



G. PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

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Department of Civil Engineering

Bridge Course
On
Engineering Geology

Introduction

Engineering geology is the application of geological knowledge in engineering works. It has wide applications in various engineering fields especially in urban planning and expansion. Site investigation for major structures such as dams, factories, and heavy buildings is one of the main parts of engineering applications. Others include earth material characterization, exploration and assessment of construction materials and assessment of difficult grounds such as expansive and collapsible soils. The obtained information can be presented in a form of engineering geological maps, which is essential in several projects. Engineering geology is the application of geology in design, engineering geological studies may be performed during the planning, construction and performance of civil engineering works. environmental impact analysis, civil or structural engineering design, value engineering and construction phases of public and private works Soil/Rock deformability pattern, stability are main concern of projects, and during post-construction and forensic phases of projects. The first book entitled Engineering Geology was published in 1880 by HISTORY OF ENGINEERING GEOLOGY. The first American engineering geology text book was written in 1914 William Penning. The need for geologist on engineering works gained worldwide by Ries and Watson. Attention in 1928 with the failure of the St. Francis dam in California, the engineering failures which occurred the following years also and the loss of 426 lives prompted the requirement for engineering geologists to work on large engineering projects.

Importance of Engineering Geology in Development

- To recognize potential difficult ground conditions prior to detailed design and construction
- It helps to identify areas susceptible to failure due to geological hazards
- To establish design specifications
- To have best selection of site for engineering purposes

Basic Methods Used By Engineering

Geological field mapping of geological structures, formations, soil units and review of Geological literatures, maps, Geotechnical reports, engineering plans, hazards. environmental reports, Arial photographic studies, remote sensing data, The surface and subsurface investigations as the excavation, sampling and logging, topographical map etc. of earth/rock materials in drilled borings, backhoe test pits and trenches, fault Deformation monitoring of soil (Plate load Test), Rock on surface & Geophysical survey. Trenching, and bulldozer pits, Geomechanical test, hydrological tests etc. & Recommendation for safety measures.

Weathering

Weathering is the breaking down or dissolving of rocks and minerals on Earth's surface. Water, ice, acids, salt, plants, animals, and changes in temperature are all agents of weathering. Once the rock has been broken down, a process called erosion transports the bits of rock and minerals away. Two important classifications of weathering processes exist – physical and chemical weathering; each sometimes involves a biological component. Mechanical or physical weathering involves the breakdown of rocks and soils through direct contact with atmospheric conditions, such as heat, water, ice and

pressure. The second classification, chemical weathering, involves the direct effect of atmospheric chemicals or biologically produced chemicals also known as biological weathering in the breakdown of rocks, soils and minerals. While physical weathering is accentuated in very cold or very dry environments, chemical reactions are most intense where the climate is wet and hot. However, both types of weathering occur together, and each tends to accelerate the other. For example, physical abrasion (rubbing together) decreases the size of particles and therefore increases their surface area, making them more susceptible to rapid chemical reactions. The various agents act in concert to convert primary minerals (feldspars and micas) to secondary minerals (clays and carbonates) and release plant nutrient elements in soluble forms. The materials left over after the rock breaks down combined with organic material creates soil. The mineral content of the soil is determined by the parent material; thus, a soil derived from a single rock type can often be deficient in one or more minerals needed for good fertility, while a soil weathered from a mix of rock types (as in glacial, Aeolian or alluvial sediments) often makes more fertile soil. In addition, many of Earth's landforms and landscapes are the result of weathering processes combined with erosion and re-deposition.

Physical weathering

Physical weathering, also called mechanical weathering or disaggregation, is the class of processes that causes the disintegration of rocks without chemical change. The primary process in physical weathering is abrasion (the process by which clasts and other particles are reduced in size). However, chemical and physical weathering often goes hand in hand. Physical weathering can occur due to temperature, pressure, frost etc. For example, cracks exploited by physical weathering will increase the surface area exposed to chemical action, thus amplifying the rate of disintegration.

Abrasion by water, ice, and wind processes loaded with sediment can have tremendous cutting power, as is amply demonstrated by the gorges, ravines, and valleys around the world. In glacial areas, huge moving ice masses embedded with soil and rock fragments grind down rocks in their path and carry away large volumes of material. Plant roots sometimes enter cracks in rocks and pry them apart, resulting in some disintegration; the burrowing of animals may help disintegrate rock. However, such biotic influences are usually of little importance in producing parent material when compared to the drastic physical effects of water, ice, wind, and temperature change.

Thermal stress

Thermal stress weathering (sometimes called insulation weathering) results from the expansion and contraction of rock, caused by temperature changes. For example, heating of rocks by sunlight or fires can cause expansion of their constituent minerals. As some minerals expand more than others, temperature changes set up differential stresses that eventually cause the rock to crack apart. Because the outer surface of a rock is often warmer or colder than the more protected inner portions, some rocks may weather by exfoliation – the peeling away of outer layers. This process may be sharply accelerated if ice forms in the surface cracks. When water freezes, it expands with a force of about 1465 Mg/m^2 , disintegrating huge rock masses and dislodging mineral grains from smaller fragments.

Thermal stress weathering comprises two main types, thermal shock and thermal fatigue. Thermal stress weathering is an important mechanism in deserts, where there is a large diurnal temperature range, hot in the day and cold at night. The repeated heating and cooling exerts stress on the outer layers of rocks, which can cause their outer layers to peel off in thin sheets. The process of peeling off is

also called exfoliation. Although temperature changes are the principal driver, moisture can enhance thermal expansion in rock. Forest fires and range fires are also known to cause significant weathering of rocks and boulders exposed along the ground surface. Intense localized heat can rapidly expand a boulder.

The thermal heat from wildfire can cause significant weathering of rocks and boulders, heat can rapidly expand a boulder and thermal shock can occur. The differential expansion of a thermal gradient can be understood in terms of stress or of strain, equivalently. At some point, this stress can exceed the strength of the material, causing a crack to form. If nothing stops this crack from propagating through the material, it will result in the object's structure to fail.

Mineralogy

Mineralogy is a subject of geology specializing in the scientific study of chemistry, crystal structure, and physical (including optical) properties of minerals and mineralized artifacts. Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.

A mineral is a naturally-occurring, homogeneous solid with a definite, but generally not fixed, chemical composition and an ordered atomic arrangement. It is usually formed by inorganic processes.

Let's look at the five parts of this definition:

1) "Naturally occurring" means that synthetic compounds not known to occur in nature cannot have a mineral name. However, it may occur anywhere, other planets, deep in the earth, as long as there exists a natural sample to describe.

2) "Homogeneous solid" means that it must be chemically and physically homogeneous down to the basic repeat unit of the atoms. It will then have absolutely predictable physical properties (density, compressibility, index of refraction, etc.). This means that rocks such as granite or basalt are not minerals because they contain more than one compound.

3) "Definite, but generally not fixed, composition" means that atoms, or groups of atoms must occur in specific ratios. For ionic crystals (i.e. most minerals) ratios of cations to anions will be constrained by charge balance, however, atoms of similar charge and ionic radius may substitute freely for one another; hence definite, but not fixed.

4) "Ordered atomic arrangement" means crystalline. Crystalline materials are three-dimensional periodic arrays of precise geometric arrangement of atoms. Glasses such as obsidian, which are disordered solids, liquids (e.g., water, mercury), and gases (e.g., air) are not minerals.

5) "Inorganic processes" means that crystalline organic compounds formed by organisms are generally not considered minerals. However, carbonate shells are minerals because they are identical to compounds formed by purely inorganic processes.

An abbreviated definition of a mineral would be "a natural, crystalline phase". Chemists have a precise definition of a phase:

A phase is that part of a system which is physically and chemically homogeneous within itself and is surrounded by a boundary such that it is mechanically separable from the rest of the system.

The third part of our definition of a mineral leads us to a brief discussion of stoichiometry, the ratios in which different elements (atoms) occur in minerals. Because minerals are crystals, dissimilar elements must occur in fixed ratios to one another. However, complete free substitution of very similar elements (e.g., Mg^{+2} and Fe^{+2} which are very similar in charge (valence) and radius) is very common and usually results in a crystalline solution (solid solution). For example, the minerals forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4) are members of the olivine group and have the same crystal structure, that is, the same geometric arrangement of atoms. Mg and Fe substitute freely for each other in this structure, and all compositions between the two extremes, forsterite and fayalite, may occur. However, Mg or Fe do not substitute for Si or O, so that the three components, Mg/Fe, Si and O always maintain the same 2 to 1 to 4 ratio because the ratio is fixed by the crystalline structure. These two minerals are called **end-members** of the olivine series and represent extremes or "pure" compositions. Because these two minerals have the same structure, they are called isomorphs and the series, an isomorphism series.

In contrast to the isomorphism series, it is also common for a single compound (composition) to occur with different crystal structures. Each of these structures is then a different mineral and, in general, will be stable under different conditions of temperature and pressure. Different structural modifications of the same compound are called polymorphs. An example of polymorphism is the different minerals of SiO_2 (silica); alpha-quartz, beta-quartz, tridymite, cristobalite, coesite, and stishovite. Although each of these has the same formula and composition, they are different minerals because they have different crystal structures. Each is stable under a different set of temperature and pressure conditions, and the presence of one of these in a rock may be used to infer the conditions of formation of a rock. Another familiar example of polymorphism is graphite and diamond, two different minerals with the same formula, C (carbon).

Glasses (obsidian), liquids, and gases however, are not crystalline, and the elements in them may occur in any ratios, so they are not minerals. So in order for a natural compound to be a mineral, it must have a unique composition and structure. We will return in a few weeks to further discussion of stoichiometry and stability. The fourth part of our definition of a mineral, the part about the ordered atomic arrangement, leads us to a discussion of symmetry which will occupy our first few weeks.

Mineral Properties in Hand Specimen

Learning to recognize hand specimens of approximately 100 of the most common rock-forming minerals is an important part of this course. This recognition is based on seven easily examined properties plus a few unique properties such as magnetism or radioactivity that are strong clues to a mineral's identity. These seven properties are:

1. Crystal form and habit (shape).
2. Luster and transparency
3. Color and streak.
4. Cleavage, fracture, and parting.

5. Tenacity

6. Density

7. Hardness

Crystal form and habit

Recognizing crystal forms (a crystal face plus its symmetry equivalents) in the various crystal systems is one of the reasons we spend some time in lab studying block models. The crystal faces developed on a specimen may arise either as a result of growth or of cleavage. In either case, they reflect the internal symmetry of the crystal structure that makes the mineral unique. The crystal faces commonly seen on quartz are growth faces and represent the slowest growing directions in the structure. Quartz grows rapidly along its c-axis (three-fold or trigonal symmetry axis) direction and so never shows faces perpendicular to this direction. On the other hand, calcite rhomb faces and mica plates are cleavages and represent the weakest chemical bonds in the structure. There is a complex terminology for crystal faces, but some obvious names for faces are prisms and pyramids. A prism is a face that is perpendicular to a major axis of the crystal, whereas a pyramid is one that is not perpendicular to any major axis.

Crystals that commonly develop prism faces are said to have a prismatic or columnar habit. Crystals that grow in fine needles are acicular; crystals growing flat plates are tabular. Crystals forming radiating sprays of needles or fibers are stellate. Crystals forming parallel fibers are fibrous, and crystals forming branching, tree-like growths are dendritic.

Luster and transparency

The way a mineral transmits or reflects light is a diagnostic property. The transparency may be opaque, translucent, or transparent. This reflectance property is called luster. Native metals and many sulfides are opaque and reflect most of the light hitting their surfaces and have a metallic luster. Other opaque or nearly opaque oxides may appear dull, or resinous. Transparent minerals with a high index of refraction such as diamond appear brilliant and are said to have an adamantine luster, whereas those with a lower index of refraction such as quartz or calcite appear glassy and are said to have a vitreous luster. Color and streak.

Color is fairly self-explanatory property describing the reflectance. Metallic minerals are white, gray, or yellow. The presence of transition metals with unfilled electron shells (e.g. V, Cr, Mn, Fe, Co, Ni, and Cu) in oxide and silicate minerals causes them to be opaque or strongly colored so that the streak, the mark that they leave when scratched on a white ceramic tile, will also be strongly colored.

Cleavage, Fracture, and Parting

Because bonding is not of equal strength in all directions in most crystals, they will tend to break along crystallographic directions giving them a fracture property that reflects the underlying structure and is frequently diagnostic. A perfect cleavage results in regular flat faces resembling growth faces such as in mica, or calcite. A less well developed cleavage is said to be imperfect, or if very weak, a parting. If a fracture is irregular and results in a rough surface, it is hackly. If the irregular fracture propagates as a single surface resulting in a shiny surface as in glass, the fracture is said to be Conchoidal.

Tenacity

It is the ability of a mineral to deform plastically under stress. Minerals may be brittle, that is, they do not deform, but rather fracture, under stress as do most silicates and oxides. They may be sectile, or be able to deform so that they can be cut with a knife. Or, they may be ductile and deform readily under stress as does gold.

Density

It is a well-defined physical property measured in g/cm^3 . Most silicates of light element have densities in the range 2.6 to 3.5. Sulfides are typically 5 to 6. Iron metal about 8, lead about 13, gold about 19, and osmium, the densest substance, and a native element mineral, is 22. Density may be measured by measuring the volume, usually by displacing water in a graduated cylinder, and the mass. Specific gravity is very similar to density, but is a dimensionless quantity and is measured in a slightly different way.

Hardness

It is usually tested by seeing if some standard minerals are able to scratch others. A standard scale was developed by Friedrich Mohs in 1812. The standard minerals making up the Mohs scale of hardness are:

1. Talc
2. Orthoclase
3. Gypsum
4. Calcite
5. Fluorite
6. Apatite
7. Diamond

This scale is approximately linear up to corundum, but diamond is approximately 5 times harder than corundum.

Unique Properties

A few minerals may have easily tested unique properties that may greatly aid identification. For example, halite (NaCl) (common table salt) and sylvite (KCl) are very similar in most of their physical properties, but have a distinctly different taste on the tongue, with sylvite having a more bitter taste. Whereas it is not recommended that students routinely taste mineral specimens (some are toxic), taste can be used to distinguish between these two common minerals. Another unique property that can be used to distinguish between otherwise similar but opaque minerals is magnetism. For example, magnetite (Fe_3O_4), ilmenite (FeTiO_3), and pyrolusite (MnO_2) are all dense, black, opaque minerals which can easily be distinguished by testing the magnetism with a magnet. Magnetite is strongly magnetic and can be permanently magnetized to form a lodestone; ilmenite is weakly magnetic; and pyrolusite is not magnetic at all.

Other Properties

There are numerous other properties that are diagnostic of minerals, but which generally require more sophisticated devices to measure or detect. Some minerals may also be fluorescent under ultraviolet light that is they absorb UV light and emit in the visible. (There is a display of fluorescent mineral on the first floor of the (old) Geology Building.) Other optical properties such as index of refraction and

pleochroism (differential light absorption) require an optical microscope to measure and are the subject of a major section of this course. Electrical conductivity is an important physical property but requires an impedance bridge to measure. In general native metals are good conductors; sulfides of transition metals are semi-conductors, whereas most oxygen-bearing minerals (i.e., silicates, carbonates, oxides, etc.) are insulators. Additionally, quartz (SiO_2) is piezoelectric (develops an electrical charge at opposite end under an applied mechanical stress); and tourmaline is pyroelectric (develops an electrical charge at opposite end under an applied thermal gradient).

Mineral Occurrences and Environments

In addition to physical properties, one of the most diagnostic features of a mineral is the geological environment in which it occurs. Learning to recognize different types of geological environments can be thus very helpful in recognizing the common minerals. For the purposes of aiding mineral identification, we have developed a very rough classification of geological environments, most of which can be visited locally.

Igneous Minerals

Minerals in igneous rocks must have high melting points and be able to co-exist with, or crystallize from, silicate melts at temperatures above 800°C . Igneous rocks can be generally classed according to their silica content with low-silica ($\ll 50\% \text{SiO}_2$) igneous rocks being termed basic or mafic, and high-silica igneous rocks being termed silicic or acidic. Basic igneous rocks (BIR) include basalts, dolerites, gabbros, kimberlitic, and peridotites, and abundant minerals in such rocks include olivine, pyroxenes, Ca-feldspar (plagioclase), amphiboles, and biotite. The abundance of Fe in these rocks causes them to be dark-colored. Silicic igneous rocks (SIR) include granites, granodiorites, and rhyolites, and abundant minerals include quartz, muscovite, and alkali feldspars. These are commonly light-colored although color is not always diagnostic. In addition to basic and silicic igneous rocks, a third igneous mineral environment representing the final stages of igneous fractionation is called a pegmatite (PEG) which is typically very coarse-grained and similar in composition to silicic igneous rocks (i.e. high in silica). Elements that do not readily substitute into the abundant minerals are called incompatible elements, and these typically accumulate to form their own minerals in pegmatite's. Minerals containing the incompatible elements, Li, Be, B, P, Rb, Sr, Y, Nb, rare earths, Cs, and Ta are typical and characteristic of pegmatites.

Metamorphic Minerals

Minerals in metamorphic rocks have crystallized from other minerals rather than from melts and need not be stable to such high temperatures as igneous minerals. In a very general way, metamorphic environments may be classified as low-grade metamorphic (LGM) (temperatures of 60° to 400°C and pressures $\ll .5\text{ GPa}$ (=15km depth) and high-grade meta morphic (HGM) (temperatures $> 400^\circ$ and/or pressures $> .5\text{GPa}$). Minerals characteristic of low- grade metamorphic environments include the zeolites, chlorites, and andalusite. Minerals characteristic of high grade metamorphic environments include sillimanite, kyanite, staurolite, epidote, and amphiboles.

Sedimentary Minerals

Minerals in sedimentary rocks are either stable in low-temperature hydrous environments (e.g. clays) or are high temperature minerals that are extremely resistant to chemical weathering (e.g. quartz). One can think of sedimentary minerals as exhibiting a range of solubilities so that the most insoluble minerals such as quartz, gold, and diamond accumulate in the coarsest detrital sedimentary rocks, less resistant minerals such as feldspars, which weather to clays, accumulate in finer grained siltstones and mudstones, and the most soluble minerals such as calcite and halite (rock-salt) are chemically precipitated in evaporite deposits. Accordingly, I would classify sedimentary minerals into detrital sediments (DSD) and evaporites (EVP). Detrital sedimentary minerals include quartz, gold, diamond, apatite and other phosphates, calcite, and clays. Evaporite sedimentary minerals include calcite, gypsum, anhydrite, halite and sylvite, plus some of the borate minerals.

Hydrothermal Minerals

The fourth major mineral environment is hydrothermal, minerals precipitated from hot aqueous solutions associated with emplacement of intrusive igneous rocks. This environment is commonly grouped with metamorphic environments, but the minerals that form by this process and the elements that they contain are so distinct from contact or regional metamorphic rocks that it is useful to consider them as a separate group. These may be sub-classified as high temperature hydrothermal (HTH), low temperature hydrothermal (LTH), and oxidized hydrothermal (OXH). Metals of the center and right-hand side of the periodic table (e.g. Cu, Zn, Sb, As, Pb, Sn, Cd, Hg, Ag) most commonly occur in sulfide minerals and are termed the chalcophile elements. Sulfides may occur in igneous and metamorphic rocks, but are most typically hydrothermal. High temperature hydrothermal minerals include gold, silver, tungstate minerals, chalcopyrite, bornite, the tellurides, and molybdenite. Low temperature hydrothermal minerals include barite, gold, cinnabar, pyrite, and cassiterite. Sulfide minerals are not stable in atmospheric oxygen and will weather by oxidation to form oxides, sulfates and carbonates of the chalcophile metals, and these minerals are characteristic of oxidized hydrothermal deposits. Such deposits are called gossans and are marked by yellow-red iron oxide stains on rock surfaces. These usually mark mineralized zones at depth and are very common in Colorado.

Classification of Minerals

Minerals are classified on their chemistry, particularly on the anionic element or polyanionic group of elements that occur in the mineral. An anion is a negatively charged atom, and a polyanionic is a strongly bound group of atoms consisting of a cation plus several anions (typically oxygen) that has a net negative charge. For example carbonate, $(\text{CO}_3)^{2-}$, silicate, $(\text{SiO}_4)^{4-}$ are common poly anions. This classification has been successful because minerals rarely contain more than one anion or polyanionic, whereas they typically contain several different cations.

Petrology

Petrology is the branch of geology that studies the origin, composition, distribution and structure of rocks. Lithology was once approximately synonymous with petrography, but in current usage, Lithology focuses on macroscopic hand-sample or outcrop-scale description of rocks while petrography is the specialty that deals with microscopic details. In the petroleum industry, Lithology, or more specifically mud logging, is the graphic representation of geological formations being drilled through, and drawn on a log called a mud log.

Grouting

Grouting is a particularly fluid form of concrete used to fill gaps. Grout is generally a mixture of water, cement, and sand, and is employed in pressure grouting, embedding rebar in masonry walls, connecting sections of pre-cast concrete, filling voids, and sealing joints such as those between tiles. It is often color tinted when it will remain visible, and sometimes includes fine gravel when being used to fill large spaces such as the cores of concrete blocks). Unlike other structural pastes such as plaster or joint compound, correctly mixed and applied grout forms a waterproof seal. Although both grout and its close relative mortar are applied as a thick emulsion and harden over time, grout is distinguished by its high viscosity and lack of lime (added to mortar for pliability); grout is thin so it flows readily into gaps, while mortar is thick enough to support not only its own weight, but also that of masonry placed above it

Geology of Dam Sites

The Important Geological requirements which should be considered in the selection of a dam are as follows:

1. Narrow River Valleys
2. Occurrence of the bedrock at a shallow depth
3. Competent rocks to offer a stable foundation
4. Proper Geological Structures

Tunnels and their Effects on the grounds

The tunneling process deteriorates the physical conditions of the ground. This happens because due to heavy and repeated blasting excavation, the rocks gets shattered to great extent and develop numerous cracks and fractures. This reduces the cohesiveness and compactness of rocks. In other words, rocks become loose and more fractured and porous. This naturally adversely affects the competence of the rocks concerned.