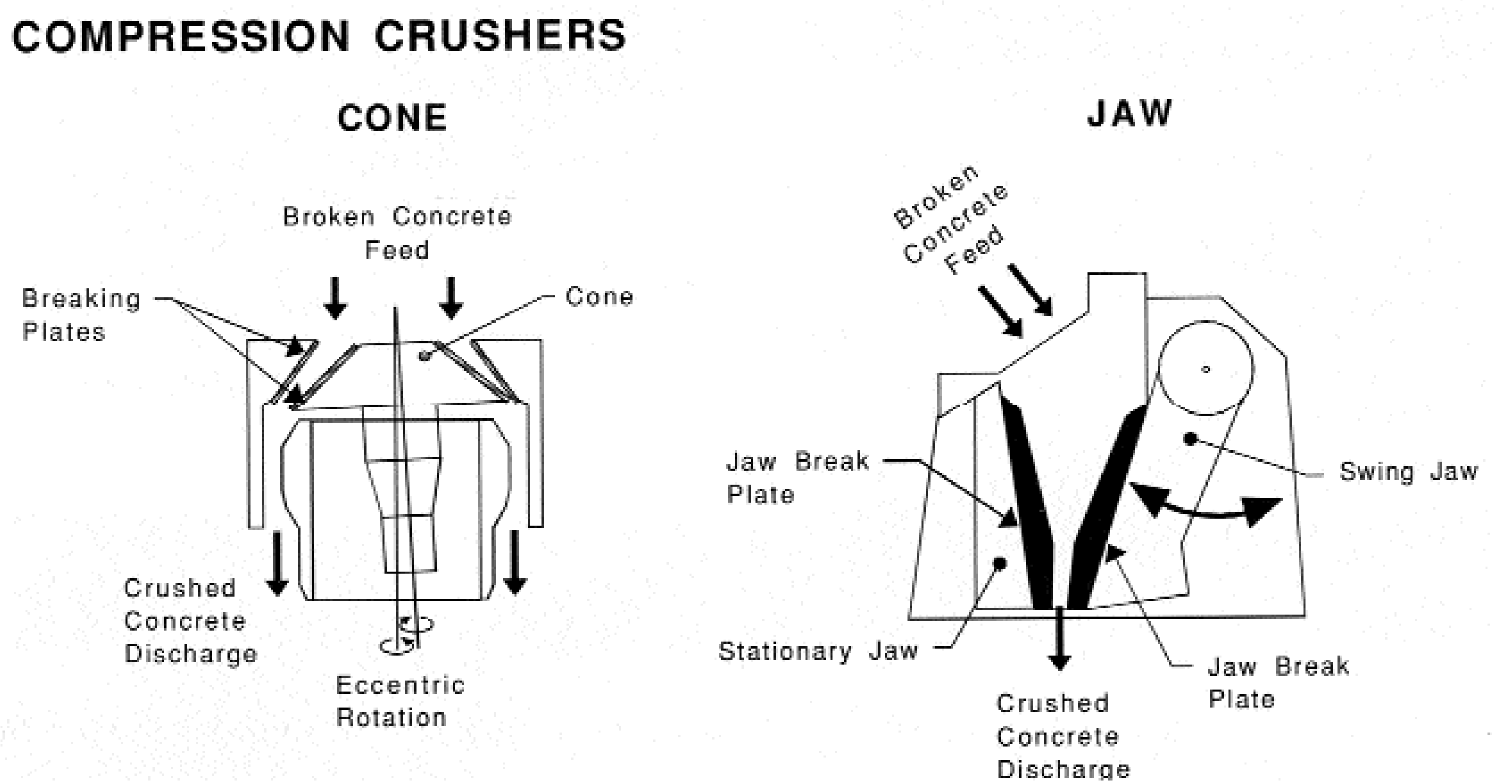
- Initial processing to obtain suitable grading, uniformity and cleanliness
    1. Crushing
    2. Screening
    3. Washing
- Aggregate beneficiation

Aggregate Production
Crushed Rock

1. Crushing

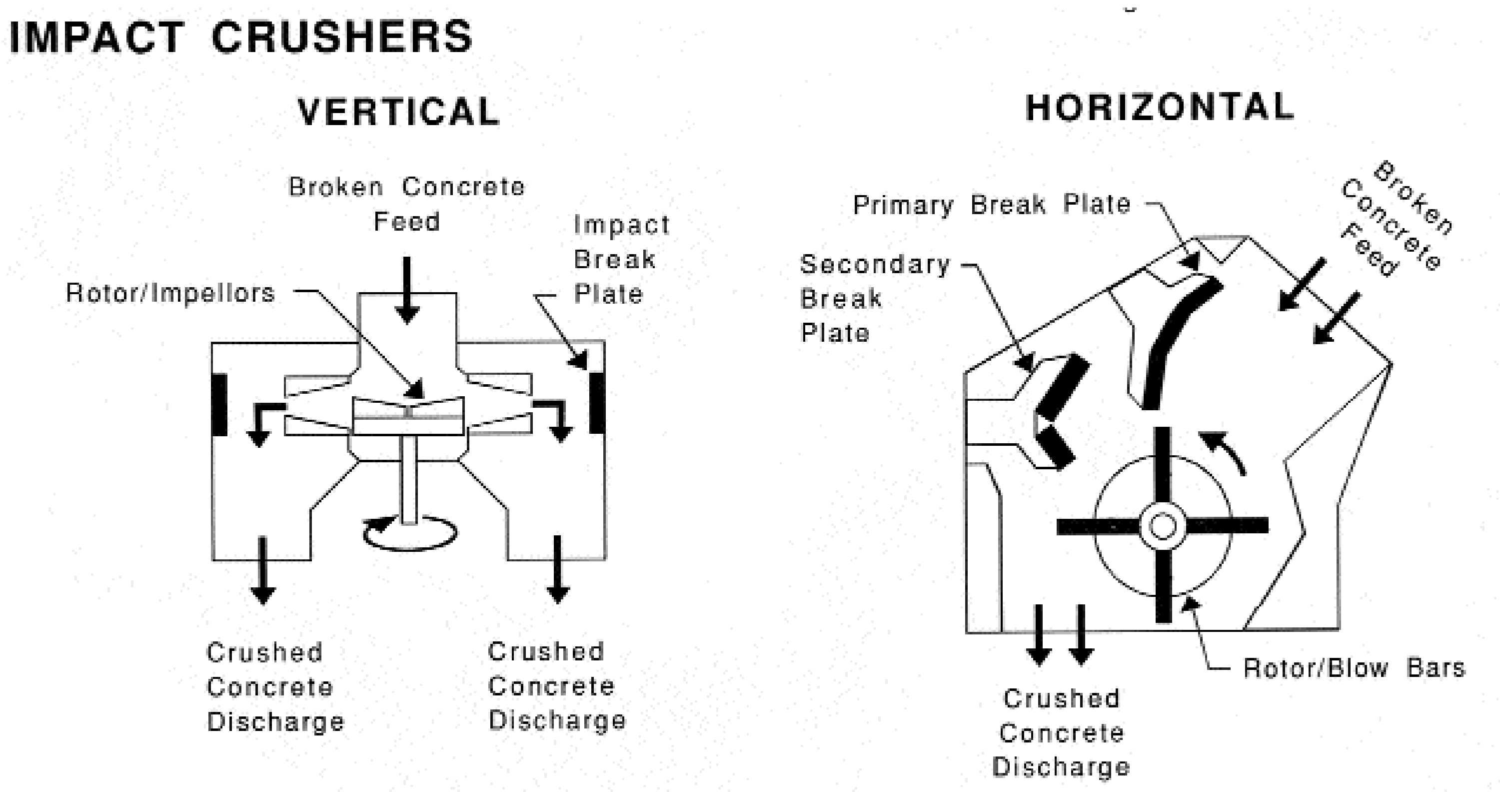
Aggregate Production Crushed Rock

1. Crushing



Aggregate Production
Crushed Rock

1. Crushing



Aggregate Production Crushed Rock

2. Screening– Vibrating screens

Aggregate Production
Crushed Rock

2. Screening– Cylindrical revolving screens

Aggregate Production
Crushed Rock

3. Washing

Aggregate Production
Crushed Rock

- Aggregate beneficiation
  - applying processing methods to upgrade the quality of the aggregates
  - typically involves removal of undesirable or deleterious particles

Aggregate Production Crushed Rock

- Aggregate beneficiation

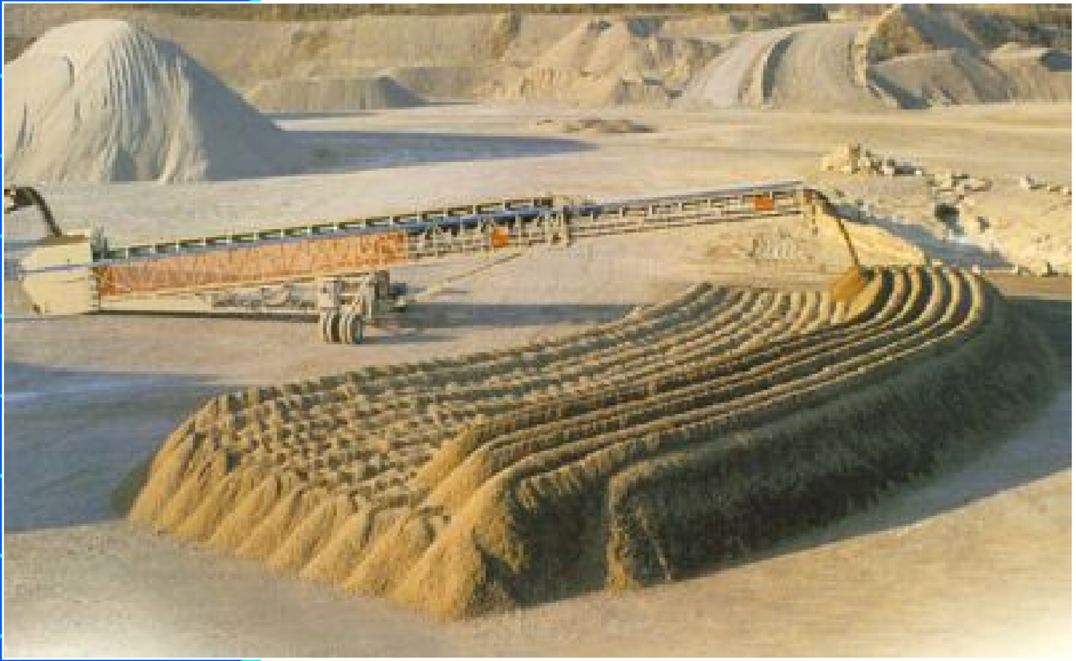
Treatment	Objective
Crushing	Remove friable particles
Heavy media separation	Remove lightweight particles
Reverse air or water flow	Remove lightweight particles
Hydraulic jigging	Remove lightweight particles
Elastic fractionation (bounce)	Remove lightweight and soft particles
Washing and scrubbing	Remove coating and fines
Blending	Control deleterious components
Screening	Control gradation

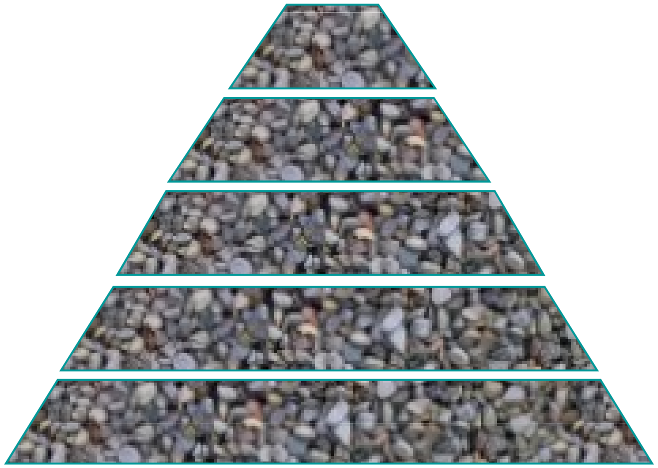
Aggregate Production
Crushed Rock

- Aggregate beneficiation

Aggregate Storage and Handling

- Build stockpiles in thin layers of uniform thickness





Aggregate Storage and Handling

- Retrieve samples from edges of pile, bottom to top

Aggregate Storage and Handling

- Stockpiling separate size fractions can minimize segregation of coarse aggregates

Aggregate Storage and Handling

- Damp sand segregates less than dry sand

Aggregate Storage and Handling

- Crushed aggregate segregates less than rounded aggregate

Aggregate Storage and Handling

- Bulkheads or dividers minimize cross-contamination of stockpiles

Aggregate Physical Properties

Aggregate Physical Properties

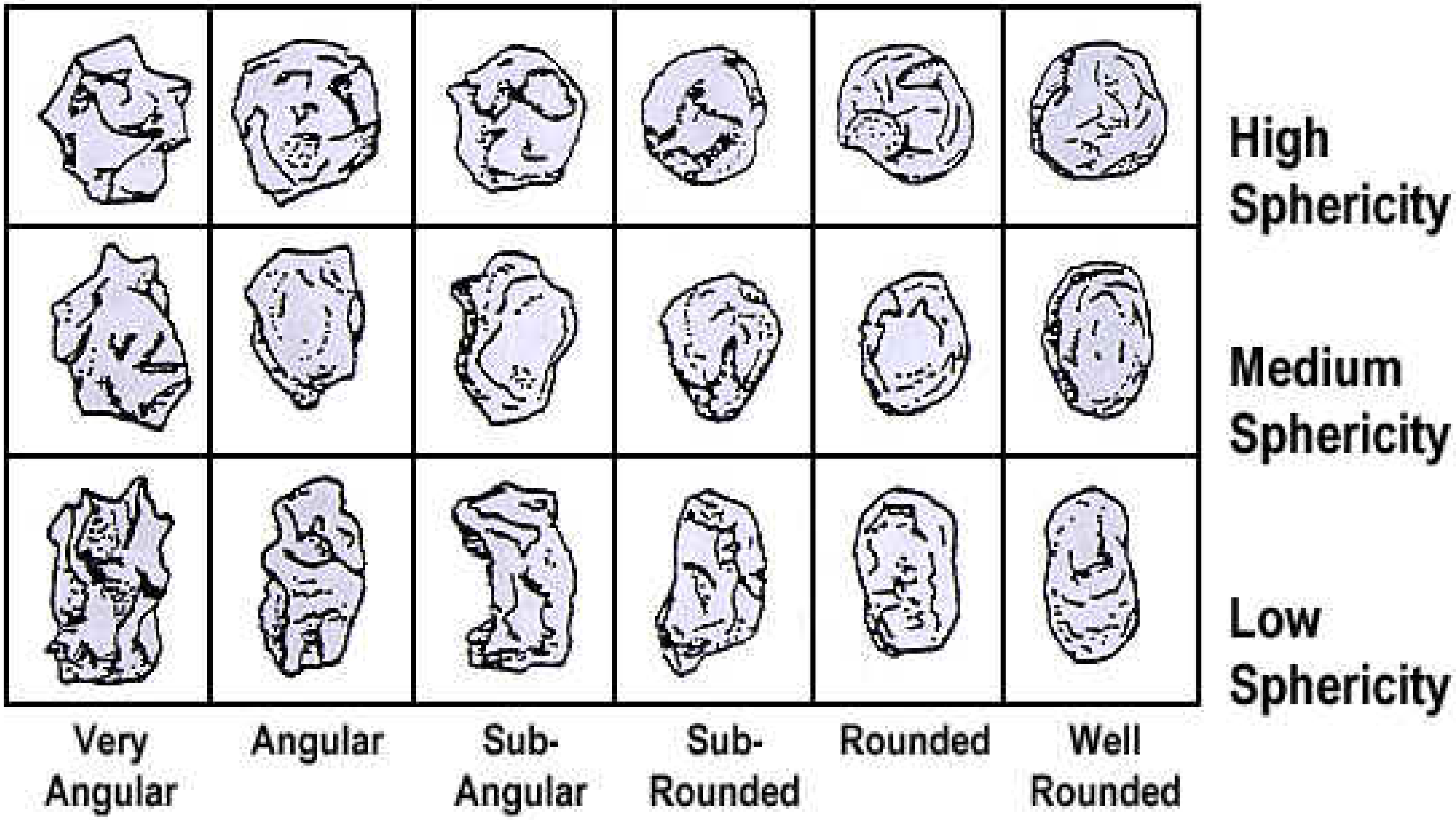
- Particle shape and surface texture
- Bulk density and relative density
- Absorption and surface moisture
- Shrinkage
- Strength and hardness
- Thermal properties
- Grading
- Resistance to freezing and thawing
- Volume stability
- Abrasion and skid resistance
- Resistance to corrosive substances

Particle Shape

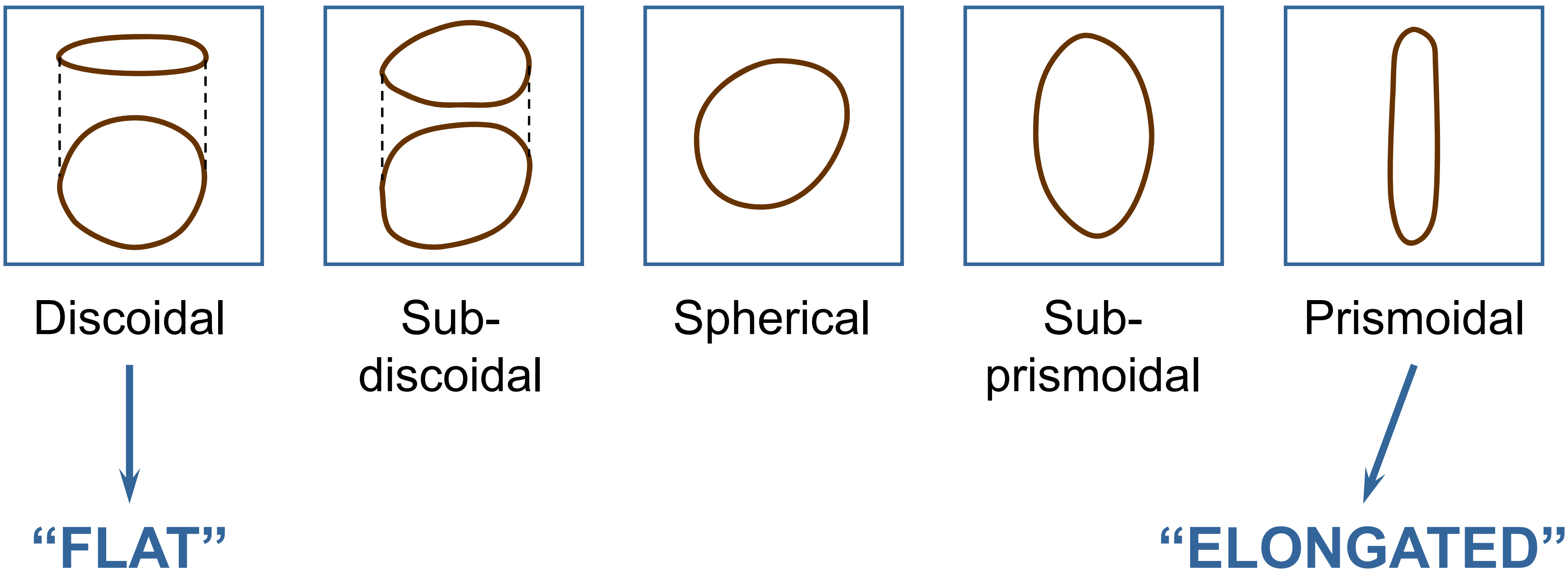
Classifications

- Rounded
- Irregular
- Angular
- Flat
- Elongated
- Flat and elongated

Particle Shape



Particle Shape



Particle Shape

Flat and elongated particles

- Significantly affect workability and pumpability
- May trap bleedwater and contribute to mortar flaking
- Limited to less than 15% of total aggregate mass

Surface Texture

Classifications

- Glassy
- Smooth
- Granular
- Rough
- Crystalline
- Honeycomb

Surface Texture

Smooth Surface

Surface Texture

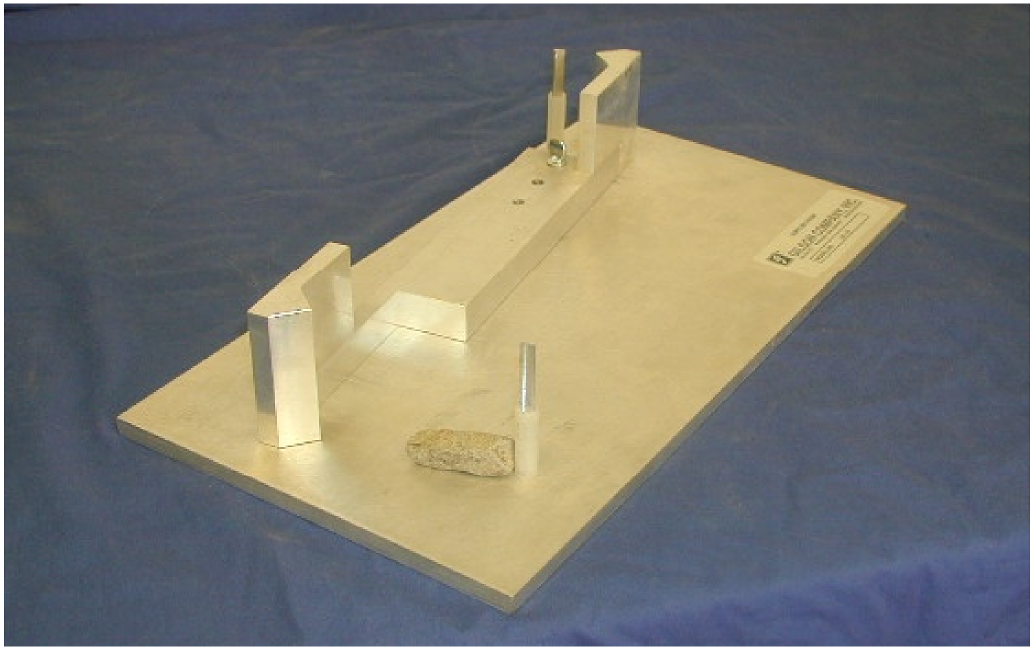
Rough Surface

Particle Shape & Surface Texture

- Can significantly affect fresh concrete properties
- Rough, angular particles:
  - Have more interparticle interaction and greater resistance to movement
  - Require more lubrication (paste & water)
  - Have larger surface-to-volume ratio
  - Requires more paste to coat aggregate
  - Generally achieve improved bond with cement paste
  - Generally provide greater flexural strength

Particle Shape & Surface Texture

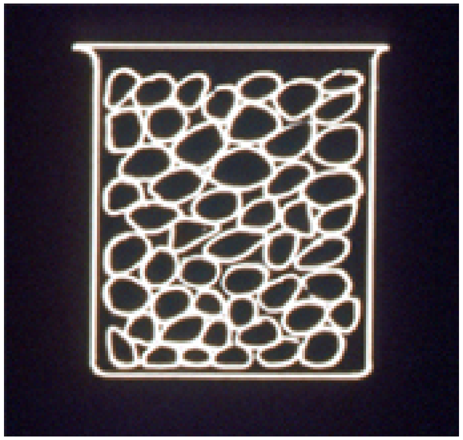
ASTM D4791: Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate



Particle Shape & Surface Texture

ASTM C1252: Standard Test Method for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)

Bulk Density

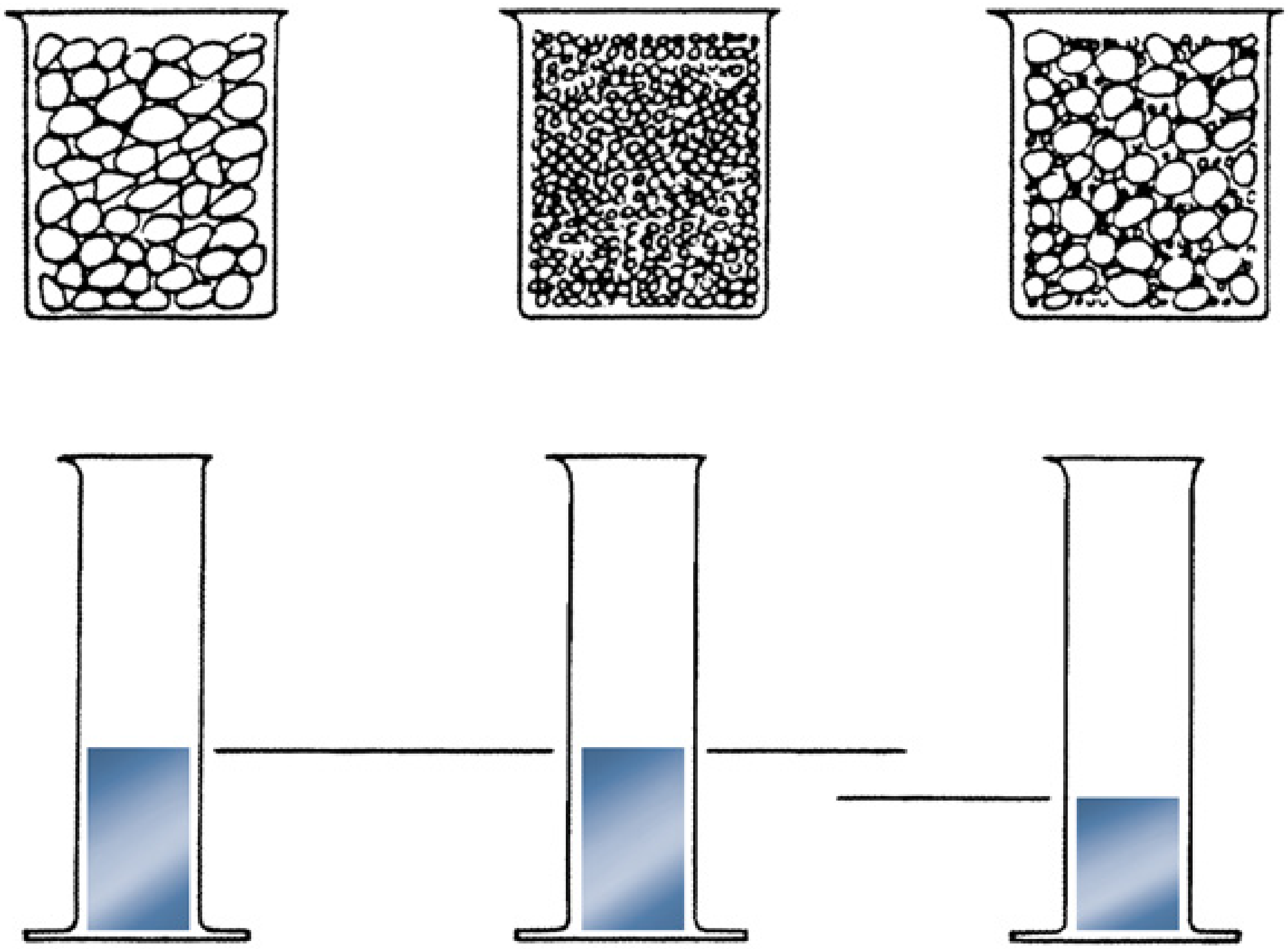


- Also called unit weight
- Mass or weight of aggregate per unit volume
- Volume occupied by both aggregate particles and voids between particles
- Void content:
  - 30 to 45% for coarse aggregate
  - 40 to 50% for fine aggregate

Bulk Density

- Angularity increases void content
- Large top size, even gradation decreases voids, increases bulk density
- Normal-weight: 1200 to 1700 kg/m^3 (75 to 110 lb/ft^3)
- ASTM C29: Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate

Bulk Density



Relative Density

- Also called specific gravity
- Ratio of mass of aggregate to equal volume of water
- Used in absolute volume method of mix design
- Normal-weight: 2.4 to 2.9

Relative Density
(Mass Density)

- Mass density is product of specific gravity and density of water

$$Density_{agg} = S.G. \times Density_{H_2O}$$

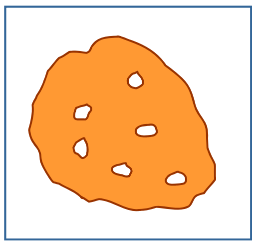
$$Density_{agg} = 2.5 \times 1000\ kg/m^3 = 2500\ kg/m^3 = 156\ lb/ft^3$$

- Normal-weight: 2400 to 2900 kg/m^3 (150 to 181 lb/ft^3)
- Mass density does not account for volume of voids between particles

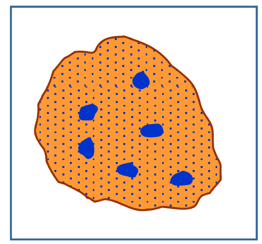
Relative Density

- ASTM C127: Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
- ASTM C128: Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate

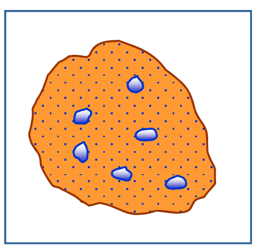
Absorption and Surface Moisture



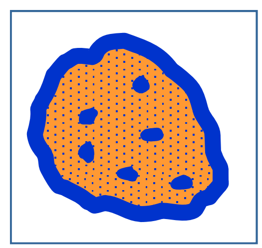
Oven dry
Aggregate contains no moisture (pores are empty)
Fully absorbent



Saturated surface dry (SSD)
Aggregate is saturated (pores are filled), but there is no free water on the surface
At equilibrium



Air dry
Aggregate contains some moisture, but is not saturated (pores are partially filled)
Somewhat absorbent



Damp or wet
Aggregate is saturated (pores are filled), and there is an excess of water on the surface
Contributing free water

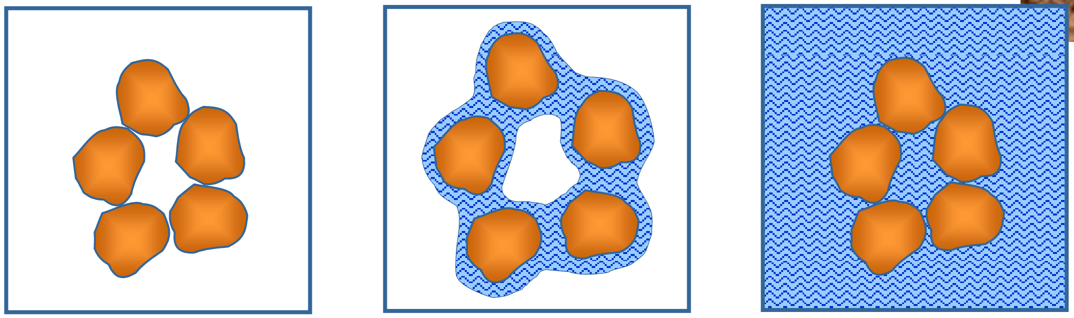
Absorption and Surface Moisture

- Moisture conditions ↔ Mix water
- ASTM C127 and C128
- Absorption ⇒ mass % of water to reach SSD
  - Coarse aggregate: 0.2 to 4%
  - Fine aggregate: 0.2 to 2%
- Free water content of moist aggregates
  - Coarse aggregate: 0.5 to 2%
  - Fine aggregate: 2 to 6%

Absorption and Surface Moisture

Bulking

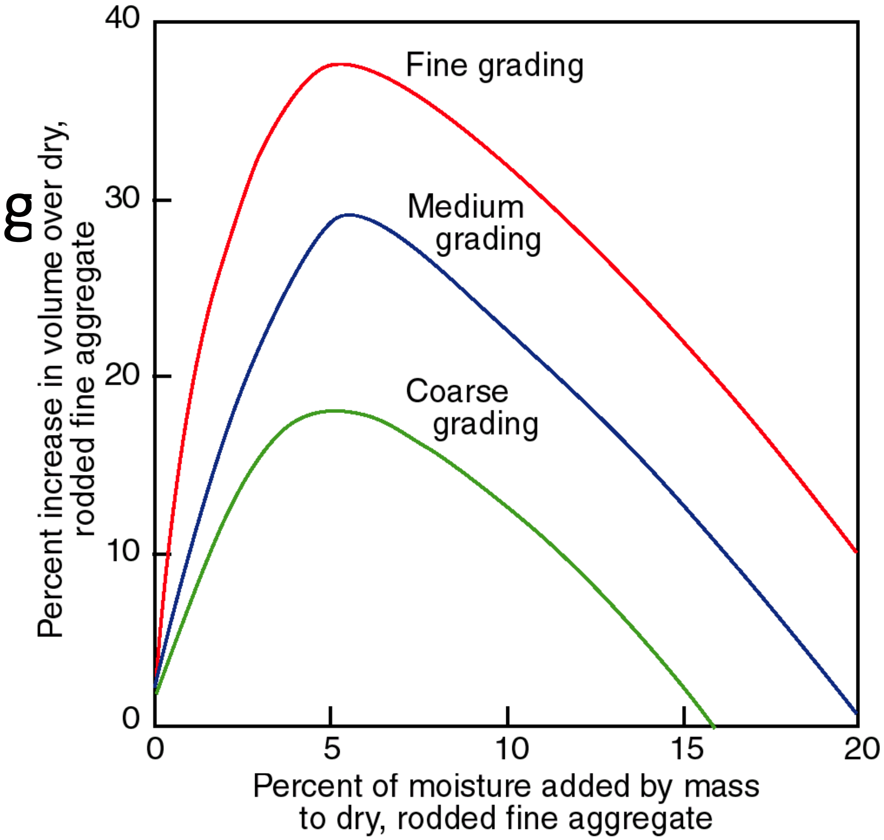
- Increase in total volume of fine aggregate when moist compared to same mass when dry



Absorption and Surface Moisture

Bulking

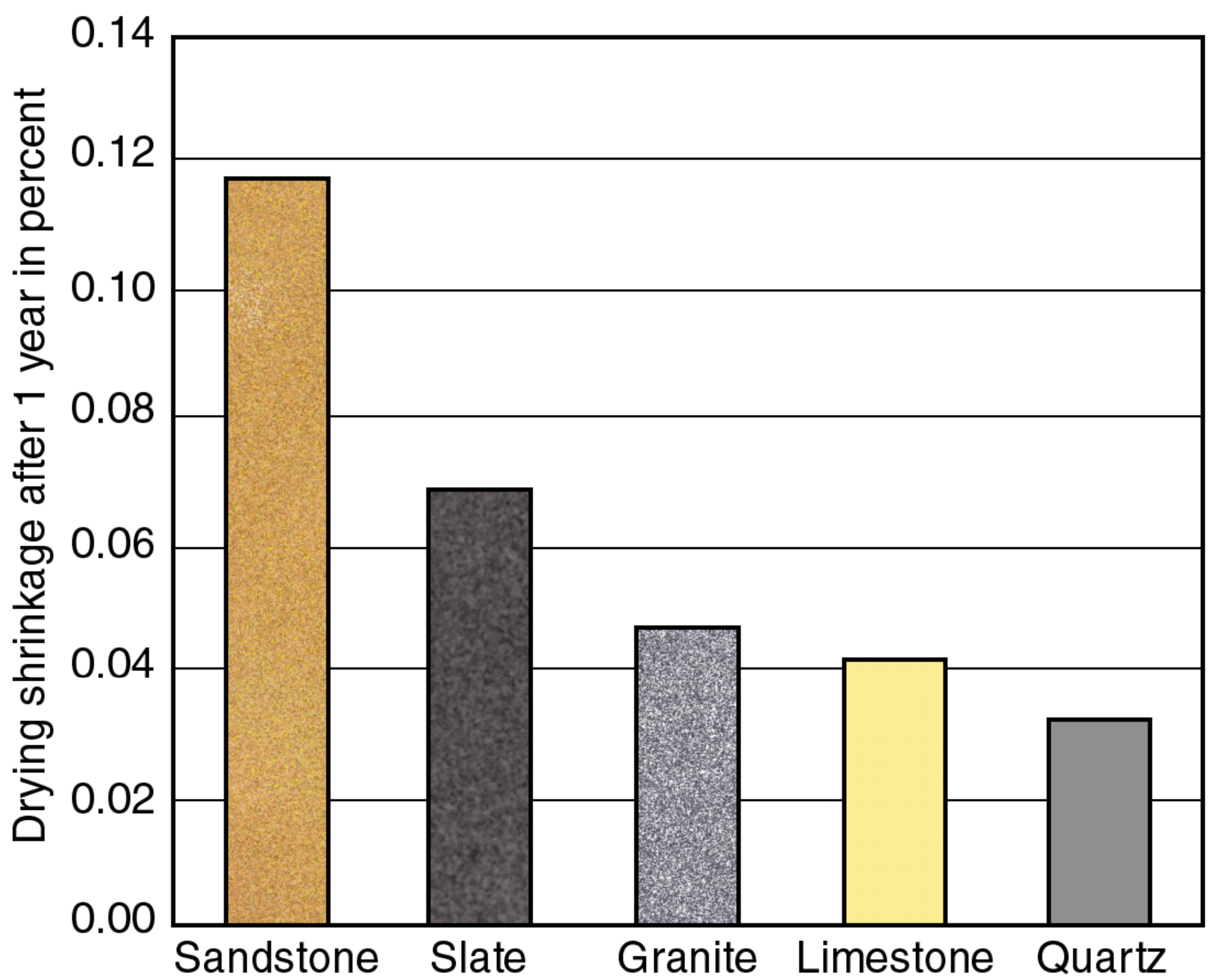
- Can cause batching errors
- Effect more prominent with finer gradations



Shrinkage– Aggregates

- Often related to absorption characteristics
- High absorption → high shrinkage
- Low shrinkage aggregates
  - Quartz
  - Limestone
  - Feldspar
  - Dolomite
  - Granite
- High shrinkage aggregates
  - Sandstone
  - Shale
  - Slate
  - Graywacke
  - Hornblende

Shrinkage– Concrete



Shrinkage– Concrete

Influenced by many aggregate characteristics

- Stiffness, compressibility, modulus of elasticity
- Grading, particle shape, aggregate top size
- Paste-aggregate bond (texture, porosity)
- Presence of clay on or within aggregate

Aggregate Strength

- Compressive: 65 to 270 Mpa (10,000 to 40,000 psi)
- Tensile: 2 to 15 Mpa (300 to 2,300 psi)
- Does not usually influence normal-strength concrete
- Rarely tested directly
- Paste hardness and paste-aggregate bond more critical

Aggregate Hardness

Mohs scale for ***minerals***

Relative Scale		Mineral	Common Object
Hardest	10	Diamond	
	9	Corundum	
	8	Topaz	
	7	Quartz	
	6	Potassium feldspar	Glass, pocket knife (5.5)
	5	Apatite	
	4	Fluorite	
	3	Calcite	Copper penny (3)
	2	Gypsum	Fingernail (2.5)
Softest	1	Talc	

Aggregate Hardness

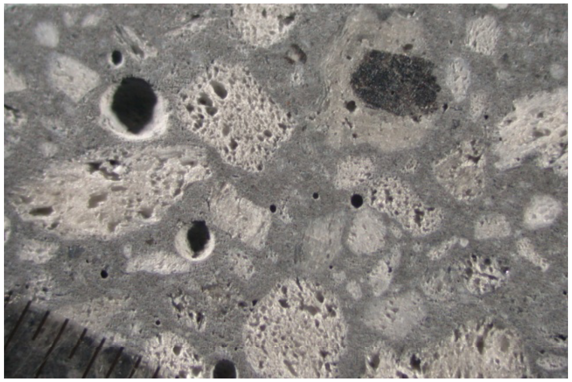
- Hard to quantify for rocks
- Varies with rock type
- Soft and friable particles
  - Prone to crumbling
  - Increase fines content
  - ASTM C33 limits mass %
- Will affect abrasion resistance

Aggregate Thermal Properties

- Coefficient of thermal expansion (CTE)
  - ~1 to 16 $x10^{-6}$/°C (~2 to 29 $x10^{-6}$/°F)
  - CTE of paste and aggregate vary greatly
  - Strongly influences CTE of concrete
- Conductivity
- Diffusivity
- Properties depend somewhat on aggregate mineralogy

Aggregate and Fire Resistance

- Manufactured and lightweight aggregates have better insulating properties
  ⇒ provide greater fire resistance



- Quartz expands 0.85% at ~570°C (1060°F)
  ⇒ concrete with calcareous coarse aggregate often exhibits less damage after fire than concrete with siliceous aggregate

Summary

- Aggregates comprise 60 to 75% of concrete volume
- Aggregates influence fresh and hardened concrete properties

Summary

- Rocks are naturally occurring assemblages of one or more minerals
- Rocks grouped by mode of formation
  - Igneous
  - Sedimentary
  - Metamorphic

Summary

- Aggregates most often natural sand and gravel, or crushed rock
- Aggregate is often processed to achieve desired quality, uniformity, and gradation

Summary

- Physical properties of aggregate include:
  - Particle shape and surface texture
  - Bulk density and relative density
  - Absorption and surface moisture
  - Shrinkage
  - Strength and hardness
  - Thermal properties

Summary

- Physical properties of aggregate may influence mix design process and overall properties of concrete