MINERALS AND MINERALOIDS

1. Introduction

1.1 Organization of the Earth Materials

The traditional organization of minerals in most geology student texts follows the so-called *Berzelian system* that arranges minerals according to chemical groups. The groups include: native elements (gold, graphite, diamond and sulfur), sulfides, sulfo salts, oxides, halides, carbonates, phosphates, sulfates, and silicates (the largest group of minerals). The Berzelian system was designed primarily for the purpose of curating collections and popularized in mineralogy texts used by generations of geology students. Presentation of the minerals by chemical groups provides a good means for organizing reference material but it is not necessarily the best organization of Earth materials for an applied course because chemical groups differ from the assemblages encountered in the field. To overcome this problem, these notes first present minerals for the main purpose of learning about basic properties and terminology but present rocks and minerals together for the purpose of learning the materials in hand specimen as *paragenetic suites.* As already discussed in Lecture Notes 4, *paragenesis* refers to the sequence of deposition of minerals within a particular environment. Paragenetic suites refer to a sequence or grouping of minerals that are deposited together. The most basic examples of paragenetic suites are the three rock suites (sedimentary, igneous and metamorphic suites), and the hydrothermal mineral suite that forms its own separate mineral associations but may be found within any rock suite. Further paragenetic subdivisions within each suite are possible. For example, the sedimentary suite can be divided into the clastic suite, evaporite suite, diagenetic suite, and the organic suite. The hydrothermal suite may be subdivided as low temperature (epithermal), medium temperature (mesothermal), and high temperature (hypothermal).

These lecture notes introduce you to the basic building blocks of the Earth - the minerals and mineraloids. Through careful study of specimens, you can learn to recognize most of them on sight. You should not try too hard to memorize all of these substances in hand specimen. Instead, strive to learn to see diagnostic physical properties and to mentally arrange specimens by associations into groups that will aid in later memory retention and in identification.

1.2 Identification of Minerals

Two techniques are commonly used for identifying minerals. The first consists of examining *hand specimens* by visual inspection or using a hand lens. The second technique consists of examining thin slices of rock or of the mineral of interest. These slices (*thin sections*) are ground down to a thickness of 0.03 mm and are mounted on a microscope. The optical properties of minerals under natural or polarized light are then used for mineral identification. Most engineers use hand specimens.

The following physical properties are often used to identify minerals: (1) External crystal form (see Figure 1), (2) Hardness (see Table 1), (3) Cleavages and fractures (see Figure 2), (4) Specific gravity,

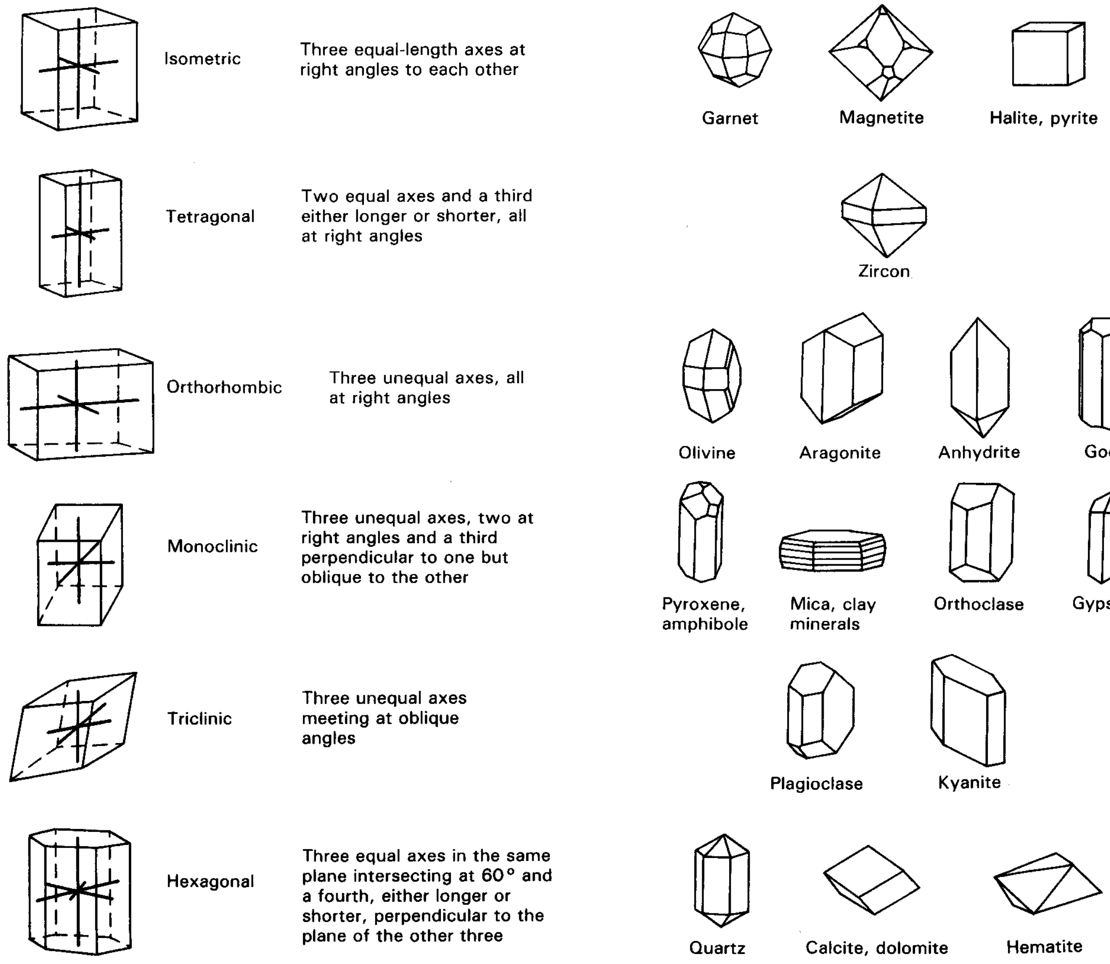
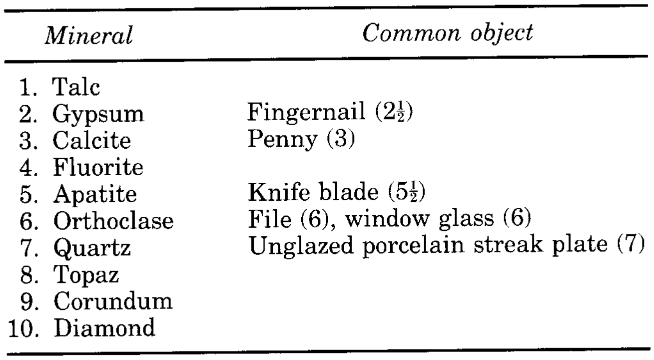


Figure 1. The six crystal systems with representative minerals and crystal forms (after Kehew, 1995.)



Mineral	*Common object*
1. Talc	
2. Gypsum	Fingernail ($2\frac{1}{2}$)
3. Calcite	Penny (3)
4. Fluorite	
5. Apatite	Knife blade ($5\frac{1}{2}$)
6. Orthoclase	File (6), window glass (6)
7. Quartz	Unglazed porcelain streak plate (7)
8. Topaz	
9. Corundum	
10. Diamond	

Table 1. The Mohs Hardness Scale (after Kehew, 1995.)

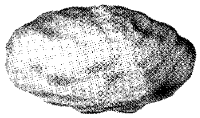
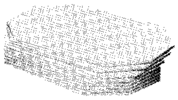
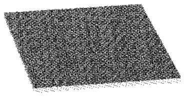
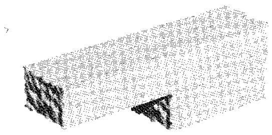
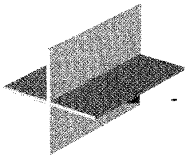
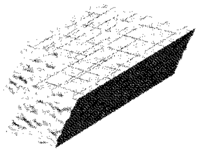
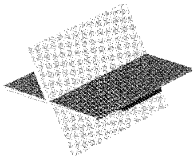
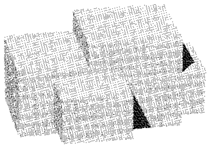
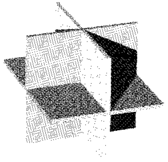
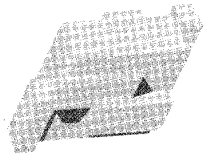
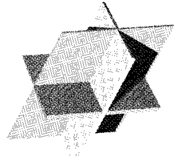
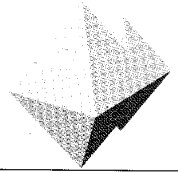
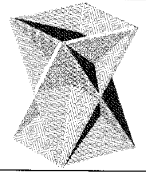
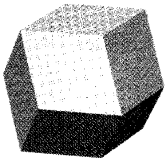
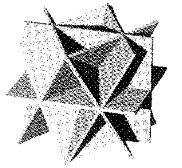
Number of Cleavage Directions	Shapes that Crystal Breaks Into	Sketch	Illustration of Cleavage Directions
0 No cleavage, only fracture	Irregular masses with no flat surfaces		None
1	"Books" that split apart along flat sheets		
2 at 90°	Elongated form with rectangular cross sections (prisms) and parts of such forms		
2 not at 90°	Elongated form with parallelogram cross sections (prisms) and parts of such forms		
3 at 90°	Shapes made of cubes and parts of cubes		
3 not at 90°	Shapes made of rhombohedrons and parts of rhombohedrons		
4	Shapes made of octahedrons and parts of octahedrons		
6	Shapes made of dodecahedrons and parts of dodecahedrons		

Table 2. Common cleavage patterns of minerals, which cause minerals to break into preferred shapes (from *Laboratory Manual in Physical Geology*, 1997).

(5) Color and streak (color of a mineral when pulverized), (6) Luster (quality and intensity of light that is reflected from the surface of a mineral), (7) Tenacity (resistance of a mineral to breakage), (8) Transparency (describes the way a mineral transmits light), (9) Reaction to HCL, (10) Magnetism, and (11) Taste.

1.3 Terms to Understand

Consult an introductory text, your class notes, or if necessary a *Dictionary of Geological Terms* for meaning of any of the following terms that are not familiar to you:

mineral
crystal structure
streak
specific gravity
metallic bonding
diagenetic
mineraloid
crystal habit
luster
density
covalent bonding
clastic
rock
cleavage
hardness
diaphaneity
paragenetic suite
precipitate
soil
color
tenacity
ionic bonding
feldspar
striations

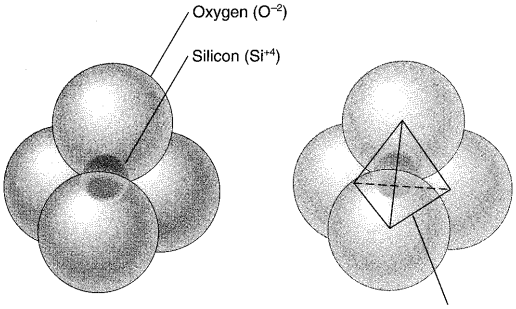
The descriptions that follow provide the minimum criteria needed to recognize the substance in hand specimen and provide additional information on composition and engineering/environmental properties. It is very important that you recognize the difference between learning the properties that allow identification and memorizing the words that list the properties about each specimen.

A final word of caution is merited. Simply because a material is "natural" does not mean that it is harmless. It is a good practice to handle all materials safely, never to taste or inhale the dust of any unknown specimen and to wash hands thoroughly after touching the specimens (Puffer, 1979).

1.4 The Silicon-Oxygen Tetrahedron

The two most abundant elements of the crust, silicon and oxygen, combine to form the “basic building block” for silicate minerals. In each block, four oxygen atoms are combined together around a single, much smaller, silicon atom (see Figure 2a). The four-sided, pyramidal, geometric shape called a tetrahedron is used to represent the four oxygen atoms surrounding a silicon atom (Figure 2b). This basic building block of a crystal is called a silicon-oxygen tetrahedron (also known as the *silica tetrahedron*). Within a silicon-oxygen tetrahedron the negative charges exceed the positive charges. A single silicon-oxygen tetrahedron is a complex ion with a formula of $[SiO_4]^{-4}$ because silicon has a charge of +4 and the four oxygen ions have 8 negative charges (-2 for each oxygen atom).

For the silicon-oxygen tetrahedron to be stable within a crystal structure, it must either be balanced by enough positively charged ions or it must share oxygen atoms with adjacent tetrahedrons. The structures of silicate minerals range from an *isolated silicate structure* (olivine, for example) that depends entirely on positively charged ions to hold the tetrahedrons together, *to framework* *structures* (quartz, for example) in which all oxygen atoms are shared by adjacent tetrahedrons. The various types of silicate structures are shown diagrammatically in Figure 3.



A Arrangement of atoms in silicon-oxygen tetrahedron

B Diagrammatic representation of a silicon-oxygen tetrahedron

Figure 2. The silicon-oxygen tetrahedron (after Plummer et al., 1999)

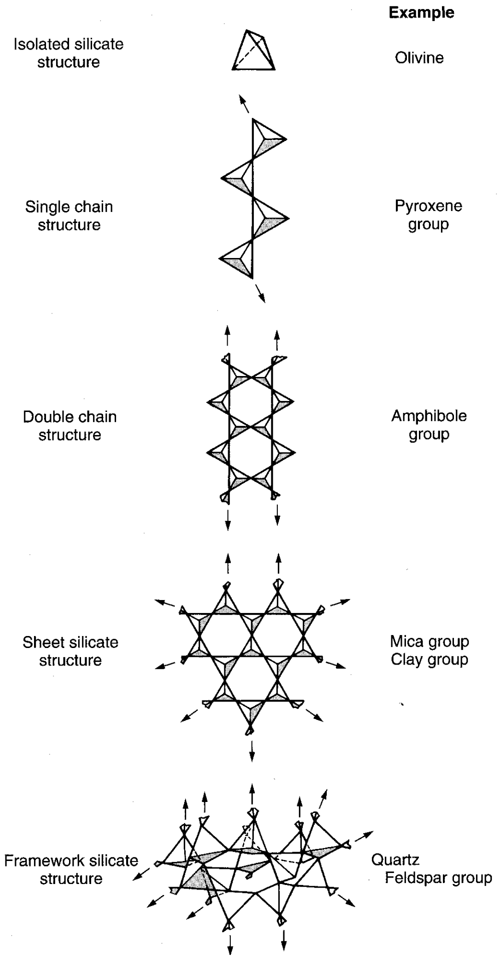


Figure 3. Common silicate structures. Arrows indicate directions, in which structure repeats indefinitely (after Plummer et al., 1999.)

2. Minerals

1) *Quartz* (SiO_2) is the most common mineral of all. It is most easily recognized by conchoidal fracture, vitreous luster and usual light (white through gray) colors in most rocks. Paragenetically it occurs in all three rock suites and in the hydrothermal suite. Quartz is the primary constituent of most sands and sandstones, is abundant in most light-colored igneous rocks, and in most metamorphic rocks. *Quartzite* is a metamorphic rock composed almost entirely of quartz. It is the usual material in isolated "veins" that are often seen as white fracture fillings in metamorphic rocks. Its structure consists of silicon bound to oxygen by strong covalent bonds in three dimensions. This makes quartz hard, durable and chemically inert even to very strong acids and bases. More information about quartz in general can be found on the web at http://en.wikipedia.org/wiki/Quartz.

The mineral occurs in many varied colors and textures. Colors due to impurities give rise to many varieties of quartz. Smokey, milky, amethyst, rose, jasper, agate, tiger-eye are common semi-precious gem forms of quartz. Textures range from large individual crystals such as the common six-sided prisms or the amethyst crystal linings of geodes sold in many gift shops to the micro- (or crypto-) crystalline forms of rock such as chert or flint.

High-purity quartz sand is in great demand as a construction material and for the glass industry. After fuels, sand and gravel production constitutes the largest mineral industry in the United States. Quartz has hundreds of uses in engineering, including filter sand in water treatment plants, construction filler for concretes, traction sand for treatment of icy highways, or as a primary constituent of many building stones.

Chert (a variety of cryptocristalline quartz) often occurs as nodules in limestones and dolostones. Its presence there causes increased wear on crushers and equipment. It breaks into sharp shards that may cut or puncture rubber-tired equipment at quarries or on automobiles when the sharp shards are present in crushed stone used for surfacing of secondary roads. Chert also reacts with Portland cement to produce an expansive reaction (alkali - silica) that causes premature cracking and deterioration of concrete (Gillott, 1975).

Because quartz is both hard and abundant, it is a measure factor in determining performance and wear on drilling bits and tunnel boring machines (Nelson, and Kulhawy, 1984; Selmer-Olsen and Blindheim, 1970). Pure forms of silica such as quartz and its high temperature counterparts (cristobalite and tridymite) in fine dust can produce the disease, *silicosis*, if inhaled regularly in the work place. Therefore, dust control and protective filters and respirators are mandated when silica dust is created during drilling, blasting or grinding (www.osha.gov/SLTC/silicacrystalline).

2) *Potassium Feldspars* (also often simply called "K - feldspar" or "K- spar" - $KAlSi_3O_8$) form a group of aluminosilicates that are common in all three rock suites. All K-spars have a vitreous luster

and two good cleavages at nearly right angles. The most common K-spar is orthoclase, which is usually pink. Paragenetically, the potassium feldspars are common and abundant in all three rocks suites. K-spar is the dominant mineral in light colored igneous rocks such as granite, syenite and rhyolite. When it occurs as a major clastic constituent of many reddish or pink-tinted sandstones and siltstone, these sandstones are called *arkosic.* It is common in metamorphic rocks, particularly in the lighter colored bands of gneiss. K-feldspar is used in pure form in the ceramic industry and is a major constituent of building stones such as granite or some sandstones (arkosic "brownstones"). When abundant in sands used as concrete aggregate, it may cause detrimental reactions called "alkali-aggregate reactions" (Gillott, 1975; 1986) with common cements that shorten useful life of the concrete.

3) *Plagioclase* is a group name applied to aluminosilicates with a sodic end member (Albite - $NaAlSi_3O_8$) and calcic end member (Anorthite - $CaAl_2Si_2O_8$). Plagioclases have a vitreous luster and two good cleavages at right angles. Plagioclases are distinguished by the presence of striations, luster and color. The sodic end member is white whereas the members richer in calcium tend toward darker gray in common rocks. The most likely confusion in identification occurs between light colored K-spar and sodic-rich plagioclase. In such cases, distinction by selective chemical staining methods requiring the reagents K-rhodozionate, Na cobaltnitrite, Ba chloride and hydrofluoric acid (Bailey and Stevens, 1960) may be necessary even for experts. Plagioclase, as a group, is the most abundant rock-forming mineral in the Earth's crust. Paragenetically, plagioclases are especially abundant in igneous rocks and somewhat abundant in metamorphic rocks. Anorthite weathers more easily than albite and both weather more easily than K-spar. Therefore the plagioclases are found only in trace amounts in most sedimentary rocks. In engineering applications, plagioclase is an important constituent of many igneous building stones such as diorite or granodiorite. A particularly striking variety of the rock, *anorthosite*, is composed entirely of calcic-rich plagioclase and exhibits a fiery blue opalescence in polished slabs. It is often used as a facing stone on buildings. Sands high in plagioclase feldspars may have a swelling reaction (alkali-aggregate reaction) when mixed with Portland cement (Derucher and Korfiatis, 1988; Gillott, 1975; 1986). The reactions are understood and can usually be overcome by using additives.

4) *Feldspar* is the general group name that encompasses both the potassium feldspars and the plagioclase feldspars. Clay minerals in sediments and sedimentary rocks arise primarily from the reactions between feldspars and water (hydrolysis reactions). For more information about feldspars in general, check the web site: http://en.wikipedia.org/wiki/Feldspar.

5) *Olivine* ($Fe,MgSiO_4$ - a ferromagnesian silicate). "Olivine" is actually a group which, like the feldspars, consists of two end-member minerals, forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). Common olivine is of intermediate composition and is easily identified by its green color and granular habit. It is abundant only in dark (green to black) igneous rocks. The mineral is held together primarily by tightly packed ionic bonds and therefore reacts with water too easily to survive in the sedimentary environment. Olivine weathers so rapidly that many stones that contain it will weather in moist climates to quickly yield a rust-colored stained surface. In the metamorphic regimes olivine is easily altered by hot water solutions to produce chlorite or amphiboles. Some

olivine (forsterite) forms through the metamorphism of Mg-rich rocks. Pure olivine rock (dunite) has been used for refractory furnace liners and single crystals used as a gem (peridot) but its civil engineering uses are primarily linked to its being an ingredient of basalt which is an important dark, fine-grained, dense, igneous rock used for building, rip-rap, dock cribbing, road metal, and railroad ballast. For more information on olivine, check the web site: http://en.wikipedia.org/wiki/Olivine.

6) *Pyroxenes* - (Fe,Mg,Ca,NaSiO_3 - A mineral group whose most common varieties are essentially green to black ferromagnesian silicates). The common pyroxenes are recognized in hand specimen by their vitreous luster, black to green color, and two cleavages at nearly right angles. In pyroxenes, the silica tetrahedra are linked to make chains with the strong covalent bond within the chains and a weaker ionic bond holding chain to chain. When struck with a hammer, the break occurs around the chains rather than through them and gives rise to 2 cleavages at near right angles. Although the two directions of cleavage are very good, in practice the size of the breaks is usually small so that one must often look for small "stair steps" on the scale of one to a few millimeters in size. There is more covalent bonding in pyroxene than olivine and while it weathers too easily to survive in the sedimentary environment, it is more durable than olivine. The high-temperature paragenetic association of pyroxenes places some (augite, hypersthene, aegerine) as abundant constituents in the darker igneous rocks and some (diopside, augite, hypersthene) as constituents of Fe-rich or Mg-rich metamorphic rocks. The engineering applications of the pyroxenes are about the same as olivine in being a rock-forming constituent of basalt and gabbro. For more information on pyroxenes, check the web site: http://en.wikipedia.org/wiki/Pyroxenes.

7) *Amphiboles* (Fe,Mg,Na,Ca$Si_4O_{11}(OH)_2$ - A mineral group whose most abundant constituents are mainly black to very dark green basic ferromagnesian silicates). The structure is double chains made of linked silica tetrahedra that run parallel to each other. The cleavage is again around the weak ionic bond that gives rise to two cleavages at 60° and 120°. The common amphiboles are most likely to be confused in hand specimen with the common pyroxenes, which are also dark green to black with a vitreous luster. The 60° and 120° cleavage is diagnostic where it can be seen. Another aid is the longer more prismatic shapes of the amphibole crystals, which tend to give the cleavage of amphiboles longer and more continuous parallel hackles on the broken surfaces of amphiboles than on the pyroxenes. There is more covalent bonding in amphibole than pyroxene and while it weathers too easily to survive in the sedimentary environment, it is more durable than pyroxene. For more information on amphiboles, check the web site: http://en.wikipedia.org/wiki/Amphiboles.

Amphiboles are a major rock-forming mineral in building stones and traces to major amounts occur in most igneous and in many metamorphic rocks. However, the most distinctive use of amphiboles comes from the fibrous habit and flame resistance of some varieties, which has given rise to many important applications in construction under the generic term "*asbestos*." Uses include heating ducts, furnace grout and insulation, water pipe coverings, room and corridor insulation, fireproofing in buildings on floors, walls, ceilings and trim, floor tile and tar mastic, asbestos plaster, roof coatings, sealants, cement sheets, installation in underground sewage and water pipes, airplane insulation, railroad sleeper cars of molded asbestos, older running tracks for track and field sports, brake linings for automobiles, acoustical tiles, gaskets and packings, sealing tapes, and fireproofing for steel structural members in buildings.

The term, "asbestos" most properly refers, not to amphiboles, but to a fibrous variety of the layer silicate, *chrysotile*. However, in contemporary use, "asbestos" refers to a broader group of minerals, the grouping actually based upon federal legislation. Amphibole members of this group include *amosite* (asbestiform grunerite, an iron-magnesium silicate) *crocidolite* (asbestiform sodium-iron silicate), *anthophyllite* (a magnesium-iron silicate), *tremolite* (calcium-magnesium silicate), *actinolite* (magnesium-iron silicate), and *ferroactinolite* (calcium-iron silicate).

The discovery that at least some varieties of asbestos are carcinogenic (World Health Organization, 1986), in combination with the abundance of asbestos products now in the home, school, industry and business environments, has led to a national concern of near-crisis proportions. Unfortunately, all forms of "asbestos" have been attributed to be a major concern to health without much scientific documentation. The problem is further compounded when self-taught or poorly trained technicians misidentify fibrous materials unrelated to amphiboles or to fibrous clay minerals. Check the OSHA web site on asbestos: http://www.osha.gov/SLTC/asbestos and http://en.wikipedia.org/wiki/Asbestos.

With much specific proof about asbestos hazards, the student (particularly the engineering student) should be aware that most serious hazards documented links cancer to certain types of "asbestos" (particularly amphiboles) and the hazard to the individual is greatly increased by smoking (see also discussion on specimen 11, *chrysotile*, below.) Any blasting, tunneling or excavation through metamorphic rocks that is likely to raise much dust should have the rock material monitored for "asbestos" throughout the operation. The brief writings by McCrone (1989) and Rutstein (1989) cited at the end of this section are particularly incisive and clearly written evaluations of the current asbestos crisis. *No individual without in-depth training should, on his/her own recognizance, attempt to identify "asbestos" or recommend any remediation procedures until the material is clearly identified.* Identification and remediation is a job for trained specialists (McCrone, 1970, 1987; McCrone and Delly, 1973; and 1978; Skinner et al., 1988 as examples of specialty references in asbestos) and the skill cannot be obtained in a single course such as engineering geology. *Identification of asbestos materials should be attempted only by those with a very strong background in light microscopy* (minimally a formal course in mineralogy, a formal course in petrology, and a formal course in optical mineralogy).

8) *Biotite* ($K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$ - a basic potassium ferromagnesian mica). Biotite is easily identified by its micaceous (sheet) form and black color. The structure is arranged as sheets of silica tetrahedra with a little aluminum substituting for silicon. The sheets are held one-to-another by weak ionic bonds of iron, magnesium and small amounts of potassium. Although more durable than amphibole, biotite still weathers too easily to permit it to survive in the sedimentary environment. The paragenesis of biotite places its primarily abundance in the metamorphic schists and gneisses. Biotite is also abundant in light to intermediate colored igneous rocks and usually constitutes the "black spots" found in white granites and syenites. Biotite has sometimes been ground and used as filler for asphalt roofing. When biotite weathers in abundance, it forms deposits of vermiculite, a

mineral which, when heated, expands like popcorn and is used for insulation, packing material and as a carrier for herbicides and pesticides. For more information on biotite, check the web site: http://en.wikipedia.org/wiki/Biotite.

9) *Muscovite* ($KAl_4Si_3O_{10}(OH)_2$ - a potassium aluminum silicate). Muscovite is easily recognized by its light to transparent color and its micaceous character. It is sometimes called "white mica." The structure is arranged as sheets of silica tetrahedra with much aluminum substituting for silicon. The sheets are held one-to-another by weak ionic bonds with potassium. Paragenetically, muscovite forms in abundance in schists and gneisses and is also abundant in light-colored igneous rocks. It is very durable in the weathering environment and often survives as a minor clastic constituent in the sedimentary suite. Illite, an abundant clay mineral in siltstones and mudrocks is a very weathered fine-grained mineral formed from muscovite and has most of the properties of muscovite. Muscovite once had important commercial uses in electrical insulators capacitors and was the most critical mineral in short supply during World War II. It is still used as filler for asphalt roofing and is a minor constituent of many building stones. For more information on muscovite, check the web site: http://en.wikipedia.org/wiki/Muscovite.

10) *Clay mineral group* - most clays are sheet structures consisting of abundant silica and alumina with varying amounts of alkali or alkaline Earth elements. *Clay* is a size term for particles generally smaller than two microns whereas *clay mineral* refers to the specific mineral group. The two terms should not be used interchangeably.

The clay minerals are so important to civil engineering (Baker, 1975; Cakmak, 1987; Chen, 1975, 1988; Derucher and Korfiatis, 1988; Fenner et al., 1983;Gillott, 1975, 1987; Gromko, 1974; Huang et al., 1986; Holtz and Hart, 1975; Jochim, 1981; Jones and Holtz, 1973; Krohn and Slosson, 1980; Lambe, 1960; Mathewson et al., 1980; Meehan et al., 1975; Patrick and Snethen, 1976; Selmer-Olsen and Palmsrom, 1989; Shelton and Prouty, 1979; Tourtelot, 1974, Velbel, 1984) that we will cover the clay minerals in a separate set of lecture notes on soils and on clay mineral structures. The properties of load-bearing, slope stability, liquefaction, swelling and fluid transmissibility are based on the clay mineral abundance, compositions and fabric arrangements in either soils or of their parent rock constituents.

Expansive clay minerals cause over a billion dollars damage each year to residences and other buildings, more than the combined damages accumulated annually by floods, hurricanes, earthquakes and tornadoes (Jones and Jones, 1987). When segregated into thin beds within other rocks, they serve as weak zones and specific planes for failure during many landslide and tunnel and mine collapses (Arnold, 1972).

Clays are also an important construction material. Certain clays are used in ceramics and concretes and for bricks; swelling clays such as bentonites are used for sealing of small ponds, waste disposal sites and for sealing foundations and basements against water leakage (Alther, 1982).

At this stage, you should merely recognize that clay minerals are a major constituent of the clastic mineral suite and most encountered in civil engineering applications are produced by weathering.

11) *Chrysotile* ($Mg_6Si_4O_{10}(OH)_8$ - a hydrated magnesium silicate of the serpentine mineral group). Chrysotile in raw mineral form is easy to identify by its fibrous habit, white color as thin fibers and greenish tints when fibers are bound tightly together in the original rocks. The clay mineral sheet structures also produce the most abundant form of commercial asbestos. Over 90% of all asbestos utilized in the United States is chrysotile. The fibrous habit occurs because the sheet structure coils into a tight roll, much like a roll of gift-wrapping paper. Chrysotile is commonly found in ultra-basic rocks (i.e. dunites, pyroxenites and peridotites), which have undergone some low-grade hydrothermal or metamorphic alteration. Chrysotile has been commercially mined in Quebec, South Africa, Russia, Italy, Cyprus, Rhodesia, and domestically in the U. S. along the west flank of the Sierra Nevada Mountains and in Arizona, New York and New Jersey.

Exposure to certain types of asbestos and asbestos containing material has been found to be the cause of asbestosis (diffuse pulmonary fibrosis), bronchial carcinoma, and mesothelioma (primary malignant tumors of the pleura and peritonium). These health problems arise because asbestos fibers cannot be broken down in the lung. A fiber becomes a constant irritant in the lung and can trigger cancerous cell growth. The adverse health effects can take between 5 and 20 years to develop. Once active, rapid mortality usually follows. Asbestos may cause cancers at other body sites as well. Exposure to cigarette smoke has been found to increase the incidence of asbestos-related cancers by a factor of 90 in persons also exposed to asbestos. Asbestos only becomes a health hazard if it becomes friable and airborne so that it may be inhaled. Recent studies also raise questions about the carcinogenicity of asbestos when ingested. Asbestos fibers can be transmitted into groundwater by several pathways. This may pose a threat to municipal and private water supplies, especially private wells adjacent to asbestos landfill sites. (References on asbestos, including chrysotile, are provided above under the amphiboles.)

Although dangers to health have been firmly documented with respect to certain amphibole types of asbestos, there has been no clear link of asbestosis through exposure to chrysotile. There seems at time of this writing to be no particular increase in cancer, for instance, among carpenters who installed asbestos (chrysotile) shingles or among chemists and chemistry teachers who used asbestos (chrysotile) gloves, etc. in laboratories. Therefore there are strong and perhaps legitimate objections to mandated remediation of chrysotile in buildings because such expensive remediation may be needless.

12) *Calcite* ($CaCO_3$ - calcium carbonate). Calcite is easy to identify because it is only slightly harder than the fingernail and fizzes readily in dilute (2%) HCl. Calcite occurs in rare igneous rocks called carbonatites and in metamorphic rocks as marble. Some even occurs in hydrothermal vein deposits. However, the dominant paragenetic occurrence of calcite is in the sedimentary regime where is the most common precipitate. Calcite forms limestones, which occur, in a variety of forms including chalk. The greatest formers of limestones are algae. Many crustaceans (clams snails, oysters) as well as coelenterates (corals), bryozoa and brachiopods also make their shells and exoskeletons of

calcite, and this accounts for the abundance of fossils in many limestones. Over historic time, calcite would be considered fairly durable but over short periods of geologic time limestone is easily dissolved and many surficial exposures of thick carbonate deposits have underground networks of caverns and dolines that result from solutioning along fractures. Often, this solution is so severe that a special topography (*karst* topography) is created which is characterized by many collapse sinkholes and by extensive underground drainage rather than surface streams.

In engineering applications, calcite is the most common raw material used for construction industries. It is used in everything from a required ingredient of Portland cement to actual building stone (Gillott, 1975). Limestones are abundant, easy to cut and quarry and have been used for thousands of years as building stone. The Egyptian Pyramids are made of limestone. The Bedford Limestone, quarried near Bedford, Indiana, is one of the most famous building stones and is found in buildings all over the world. Hundreds of commercial uses of calcite exist, particularly in the form of limestones. These include a range from poultry grit, to an acid neutralizer in soils and acid-contaminated streams through the chemical and manufacturing industries to metallurgical fluxes.

Because of the solubility of carbonate minerals, terrains underlain with thick calcite and/or dolomite beds may pose problems for construction due to subsidence into natural caverns and dolines (Allen, 1969; American Society of Civil Engineers, 1988; Beck and Wilson, 1987; Foose, 1979; Legrand and Stringfield, 1973; Prokopovick, 1976; Sowers, 1975)

13) *Dolomite* ($CaMg(CO_3)_2$ - calcium magnesium carbonate). Dolomite is identified by its light color, rhombohedral cleavage, hardness softer than glass and its reluctance to react with 2% HCl unless powdered. In the field, the simple HCl test is still the most effective way to distinguish dolostones from limestones. When significant amounts of calcite are present within a dolomite-rich rock, the only way to distinguish the amounts quantitatively are through chemical analyses for Ca and Mg or through selective staining of the rock, usually in thin section because most dolostones are fine-grained, for the two carbonate minerals. The most convenient stain is alizarin red in a very weak (0.5%) HCl solution. This stains calcite brilliant red and leaves dolomite unstained (Friedman, 1959). Paragenetically, most dolomite is associated with the sedimentary suite and is present in greatest abundance in rocks deposited along tropical marine supratidal flats and sabkhas. Although dolomite is abundant in the sedimentary rocks of the lithosphere, very little dolomite is present in modern sedimentary environments. This is because dolomite is a *diagenetic* mineral that forms very slowly (over thousands of years) after burial of high Mg calcite. Over time, the mixed Ca^{+2} and Mg^{+2} along crystallographic planes unmix into discrete planes of pure Mg^{+2} and pure Ca^{+2} alternating between layers of CO_3^{-2} anions. Eventually, whole limestone formations may be converted to dolomite (dolostone). Because the conversion of high Mg calcite to dolomite involves a density increase (from 2.71 g/cc to 2.84 g/cc), the volume of rock that is dolomitized must decrease in volume of solids. This shrinkage leaves vuggy pores in many dolostones that enhance the fluid transmissibility of the rock well beyond what it was as a pure unrecrystallized limestone. The recrystallization generally leads to crystals of dolomite that are larger than the original calcite muds. In weathered hand specimen, this imparts a granular or sandy feel to many dolostone surfaces, which serves as a further aid in field identification.

Dolostones are used as aggregates, in metallurgical fluxes, as quarry stone and occasionally for chemicals, drugs and dietary supplements for calcium and magnesium. The dolomite reaction with concrete and the dolomite pop outs noted in asphalt (Van Dine and Harrison, 1982) are usually due to clay impurities in the stone used (Gillott, 1975; 1986), not in the dolomite itself.

14) *Gypsum* ($CaSO_4 \cdot 2H_20$ - hydrated calcium sulfate). Gypsum in rock form is usually white to tan and often occurs in pure well-formed, vitreous, transparent crystals. It is easily identified by its softness, which is less than that of the fingernail. Paragenetically, gypsum is mainly a sedimentary mineral of the evaporite suite. It is often found associated with beds of halite, anhydrite and dolomite.

Gypsum is a very important mineral in the construction industry where it is used extensively in construction of wallboard, plaster and other interior surfaces. In some places, crushed gypsum rock is used as a soil conditioner to loosen up tight clayey soils for gardening or lawns. Gypsum is also seen as a whitish effloresence on structures, pavements and retainer walls where sulfuric acids from soils or from the atmosphere reacts with Portland cement-based concretes (Derucher, and Korfiatis, 1988; Gillott, 1975, 1986; Whitehead et al., 1969). The conversion of anhydrite (calcium sulfate) to gypsum (hydrated calcium sulfate) involves an expansive reaction that exerts pressures up to 700 tons per square foot and has resulted in rare but spectacular natural rock bursts (Brune, 1965). The solubility of gypsum renders terrains underlain by gypsum and anhydrite beds as potential areas for subsidence.

15) *Halite* (NaCl - sodium chloride) Halite or common "salt" is easily identified by its salty taste, solubility and cubic cleavage. The paragenesis of bedded halite is sedimentary, primarily from marine evaporites with lesser amounts being related to evaporites of inland brine lakes. Salt is one of the most important industrial minerals and is virtually a cornerstone of civilization. The word "salary" comes from the fact that workers were once paid in salt that is essential for human life and once was a rare and highly prized commodity before it became widely available. It has many industrial uses, particularly in the chemical industry.

Other than on marine coasts, most salt is produced by either underground mining or by brine pumping, both of which may cause subsidence in terrain underlain by exploited deposits. Halite is such a soluble mineral that natural dissolution can remove salt from beneath extensive areas and cause subsidence (Allen, 1969; Poland and Davis, 1969; Walters, 1977). Salt beds are considered important sites for disposal of toxic or radioactive waste. On the plus side is the fact that salt behaves under lithostatic pressure somewhat as a plastic. It flows to fill voids and, when fractured, recrystallizes, heals the fractures thus restoring the seal. For this reason, many deep salt mines are completely dry and very stable. Salt beds are also easy to map in subsurface and easy to excavate as compared to harder rocks. On the minus side is the problem of ground water solution of soluble salt beds and the unpredictability of occurrences of spotty dissolution and collapse areas (Hansen, 1987). Salt crystals contain fluid-filled vacuoles and when a heat source is placed into bedded salt, the fluid dissolves salt on the side nearest the heat source and deposits salt on the side furthest from the heat source. This causes a migration of the tiny fluid inclusions toward the heat source and, over time, the process can eventually surround the heat source with brine. This is particularly important in terms of long-term storage of heat-producing radioactive wastes.

16) *Hematite* (Fe_2O_3 - ferric iron oxide). Its reddish brown streak and earthy luster identify hematite. The paragenesis of most hematite is sedimentary. Metamorphism of beds of formerly sedimentary hematite may yield the specular variety of large flaky crystals with a black color and brilliant metallic luster. The specular variety also gives a reddish-brown streak. Hematite occurs in a variety of habits including oolitic, earthy, botryoidal and nodular. Hematite gives red color to soils and to rocks. Hematite serves as the major iron ore of the world and is also used in paints, cosmetics and polishing compounds. To the civil engineer in the field, hematite is mainly important to recognize in its role to impart color to a variety of rock types. A very small amount of hematite can give a rock or soil a brilliant red color. Sometimes rock outcrops become coated with hematite stains from overlying beds and much of the red Canyon-lands vistas of the southwestern U. S. owe their color to stain rather than actual rock color. The famous Redwall Limestone that forms the vistas of the Grand Canyon is actually a dull gray limestone that has been coated by hematite from above.

17) *Limonite* (a complex group of iron oxides and hydroxides). Limonite is an informal name provided to a variety of rust-colored sedimentary iron oxide compounds. In practice its rust brown to yellow-brown streak identifies it. It serves as a minor ore of iron and as a pigmenting agent. Like hematite, to the civil engineer in the field, limonite is mainly important in its role to impart a brown color to a variety of soil and rock types.

18) *Pyrite* (FeS_2 - iron sulfide). Pyrite is recognized by its bright yellow color metallic luster and its ability to scratch glass. Paragenetically, iron sulfide minerals are widely distributed and occur in many environments: pyritic materials in coal, black shales, and in dark muds of lakes, marshes, estuaries, and swamps, in small crystals in limestones; pyrite and marcasite (another iron disulfide) and pyrrhotite (a magnetic iron monosulfide) occur with all types of hydrothermal and igneous metal ores; pyrite also occurs in low-grade metamorphic rocks such as talc schists. Much pyrite of importance to civil engineers occurs in microscopic form within highly organic sedimentary rocks such as coal and black shale or in a variety of waste materials associated with metallic mining for gold, silver, copper, lead and zinc. When excavations or mining occurs water and air react with the iron sulfides to produce a reddish sludge (iron hydroxide) and sulfuric acid as described by the reaction below.

$$\text{pyrite } (4FeS_2) + \text{ water } (14H_20) + \text{ oxygen } (15O_2) \rightarrow$$
$$\text{iron hydroxide } (4Fe(OH)_3) + \text{ sulfuric acid } (8H_2SO_4)$$

Many intermediate sulfates (Kittrick et al., 1979; Nuhfer, 1976) actually form in the course of conversion of iron sulfides to iron hydroxides are not shown in this summary reaction. In nature, the reaction takes place quickly because of the presence of *Thiobacillus ferrooxidans.* This species of bacteria derives its energy from the oxidation process and serves to catalyze the reaction. Rates are increased by several hundred times what they would be in bacteria-free conditions.

In nature, the natural weathering of rock exposes only a little reactive sulfide at a time. However, when man exposes large volumes of sulfide-rich material almost instantaneously during mining, road cuts, and other excavations, then the reactions begin quickly. When the reaction occurs, the sulfuric acid released pollutes the water and the iron hydroxide sludges choke streams and reservoirs with unwanted sediment. In addition to killing aquatic life, the acid waters are able to carry toxic heavy metals that are not normally mobile in most natural waters. The acids attack man-made structures such as concrete bridge abutments and retainer walls, concrete drains and concrete and iron utility and sewer pipes and well casings. In shallow foundations built on pyrite-rich rocks, the expansive reaction that occurs in the conversion of pyrite to efflorescent iron sulfates can cause swelling and heaving (Dougherty and Barsotti, 1972; Grattan-Bellew and Eden, 1975; Quigley and Vogan, 1970) as well as acid deterioration. The reaction also produces great quantities of heat and causes problems when coal that contains reactive pyrite is stockpiled or shipped.

Over 5000 miles of streams in the United States have been ruined by acid drainage and the reaction costs mining industries over a million dollars a day simply to control it (U. S. Bureau of Mines, 1985). Damage to lands and streams that occurred before the reactions were understood, have probably produced losses in the hundreds of millions of dollars.

19) *Uraninite* (UO_2 - uranium dioxide) This specimen is included as a representative of natural uranium compounds in the geological environment. The mineral is black, metallic and of high density. However, when oxidized it is often accompanied by bright yellow phosphate mineral, carnotite. The best choice for field identification is a small portable Geiger counter. While uraninite is unlikely to be encountered in pure form by civil engineers, no manual which emphasizes engineering and environmental applications of Earth materials would be complete without consideration of radon gas (Adams and Lowder, 1964; Brookes, 1989; Cothern and Smith, 1987; EPA, 1986a and 1986b; Graves, 1987; Horton, 1985; Lafavore, 1987, Mafoske and Edelstein, 1988; Nazaroff and Nero, 1988; National Council on Radiation Protection and Measurements, 1975, 1984a, 1984b; Nero, 1985; Tanner, 1986; Vohra et al., 1982) which is a decay product of natural uranium. Low-level radiation occurs in virtually all geological materials. The most common sources are K^{40}, U^{238}, U^{235} and Th^{232}. The only source of radioactive radon gas (Radon-222) is U^{238}. All known natural uranium on our planet occurs in the proportion of $U^{238}/U^{235} = 137.8$. The assumption that the primordial materials from which the Earth was formed has U^{235} and U^{238} in equal amounts and that the amount of U^{235} has now decreased in comparison to U^{238} because of the faster decay rate of the former isotope, the time taken to change U^{238}/U^{235} from 1 to 137.8 is 4.6 billion years, which was the first radiometric date ever calculated for the age of the Earth. All subsequent dates computed from other isotope dating methods have continued to confirm the 4.6 billion year age as the age of the planet.

Radon gas can be released only where there is nearby uranium. While uranium occurs in all the rock suites, it is not usually so concentrated as to present a health hazard. Uranium is enriched in the light-colored igneous rocks such as granites, rhyolites and especially pegmatites. In sedimentary rocks, some uranium occurs in organic-rich sandstones but the overwhelming majority of uranium in the sedimentary environment occurs in marine shales and is particularly concentrated in black organic-rich marine shales. Almost all coals are low in uranium because the source of most uranium in organic rocks was the marine waters in which they accumulated, and nearly all coal is of terrestrial origin. Limestones and dolostones contain the lowest uranium (as well as thorium and potassium) content of all common rocks. Uranium is present in metamorphic rocks such as slates (particularly black slates), phyllites, schists and gneisses. Uranium is also enriched in soils, alluvium and glacial deposits that are derived from uranium-rich rock materials.

Because radon is a gas, it is easily inhaled. This gas itself decays quickly to yield a solid that lodges permanently in the lungs. The first solid formed (Polonium-218) then begins a rapid decay cycle that releases numerous alpha and beta particles inside the lung within a matter of minutes. The result is damage to lung cells. The actual magnitude of increasing the likelihood of contracting lung cancer as a result of exposure to small amounts of radon in the home has not been assessed at time of this writing, largely because there is lack of data on long-term exposure to homeowners (see Brookes, 1989). The present indication of potential danger comes from known populations of workers exposed to radon in uranium mines. These workers do have an increased frequency of lung cancer, but particularly those workers who smoke as well as suffer occupational exposure to radon. Natural radon probably does not pose a serious danger unless it is allowed to build up to high concentrations within poorly ventilated enclosures. A factor which may increase the recent incidence of hazardous radon concentrations is the employment of tighter, more energy-efficient construction methods that greatly reduce the "draftiness" associated with older buildings.

Radon-222 has a short half-life (only 3.8 days) that allows it to remain a toxic gas for less than a month, with 75% of radon produced at a given time decaying within one week after its formation. These constraints mean that radon must come either from uranium within a very immediate source (such as the materials used for construction or Earth materials in contact with the foundation) or there must be a conduits available for very rapid migration from deep below. Such conduits might be open fractures, old mines, or open well bores. Most radon contamination occurs as leakage from soil and bedrock into basement foundations. Sometimes, but rarely, water supplied by private domestic wells may be a source. In this last case, radon is dissolved in the water at depth in the domestic aquifer and everyday activities such as showering, flushing, heating or boiling of this water release the dissolved radon into the atmosphere of the building's interior.

20) *Chlorite* $(Mg,Fe,Al)_6(Al,Si)_4O_{10}(OH)_8$ - a complex group of basic ferromagnesian aluminum silicates). The chlorite group consists of a set of soft green micas that are easily identified by their color, softness (slightly less than the fingernail) and micaceous habit with non-elastic plates. Abundance of chlorite in a rock is generally used as an operational distinction between where deep burial diagenesis ends and metamorphism begins. While some chlorite occurs in soils and sedimentary rocks, the characteristic paragenesis for chlorite lies in low-grade metamorphism of other ferromagnesian minerals such as olivine and pyroxene. Nearly pure chlorite rocks called "greenstones" form from metamorphism of basaltic rocks. Some of these greenstones are enriched in chrysotile asbestos. Soapstones consisting of chlorite, talc and serpentine have long been used as

heat and reagent-resistant laboratory tabletops. Preferred downslope orientation of the chlorite sheets within large masses of rock may produce a directional weakness that is conducive to landsliding.

21) *Talc* ($Mg_3(Si_4O_{10})(OH)_2$- a basic magnesium silicate). Talc is a platy mineral distinguished by its greasy feel and the ease with which it can be scratched by the fingernail. The paragenesis of talc is distinctly metamorphic and it is formed by reaction of hydrothermal waters with ferromagnesian minerals. As a construction material, it is found with chlorite and serpentine in "soapstone" tabletops that are prized for laboratory tables because of the ease with which they can be cut and their inertness to heat and chemicals. Talc is also used as talcum powder. Although talc is presumably a harmless mineral itself, talc is paragenetically associated with serpentine. Therefore, it is obvious that not all talc deposits are safe for use such as talcum powders. This same realization raises caution when talc-rich rocks are excavated or mined in which case monitoring of the excavated materials for carcinogenic asbestiform minerals should precede and occur during all excavation operations. Severe dust control measures and even protective gear may be required. Preferred downslope orientation of the talc sheets within large masses of metamorphic rock may produce a directional weakness that is conducive to landsliding.

Coatings of talc, chlorite and serpentine along joints and concentrations of the same within thin foliated masses may make these zones unusually weak and prone to serve as slip planes for landslides and mine and tunnel failures.

22) *Garnet* (Common forms of garnet are $(Ca,Mg,Fe)_3Al_2(SiO_4)_3$). "Garnet" is a group name for a number of minerals that contain aluminum and silicon and crystallize in the cubic system. Garnets are recognized by their (cubic system) crystals and their extreme hardness (greater than glass or quartz). Most garnets are of metamorphic origin. The most common garnet type is the red *almandite* that is common as well-formed crystals in phyllites and schists. Garnet is economically valuable as an industrial abrasive, particularly for sandpaper.

3. Mineraloids

Mineraloids consist of solids that lack crystal structure. A large part of modern sediments consist of mineraloid materials; in many cases, mineraloids are predominant over minerals (Nuhfer and Anderson, 1985). Somewhat inexplicably, discussion of mineraloids has been traditionally omitted from almost all introductory undergraduate geology texts. The mineraloids form an important constituent of rock for engineering purposes. Mineraloids consist of a) glasses; b) organic matter and c) complex solids with silica, alumina, manganese, iron, phosphorus and sulfur that soon become ordered into common minerals such as quartz, clays, phosphate minerals, metal oxides, sulfides, or sulfates after burial. Only glasses and organic matter are easily studied in hand specimen or by light microscopy.

23) *Glasses* consist of various forms of amorphous silica. Opal is a special variety of hydrated glass. To distinguish most silicate minerals from glasses one may rely on conchoidal fracture, vitreous luster, and behavior in polarized light. Particles of glass are *isotropic* - that is, when they are viewed

between two polarizers set at 90° to one another, they remain dark no matter what their orientation. In contrast, most minerals (such as quartz) that are likely to be confused with glass are *anisotropic* - when particles of these are viewed between crossed polarizers set at 90° to one another, light is transmitted in most positions. Glasses are formed in two paragenetic environments - volcanic rocks and biogenically in sediments.

Natural glasses are short-lived geological phenomena. Most slowly recrystallize into quartz within a few tens of thousands of years. Modern volcanoes produce tremendous amounts of glass as obsidian, ash, pumice, and a partially glassy rock called *scoria*. In the sediments volcanic glass may be deposited by air-fall or by streams that drain drainage basins rich in volcanic glass. However most glasses in sediments are biogenically formed by algae (especially diatoms) sponges (in form of sponge spicules) and zooplankton (radiolaria). Small amounts of opal are produced from hot-spring deposits. Man is a source of glass in modern sediments. One can scarcely walk on any North American beach today (including those of the Great Lakes) without finding small and usually well-rounded glass pebbles from broken bottles or electrical resistors. Similarly, it is hard to study modern lake sediment under a microscope and not find some flyash spherules (flyash is a true man-made glass).

In terms of engineering importance, glass is more soluble than crystalline silica and is reactive to Portland cement when used as a concrete aggregate (Gillott, 1975). It is used as an abrasive, as a cleanser, ("Lava Soap"), a polishing compound and as a construction material filler. Diatomaceous Earth has many uses including use as a pesticide for shipping seeds (the sharp glass shards penetrate the carapaces of nuisance insects) and as a filter material.

Some volcanic glasses, particularly pumice are important construction constituents (Bates, 1969) and include lightweight aggregate used in construction of large buildings and in pozzolan cements. The use of lighter aggregates decreases the amount of structural steel required in buildings and the pozzolan cements are known for their resistance to infiltration and corrosion, particularly by sea water.

24) *Organic matter* consists of noncrystalline solids made mainly of carbon, hydrogen and oxygen with some sulfur, nitrogen and phosphorus. Organic matter is identified by its dark color. It is usually quantified by weight loss on ignition at 550° C after drying crushed and ground sample at 100° C. Although traces of organic compounds have been found even in meteorites, the dominant paragenesis of organic matter is in the biosphere where sediments are formed. Geochemically, solid organic matter is of two main types - marine (high hydrogen content and made predominantly from algae and zooplankton) and terrestrial (low in hydrogen content and made predominantly by vascular plants rich in cellulose.) The organic matter consist of *kerogen* and *bitumens,* the first impervious to almost all solvents and the latter extractable by some organic solvents. In addition to being a fuel source as coal and "oil shales" (kerogen-rich shale), organic matter in rocks may be studied either geochemically or by reflected light microscopy to learn about maximum burial depth of presently exposed rocks and even about the absolute age of some rocks. Both may be important considerations in siting of major structures.

In terms of engineering applications, soils rich in organic matter usually are soft and have notoriously low bearing capacities. The specific gravity of organic matter runs from about 1 to 1.6 and this greatly lowers the overall specific gravity of rocks which usually are about 2.6 to 2.7 without abundant organic matter. Rocks high in organic matter are strongly associated with high pyritic content and excavations in these may yield acid drainage problems. Marine rocks high in organic content are strongly associated with uranium enrichment that may produce radon gas enrichment in structures sited in or on such rocks or their derived soils. Some organic-rich marine rocks such as the black Pierre Shale of the Western U. S. are high in swelling clays and gypsum and thus are associated with swelling soil problems in foundations and with landslides and Earth flows. "Black soils" derived from black shales are not, as commonly thought by laymen, rich farm soils. Instead, the black kerogen is useless to plant growth and native plants growing on such soils are often stunted.

SOME PHYSICAL PROPERTIES OF COMMON EARTH MATERIALS

MATERIAL	LUSTER	COMMON COLOR	HARDNESS	DENSITY (g/cc)	CLEAVAGE
quartz	Vitreous	colorless to white*	7	2.65	none
orthoclase (K-spar)	Vitreous	flesh to red	6	2.54	yes - 2
Sodic plagioclase	Vitreous	white to gray	6	2.62	yes - 2
Calcic plagioclase	Vitreous	gray to dark gray	6	2.76	yes - 2
olivine	Vitreous	olive green	6.5 to 7	3.3 to 4.4	none
pyroxene	Vitreous	dark green to black	5 to 6	about 3.3	yes (2 subtle)
amphibole	Vitreous	dark green to black	5 to 6	about 3.3	yes (2 subtle)
biotite	splendent vitreous	black	2.5 to 3	2.8 to 3.2	yes - 1
muscovite	Vitreous	clear to white	2 to 2.5	2.8 to 2.9	yes - 1
kaolinite	dull, earthy	white when pure	2	2.6	yes - 1 microscopic
chrysotile	Vitreous	white to green	about 4	2.5 to 2.6	yes - not obvious
calcite	earthy to vitreous	white to gray & tan	3	2.71	yes - 3 rhombohedral
dolomite	earthy to sugary	white to gray & tan	3.5 to 4	2.84	yes - 3 rhombohedral
gypsum	earthy to vitreous	white	2	2.32	yes - 1 obvious
halite	Vitreous	white to colorless	2.5	2.16	yes - 3 cubic
hematite	earthy to metallic	deep red to black	5.5 to 6.5	5.3	none
limonite	earthy to submetallic	yellow, brown, black	5 to 5.5	3.6 to 4	none
pyrite	Metallic	brassy yellow	6 to 6.5	5	none
uraninite	Metallic	black w/ yellow coating^	5.5	9 to 9.7	none
chlorite	vitreous to greasy	dark green	2 to 2.5	2.6 to 2.9	yes - 1
talc	greasy to pearly	white to light green	1	2.7 to 2.8	yes - 1
garnet	Vitreous	mostly red*	6.5 to 7.5	3.5 to 4.3	none
glass	Vitreous	mostly brown and black	5.5	about 2.6	none
bituminous coal	dull to vitreous	black	about 2.7	1.3 to 1.5	none

*Table 3. Summary of physical properties of Earth materials. Substances marked with * commonly exhibit extreme variability of color even though common colors are given. ^ Uraninite, even though black, often occurs with oxidized forms of uranium-bearing minerals that exhibit bright yellow color. A Geiger counter is the only practical manner of identification in the field. Some important engineering rock properties such as hardness, density, solubility, and potential toxicity may be obtained from the mineral content alone. Look further in rocks at the fabric, texture and amount of void space to obtain a rough estimate of fluid transmissibility, strength, and degree of weathering. Beyond hand specimens, the overall characteristics of the rock mass, not simply the rock type must be considered. Hand specimen identification, physical testing and geophysical testing are all necessary and are never substitutes for one another.*

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Homework Assignment (Due April 3)

1) You have a choice between siting an underground house in soil above 1) a black shale or 2) a dolostone. Which house would be most likely to incur large quantities of radon gas?

2) We have covered two minerals that could cause expansive heave in foundations and basements. Name these three minerals.

3) You have a choice of two sand deposits for use as aggregate filler for Portland cement-based concrete. One is pure quartz sand, the other is quartz sand with large quantities of K-spar. Which concrete is likely to give the longest service and why?

4) Trout are very sensitive to pollution of any kind and require very clean well-oxygenated water. As an engineer, you are to make a 20 m high road cut through a dark marine shale at a site a few hundred yards up gradient of a trout hatchery. What consequences might result, if any? Explain.

5) You design an extensive concrete patio for an outdoor restaurant. You inspect the concrete after it is poured and the surface is well finished and correctly cured. The weather is warm and suitable for a good set and the structure is beautiful. Two years later map cracks develop all over the concrete, whitish efflorescences are present and the surface spalls. The patio is a disaster. What should you investigate as the possible cause(s)? What steps would have prevented the disaster?

6) You are a member of the school board. At a meeting the county building inspector with a degree in engineering technology declares that the school has asbestos in floor and ceiling tiles and in external furnace duct tape. He recommends that the board spend $250,000 for a local contractor to remove the asbestos and replace the offensive materials. What concerns should you raise?

7) What is the general relationship between type of chemical bonding dominant in a mineral and its weathering durability?