UTILIZATION OF GEOLOGIC MATERIALS

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Contents

Summary

The major use of geologic materials such as rock, gravel, sand and clay is in construction of roads, buildings, embankments and dams. To ensure that the structure has permanence, the material used must be of sufficient quality and durability to withstand the rigors of the environment and stresses the use.

All major rock types, igneous, metamorphic, and sedimentary are used in construction, either as dimension stone or as crushed stone. The rock is used by itself, or in combination with cement or bituminous mix. The rock must withstand repeated wetting and drying, freezing and thawing, abrasion, and chemical attack.

Chemical composition, porosity, absorption and adsorption, permeability, density and chemical resistance are the principal properties considered in evaluation the durability of geologic materials. Various rapid tests have been devised to simulate the environment of use and the rocks' response to it to ensure that the rock will remain durable in use.

Sand and gravel on one hand, and soil and clay on the other are the other major geologic materials used in construction. The former is used as crushed stone above, and soil and clay are used as fill, in embankments, and dams. Clay type and proportion, and particle size distribution are the main parameters for this use.

1. Introduction

Geologic materials have been first utilized by humans as tools for hunting, such as axes, arrowheads, scrapers made from hard rocks and minerals such as chert, flint, obsidian, and quartzite. Clays were used in early pottery making. When the humans formed first organized groups and settlements, permanent shelters became a necessity. The first structures were simple mud huts, but quickly progressed to more elaborate buildings as hierarchical structure and religion developed. The use of stone in the form of field stone, and later dimension stone culminated in such elaborate structures as the pyramids of Egypt, Yucatan, and Peru. To bind the solid rock pieces in building construction, clay was initially used as a cementaceous material, followed by burnt lime mixed with sand to form lime mortar, and ultimately, cement was perfected by the Romans, using limestone and volcanic ash as raw materials to produce a strong, durable binder. The combination of cut stone and binding materials were used to construct large structures such as castles for defense, permanent bridges over rivers, and viaducts for water supply.

As needs for transport routes evolved, the building of roads utilized stone of all varieties as the top surface layer on which wheeled conveyances of various types could travel with ease. The use of stone, sand and gravel for road construction remains the chief use of these geologic materials till the present.

Other major structures utilizing large amounts of geologic materials are dams. Rock dams need a substantial quantity of durable stone, as do massive masonry dams. Earthen dams utilize large volumes of soil and clay.

The geologic materials discussed in this paper fall under the general category of "industrial rocks and minerals". Emphasis is on rocks and minerals used in large volume, generally for construction. Specifically excluded are metallic minerals (ores), and non-metallic minerals used for specialized applications, such as abrasives, chemicals, ceramics, etc.

NOTE: In the electronic version of this report, some of the key words in this paper are hyper-linked to WEB pages that enlarge and explain the concepts to a greater degree than is possible within the confines of the paper. In the print version, the links in the text are underlined. The Web links to the keywords are also provided in a separate section for those reading the paper version. The author will strive to keep the links current for the foreseeable future. More detailed discussion of construction materials description, properties, durability, experimental data and references to other work is available on author's web site at http://web2.uwindsor.ca/courses/earth_science/hudec/

2. Origin of Geologic Materials

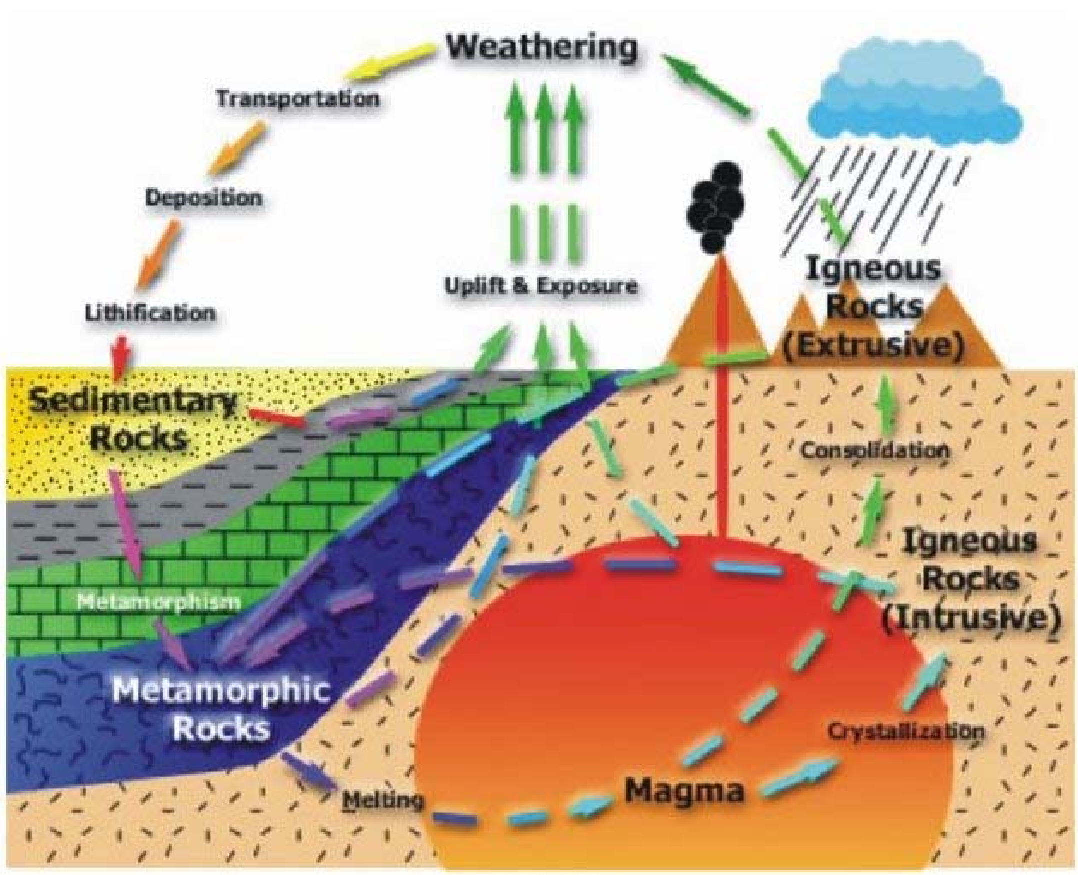

Figure 1. Rock Cycle (from National Science Teachers Association web site http://www.minsocam.org/MSA/K12/rkcycle/rkcycleindex.html)

All geologic materials are part of the geologic rock cycle that started when the earth's crust was first formed, and continues today. Rocks formed from magma are generally considered as the beginning of the cycle, but as soon as the rock forms, it is subject to erosion, resulting in sediment which gets buried, lithified into sedimentary rock, which is either eroded or buried deeper and metamorphosed; the metamorphic rock can be buried further and re-melted, or exposed and eroded into sediment. The rock cycle is shown in Figure 1.

Geologic materials can roughly be classified into consolidated, cemented deposits (rocks), and unconsolidated, mostly surface deposits (soils, as used in engineering sense). There are, of course, instances where a poorly consolidated or cemented deposit would fall between these two broad categories. Rocks, in turn, are classified by their origin: igneous, or those formed from a molten lava or magma; sedimentary, those formed in water or wind deposited and subsequently lithified into solid rock; and metamorphic, where both igneous and sedimentary are transformed under heat and pressure. All rock types have a utilization potential, but are not suitable for given use. Igneous and metamorphic rocks tend to be harder, stronger, and more brittle, more resistant to abrasion, whereas sedimentary rocks are often softer, more porous, and sometime less durable.

The uses of unconsolidated material are many and varied, depending on the nature of the material, which is principally determined by its grain size and mineralogy. The grain size can vary from clay size (less than .005 mm diameter: geologists' classification; engineer's use 0.002 mm for clays)) to cobble and boulder size. The mineralogy can vary from almost mono-mineralic in some type of clays, such as kaolinite, to multi-mineralic or multi-lithic (i.e., containing fragments of different rocks), as in most sands and gravels.

2.1. Rock Origin and Classification:

2.1.1. Igneous Rocks

Igneous rocks form from a melt, either deep in the crust or at the surface. Magma is the source of all igneous rocks. If the magma cools and solidifies before reaching the surface, a class of intrusive igneous rocks formed. These rocks are generally coarse grained, with grain sizes generally varying from 0.1mm to 10mm. Exceptionally coarse igneous rocks are called pegmatites, in which individual crystals can range to several meters in size. When magma reaches the earth's surface, it can create lava flows, or ash deposits (tuffs), each of which results in a class of extrusive volcanic rocks. Extrusive rocks are generally fine grained, less than 0.1mm in size to almost glassy. Ash deposits (pyroclastic rocks, collectively known as **tuffs**) are also fine grained, but may contain small pieces of lava or shards of volcanic glass, and young, fresh tuffs can be very porous.

The igneous rocks are further classified according to their mineralogy. Light colored igneous rocks usually contain quartz and white or flesh-colored feldspar and a small amount of dark minerals such as biotite or hornblende. Dark colored rocks contain a larger proportion of dark minerals such as pyroxene, hornblende, and biotite, white or green feldspar, and little or no quartz. A simple classification table of igneous rocks is given in Table 1

	Light Colored	**Intermediate**	**Dark Colored**
Intrusive	Granite, granodiorite	Diorite	Gabbro
Extrusive, lavas & tuffs	Rhyolite	Andesite	Basalt

Table 1. Igneous rock Classification

Igneous rocks occur in areas of recent or past volcanism, in mountainous regions, and in the Precambrian shield areas of the world. For detailed description of igneous rocks and processes, go to the websites below:
http://csmres.jmu.edu/geollab/Fichter/IgnRx/Ighome.html and http://en.wikipedia.org/wiki/Igneous_rocks

2.1.2. Sedimentary Rocks

Sedimentary rocks, as the word implies, are formed from sediments deposited in marine, lacustrine (lake), or terrestrial environments. The sediments are compressed by overlying weight of sediments, and their particles are cemented by minerals precipitating out of pore solutions to produce solid sedimentary rock. Depending on the environment of formation, nature of sediments, and the cementing minerals, a wide variety of sedimentary rock types are formed.

2.1.2.1. Marine Origin Sedimentary Rocks

Marine sedimentary rocks are the most abundant of all rock types. At different times during earth's history, the continents were flooded by shallow seas into which rivers brought sand, silt and clay and dissolved elements that spread over the sea bottom in near-shore environments. Warm tropical seas were abundant with life, and shells of organisms were incorporated into the bottom sediment. Dissolved calcium carbonate (and to some extent silica) brought in by rivers precipitated as lime (and silicate) muds in more distant, off-shore locations. Organisms living in colonies produced reefs that became progressively buried in the sediments.

Marine sedimentary rocks can thus be divided into those formed from river-derived sediments (detrital) and those precipitated out of seawater (**biogenic or chemical**). The detrital rocks take their name from the sediment from which they were derived. Thus sand gives rise to sandstone, and silt to siltstone. Clay can produce mudstone or a more compacted shale. Coarse gravels are lithified into conglomerate. Examples of chemical rock include the common limestone (and dolostone), and less common gypsum and rock salt. Limestone is formed from precipitated calcite mud containing shells or organism. Dolostone is not a primary precipitate, but subsequent replacement of calcite for dolomite by magnesium-rich solutions percolating through lime muds and limestone. Precipitated silica in form of chert forms nodules, bands, or beds, usually within limestone. Shells of organisms are often found embedded within limestone, siltstone, mudstone and shale, and less often in sandstone. Rocks containing almost exclusively shells of organisms are cemented together to form coquina, or may form detrial mounds (**biohermal limestone**) near fossil reefs cemented with lime mud. The latter two can result in a very porous rock, depending on the degree of cementation. Dolostone, which is a magnesia-altered recrystallized limestone, is often crystalline and medium grained.

Sedimentary rocks are usually found on stable cratons of continents, or in relatively young, high mountains chains, such as the Cordillera of North and South America, the Alps, and the Himalayan Mountains.

2.1.2.2 Continental Origin Sedimentary Rocks

Sediments deposited on continents are also compacted and cemented into sedimentary rocks. The most common of these are sandstones originating from sand dunes and lake deposits. Lake deposits of silt and shale also result in equivalent siltstones, mudstones, and shales. Travertine deposits form mounds around hot spring in active or former thermal areas of the continents. In some areas, such as Canada, India, and South Africa, glacial tills from Permian glacial period were lithified into tillite.

For a more in-depth description and discussion of sedimentary rocks and processes, go to websites:
http://csmres.jmu.edu/geollab/Fichter/SedRx/index.html, or http://en.wikipedia.org/wiki/Sedimentary_rocks

2.1.3. Metamorphic Rocks

Most of the rock types mentioned above can be transformed (metamorphosed) under heat, pressure, and directional stress into metamorphic rocks. The agents of metamorphism depend on the depth of burial, proximity to magma chambers, and the presence and type of interstitial fluids. Metamorphism can be regional or local, and mainly thermal or pressure-induced. Local thermal metamorphism occurs around bodies of intrusive igneous rocks. There are several grades of metamorphism, dependent on the severity of or intensity of these agents, and the reactivity of the rock to them. Sandstone, for instance, is least affected, and may simply be re-cemented into a very hard quartzite; pure limestone may recrystallize into compositionally identical marble. Shale is metamorphosed into slate or phyllite. Other rock types can undergo profound changes, especially under high degree of metamorphism. Such diverse rock types as siltstone, shale, light colored volcanic flows and tuffs can all be metamorphosed into similar looking schists and gneisses. Bulk chemical composition of such metamorphosed rock may remain the same as the parent rock, or may be changed by infusion of fluids from adjacent rocks or magma bodies.

Metamorphic rocks often exhibit a preferred orientation of minerals within them, giving the rock a pronounced banding and/or foliation. If the rock contains an abundance of preferentially oriented platy minerals such as mica or chlorite, the foliated rock is called a schist. Metamorphic banding is generally compositional: alternating bands of mostly dark foliated minerals with bands containing lighter minerals. Such banded rock is called a gneiss. Monomineralic rocks such as quartzites and marbles have a massive appearance and may not show any preferred orientation or banding of their minerals. .

Volcanic origin rocks such as basalts and andesite can metamorphose into either gneisses, schists, or simply recrystallize with no preferred orientation. Shales and mudstones can progress from indurated shales to slate**,** phyllite, and then to schist and/or gneiss.

The ultimate degree of metamorphism results in partial or full melting of the rock resulting in a granite-like, diffusely banded rock called granulite, migmatite, and ultimately granite. The amount of granite found in shield areas of ancient mountain chains produced by re-melting of pre-existing rock versus that produced by magmatic emplacement is still under debate, since the end product is indistinguishable.

Metamorphic rocks occupy vast regions in the Precambrian shield areas of all major continents. The shield areas represent eroded roots of several accreted ancient mountain chains formed in the early history of the earth. The rocks found on the surface today were buried under several tens of kilometers of mountains' mass and were gradually exposed by eons of erosion. Younger mountain chains such as the Appalachians and the Urals are partially eroded, and the rocks now exposed were subjected to medium levels of metamorphism.

Further discussion of metamorphism and metamorphic rocks can be found at the following websites:
http://csmres.jmu.edu/geollab/Fichter/MetaRx/index.html or
http://en.wikipedia.org/wiki/Metamorphic_rocks

2.2. Unconsolidated Material Origin and Classification

All rocks are subject to weathering and erosion by water, wind, and ice. Weathering is both mechanical and chemical, depending largely on the climate. The products of erosion are rock particles broken down into their individual minerals, chemically altered, or preferentially dissolved in water to be carried and re-precipitated in lakes and oceans.

Mechanical weathering is the process of size reduction of large rock mass into smaller pieces without chemical change; compositionally, the smaller particles are identical to the parent rock mass. The agents of mechanical weathering are abrasion, freezing and thawing, and thermal differential expansion and contraction. Mechanical weathering is prevalent in cooler climates. Glacial erosion is a particular form of mechanical weathering. Glaciers, as they move, grind the rock into coarse and fine fragments which are carried in the ice to be deposited under the ice, or near the glacial terminus as the ice melts. The different modes of erosion, transportation, and deposition result in a variety of unconsolidated detrital deposits.

Chemical weathering involves selective dissolution of some rock minerals, and chemical alteration of others. Some minerals in rocks formed at high temperature are relatively unstable at the ambient conditions of the earth’s surface, and in the presence of water and in warm climate are transformed into minerals that are more in equilibrium with the prevalent conditions. Some minerals, such as quartz are relatively immune to chemical changes, and weather out mostly unchanged.

Weathering products either remain in place, such as residual soils (laterites) in tropical regions, or are transported and re-deposited by wind and water.

2.2.1. Alluvial Deposits

Alluvial deposits of sand, gravel, silt and clay are deposited by running water in floodplains, banks, and beds of streams and rivers. The particles are rounded by abrasion, and the particle size is well sorted by the velocity of the water flow. The composition of the deposit is determined by the source material: the course pebbles, cobbles, and boulders comprising the gravel deposit reflect the composition of the formational rock types upstream. The finer sand and silt are derived from physical and chemical decomposition of the rocks; clays generally represent the end products of chemical weathering of upstream rocks. Alluvial deposits of any one portion of a river are often highly variable, alternating beds of gravel, sand, silt and clay, deposited as the velocity of the water changed. Mechanism of erosion, transport, and deposition of water-borne deposits are explained in:
http://en.wikipedia.org/wiki/Sediment

2.2.2. Lacustrine Deposits

As the rivers enter standing bodies of water such as lakes and seas, their load is deposited in the low velocity environments of these bodies. Waves powered by prevalent winds and storms redistribute the detritus along the shoreline, and sort the material into boulders, cobbles, pebbles, sand, silt. Having been transported a long distance in the rivers, and subsequently along the shore, the particles are well rounded, and contain the more weathering resistant rocks and minerals. The particle size found on the shore reflects the energy regime of the waves: the wave-lashed promontories and headlands have little fine sediment, and mostly, coarse boulders and cobbles, whereas quiet bays contains finer sands, silts, and clays. Local component eroded from the shore is incorporated into the shore material. In tropical areas with offshore reefs and abundant marine mollusks, the shore deposits are composed of wave-eroded and broken fragments of reefs and shells, and derived sands, containing principally minerals calcite and aragonite.

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Biographical Sketch

Peter P. Hudec received his B.Sc. (Honors) degree in geology from the University of Western Ontario in 1958, London, Ontario, Canada, and M.S. in 1960 and PhD in 1965 from Rensellear Polytechnic Institute, Troy, New York, U.S.A. While engaged in academic studies for the above degrees, he led and conducted mapping and mineral exploration parties throughout the Canadian north. From 1965 to 1970, he was a principal partner in the consulting firm of Dunn Geoscience in New York, specializing in exploration for base metals and construction aggregate. From 1970 to 2001, he taught undergraduate and graduate course in geology and geological engineering at the University of Windsor, Windsor, Ontario, rising to the rank of full professor. His principal research interests are in the field of rock aggregate properties and durability. He has supervised a large number of B.Sc., M.Sc. and Ph.D. theses and students, and has published over 100 articles in scientific journals. He supported his and his students' research with grants totaling $950,000. Now retired, he remains a Professor Emeritus at the University of Windsor.