COMMON MINERALS - A PARAGENETIC ORGANIZATION WITH AN EMPHASIS ON ENGINEERING PROPERTIES

1. Chemistry of Common Earth Materials

Although there are over 2000 known minerals, and over 100 chemical elements, the majority of the crust can be characterized with just a few elements and minerals. If we analyze most rocks for *ten elements* (after heating to drive off any organic matter and carbon dioxide) and express the elements in oxide form, their summation will be close to 100%. The elements are the following:

$$\begin{array}{c}
\mathbf{SiO_2} \\
\mathbf{Al_2O_3} \\
\mathbf{Fe_2O_3} \\
\mathbf{CaO} \\
\mathbf{Na_2O} \\
\mathbf{K_2O} \\
\mathbf{MgO} \\
\mathbf{TiO_2} \\
\mathbf{MnO} \\
\mathbf{P_2O_5} \\
\hline
\mathbf{Sum = 100\%}
\end{array}$$

YES! Just ten elements constitute close to 100% of most rocks and soils. Concentrations of other elements occur within the crust, but geologically these are exceptional occurrences. Mining engineers will encounter these and because these often constitute economic deposits, a good part of the geologist's training is with these occurrences. However, civil engineers are builders and therefore deal with common Earth materials. From the standpoint of engineering geology, we want to know how these common elements affect our engineering properties, where they occur and what they mean.

It is useful to divide these elements into those that are easily moved in water solutions (*mobile*) and those that normally form insoluble compounds (*immobile elements*):

Mobile - $\mathbf{K^+}$, $\mathbf{Na^+}$, $\mathbf{Mg^{++}}$, $\mathbf{Ca^{++}}$
Immobile - $\mathbf{Al^{+++}}$, $\mathbf{Si^{++++}}$, $\mathbf{Fe^{+++}}$ **and** $\mathbf{Fe^{++}}$, $\mathbf{Ti^{++++}}$, and $\mathbf{Mn^{++}}$
Phosphorus lies in about the middle between mobile and immobile.

Because we want to see how materials change through time, this is a good initial way to look at earth materials. Most changes will result from attack by air and water.

Now, the form these elements appear in has a lot to do with their weathering rates. You probably remember the term, "*bonding*". Elements combine with one another in nature to form special compounds called *minerals*. The minerals have a formula that can be expressed as a chemical compound, a definite crystal structure, and the elements are held together in that structure by bonding from high school chemistry. The common earth materials are put together in two primary ways (two types of bonds - *ionic* and *covalent*). Ionic bonds are easily attacked by polar water molecules and hence a mineral which is dominantly held together with ionic bonds will be reactive, partially soluble, and likely to break down in a reasonably short time. Salt or halite is an extreme example. Covalent bonds, on the other hand, are not much affected by water molecules and hence these materials will be durable and inert. Quartz is an extreme example of a mineral that is dominantly covalently bonded together. A third type of bonding, *metallic* bonding, is present in many minerals; the civil engineer sometimes sees particularly the ore minerals and these. These are easy to spot because the metallic bond in the mineral gives it a metallic luster. Pyrite is an example.

If you remember much about your periodic table from chemistry, you know that those elements that form covalent bonds lie in and near Group IVa; *the silicon to oxygen bond is the most important one in the mineral kingdom, and it is very covalent*. Those elements that bond ionically with one another lie at extreme ends (Groups Ia, IIa & VIIa) of the table and those that exhibit metallic luster fall near the center (all Group B elements). When you look up the formula, this tells you something about the durability of the mineral.

Paragenesis essentially means a "community" of minerals that occur together. Much like you would expect to find a polar bear together with seals in the arctic rather than a black bear together with seals, so can you anticipate the occurrence of a given suite of minerals within a given environment. Four basic environments exist: *igneous, sedimentary, metamorphic and hydrothermal.* The first three are distinct rock groups. The fourth represents a suite of minerals that are carried into a rock by hot water solutions. The hydrothermal suite is found within any of the three rock groups, but is not formed at the time of the rock. Instead, deposition of these comes later and most of the hydrothermal suites contain minerals that are more rare.

Given this knowledge, let's divide the minerals into suites. Some may occur in one or more suites, but some are indicators of igneous, metamorphic, or sedimentary processes. An indicator mineral is one that if you find it in abundance, particularly with another indicator mineral, you can be almost certain that you can place the rock sample correctly into the correct suite. Indicator minerals are in italic.

<u>Igneous suite</u>: *Olivine, pyroxene*, amphibole, biotite, muscovite, *calcic plagioclase*, sodic plagioclase, *potassium feldspar*, quartz and *magnetite*. Obsidian included in the set is a glass, lacks crystal structure and hence is not a mineral.

<u>Sedimentary suite</u>: Quartz (including *chert*), *calcite, dolomite, kaolinite, hematite*, *halite sylvite, gypsum*, barite.

Metamorphic suite: Quartz biotite, muscovite, *chlorite, talc, garnet, serpentine*, some amphibole, *graphite*.

Hydrothermal Suite: *Chalcopyrite, galena, sphalerite*, quartz.

Now lets look at the properties of the minerals. Some have important engineering properties in themselves.

2. Igneous Suite

Olivine - a green, grainy ferromagnesian silicate. "Olivine" is actually a group of two minerals, *forsterite* and *fayalite.* The silica tetrahedra are isolated and held one to another by ionic bonding of iron and magnesium. The bond is strong so the mineral is hard, but because it is an ionic bond, olivine weathers easily to a rusty appearance and forms hematite and dissolved magnesium ion. Exterior facing stones with olivine will weather to ugly rust colored stained rocks within a short time.

Pyroxene - another green to black ferromagnesian silicate. 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. It weathers easily, but not so easily as olivine. This is because there is more covalent bonding in pyroxene.

Amphibole - a black to very dark green ferromagnesian silicate. The structure is double chains of silica 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 degrees. It is more durable than pyroxene in weathering.

Biotite - a black ferromagnesian mica with the silica structure arranged as sheets. Weak bonds of iron, magnesium and small amounts of alkaline earth elements hold the sheets together. Biotite weathers to *vermiculite*.

Muscovite is a white mica - a potassium aluminum silicate. It had important commercial uses in electrical capacitors in World War II. It is still used as filler for asphalt roofing. Muscovite is very durable and often survives through the sedimentary weathering cycle. Weathered clay-sized muscovite that has lost some of its potassium is called "*illite*".

Plagioclase is a group name applied to aluminosilicates with a calcic end member (*Anorthite*) and a sodic end member (*Albite*). The calcic end member is usually dark gray and occurs with olivine and pyroxene in basalts. Anorthite weathers more easily than albite. Plagioclase weathers to give dissolved sodium and calcium in waters and residual clay.

Potassium feldspar forms a group of aluminosilicates that are common in all three-rock suites. The most common is orthoclase that is usually pink, and has two good cleavages nearly at right angles. It is the dominant mineral in granite.

Both plagioclase and orthoclase are durable and orthoclase in particular is common in sands. Sands high in these feldspars may have a swelling reaction (alkali-aggregate reaction) when mixed with Portland cement. The reactions are understood and can usually be overcome by using additives.

Quartz is the most common mineral of all, mostly because silica and oxygen are the two most common elements in the crust and the two elements have a strong affinity for one another. It is a three dimensional network of tetrahedra, wherein every corner of the tetrahedra is shared with another tetrahedra. The covalent bond is strong and shared equally in all directions. Hence the mineral is hard and durable. High quartz sand is in great demand as an aggregate and as a raw material for the glass industry. It has many uses in engineering, from filter sand to construction filler for concretes.

Magnetite - a hard black mineral with a metallic luster that is attracted to a magnet. Its presence indicates high temperature of the igneous rock body. It is mined as a source of iron in a few countries, particularly Sweden and Canada.

3. Sedimentary Suite

The sedimentary suite is composed of *precipitates* an*d clas*tic minerals. Clastic minerals are made of fragments and grains of the less soluble minerals (those made from immobile elements).

3.1 Precipitates

Calcite (calcium carbonate) is the most common precipitate. It forms limestones and is easy to identify because it is only slightly harder than the fingernail and fizzes readily in weak (2%) HCl. It comes in a variety of forms including chalk. Many crustaceans make their shells and exoskeletons of calcite - clams snails, oysters, corals, etc. and this accounts for the abundance of fossils in many limestones. The greatest former of limestones though is algae. Calcite is the most common construction material. It is used as everything from a required ingredient of Portland cement to building block. It is durable, particularly in arid environments. The Egyptian Pyramids are made of limestone (calcite). There are over a hundred commercial uses for lime and limestone.

Dolomite is a calcium magnesium carbonate. Most dolomites form slowly in limestones after burial. The slow reaction of formation prevents its manufacture in the lab at normal earth surface temperatures. Eventually, whole limestone formations may be converted to dolomite (dolostone). It looks like calcite in appearance but is actually distinguished by a slower reaction to 2% HCl. Dolostones are used as aggregates. The dolomite reaction with concrete and the dolomite pop outs noted in asphalt are usually due to clay impurities in the stone used, not in the dolomite itself.

Gypsum is a hydrated calcium sulfate, usually white to tan, that is identified by its softness and lack of a greasy feel. It is used extensively in construction of wallboard and plaster and in some places is used as a soil conditioner.

Halite (sodium chloride) is identified by its salty taste and cubic cleavage. It has many industrial uses, particularly in the chemical industry. It is an important contributor to civilization. The word "salary" comes from the fact that workers were once paid in salt that was a highly prized commodity before it became widely available.

Sylvite (potassium chloride) has a reddish color, cubic cleavage and a cool bitter taste. It has many industrial uses and is a source of potassium for fertilizers.

Barite or barium sulfate occurs as nodules in limestones and as vein and cavity fillings left by hydrothermal solutions. It is one of the most insoluble minerals known. Its high density makes it useful in drilling muds for deep drilling.

3.2 Clastic Minerals

Quartz (including chert) is found from clay-sized particles in mudrocks to quartzite boulders in conglomerates. Chert is a water lain cryptocrystalline variety that often occurs as nodules in limestones and dolostones. It causes fast wear on crushers because of its hardness, breaks into sharp shards which puncture tires when it is used as crushed stone surfacing for secondary roads, and reacts with alkali in cement to produce a swelling reaction that disintegrates concrete (alkali-silica reaction).

Kaolinite (aluminum silicate) is one of the simplest clay minerals. It is not a swelling clay and is a common constituent of many soils. It is distinguished by its softness, earthy odor, and lack of reaction to HCl. It is used in high gloss papers and in ceramics.

Limonite and *hematite* are iron oxides that are distinguished by their respective yellow brown and red brown streaks. Most specimens show their true color. However, metamorphosed hematite is converted into larger black metallic flakes (specular variety) that look wholly unlike the sedimentary variety. It still reveals red-brown in its streak. Hematite is the most common of iron minerals.

Pyrite (iron sulfide) is common in highly organic sedimentary rocks such as coal and black shale. In excavations, it is highly reactive to water and air and produces acid drainage through its reaction. This drainage is one of the major sources of water pollution in the east and lower Midwest. When formed in metamorphic rocks, the crystals are large, cubic, and distinguished by their luster, color, form and hardness.

4. Metamorphic Suite

Biotite and *Muscovite* (discussed under igneous rocks) are abundant in gneisses and schists. Their platy nature provides weaknesses in rocks that undergo stress parallel to the alignment of the platy mineral flakes.

Talc is a magnesium silicate formed by reaction of waters with ferromagnesian minerals. Its greasy feel and the ease with which it can be scratched by the fingernail distinguish it. As a construction material, it is found with chlorite in "soapstone" tabletops that are prized for laboratory tables because of the ease with which they can be cut and their inertness to most chemicals. Talc is also used as talcum powder

Chlorite is another group name for a complex (ferromagnesian aluminum silicates) set of soft green micas. Chlorite forms from metamorphism of other ferromagnesian minerals such as olivine and pyroxene. Orientation of the chlorite sheets produces an orientation of weakness within some metamorphic rocks.

Serpentine is one of the amphiboles. It is fibrous and the asbestos variety has many industrial applications, particularly in brake liners and brake pads. Much of the "asbestos scare" today is nonsense. Only a few varieties are actually carcinogenic, yet all "asbestos" is being treated as the same hazardous material. The costs of extracting it from buildings may make "mining" it from structures as one of the major mineral extraction economies in the nation.

Garnet - "garnet" is a group name for a number of minerals that contain aluminum and silicon and crystallize in the cubic system. The most common are the red almandine garnets that are common as well-formed crystals in metamorphic rocks. Garnet is a common industrial abrasive. It is usually recognized by its hard red to brown crystals.

Graphite - is a form of carbon that results from metamorphism of coal. It is slick, black, metallic in luster and serves an important function as an industrial lubricant.

5. Hydrothermal Suite

All of the following minerals are sulfides. A civil engineer would rarely encounter them.

Chalcopyrite - an ore of copper (Copper-iron-sulfide) is identified by a deep gold color and distinguished from pyrite by being softer than glass. and lacking well-formed crystals characteristic of pyrite.

Galena - an ore of lead is easily distinguished by its black color, cubic cleavage, and high specific gravity.

Sphalerite - an ore of zinc that is most easily distinguished by its light yellow streak and its resinous luster.

6. Web Sites

www.tms.org/ (Minerals, Metals and Materials Society)
http://minerals.usgs.gov/minerals/ (US Geological Survey Minerals Information)

MINERALS HOMEWORK ASSIGNMENT (Due March 15)

Problem 1: (adapted from *Geoscience Laboratory*, by T. Freeman, Wiley, 1996).

Answer the following questions about economic minerals

Galena [PbS]-the principal source of lead.

Question 1: Name one industrial use for lead.

Magnetite [Fe_3O_4], hematite [Fe_2O_3], and limonite [Fe_2O_3, $2H_2O$]- sources of iron.

Question 2: Name one industrial use for iron.

Bauxite [Al_2O_3. $2H_2O$]-the singular ore of aluminum.

Question 3: Name one industrial use for aluminum.

Chalcopyrite [Cu FeS_2]-the principal ore of copper.

Question 4: Name one industrial use for copper, other than that in the minting of one-cent pieces.

Quartz [SiO_2]-used in the manufacture of glass and electronic components.

Question 5: Name a common electronic component made from quartz.

Gypsum [$CaSO_4$ $2H_2O$]-used in the production of sheetrock and plaster of Paris.

Question 6: Give a common use for plaster of Paris.

Fluorite [CaF_2]-chief source of fluorine.

Question 7: Name two commercial uses of fluorine that are accepted as benefits to our health.

Sphalerite [ZnS]-the singular ore of zinc.

Calcite [$CaCO_3$]-Portland cement, soil conditioner.

Garnet [$Al_2(SiO_4)_3$ + other metals]-abrasives, semiprecious stones.

Question 8: Garnet is the birthstone for what month? What is your birthstone?

Olivine [$(Fe, Mg)_2SiO4$]-silicon chips for computers.

Halite [NaCl]--common salt; important source of sodium and chlorine.

Question 9: Name a use for salt other than that in the kitchen

Graphite [C]-lubricant, pencil lead.

Barite [$BaSO_4$]-source of barium; the mineral is used as a weighting material in oil-well drilling mud.

Sulfur [S]-source of sulfur.

Muscovite [$KAl_2(AlSi_3O_{10})(OH)_2$]-a computer chip substrate, electrical insulation; glitter used in paint, in wallpaper, and for the "snow" sprinkled on Christmas trees. Used as window panes in early houses and industrial furnaces.

Kaolinite [$H_4Al_2Si_2O_9$]-an ingredient that inhibits the melting of chocolate candy. Also an ingredient in over-the-counter medication taken for the treatment of temporary stomach disorder.

Talc [$Mg_3Si_4O_{10}(OH)_2$]-lubricating and drying agent.

*Question 10: Name a household product that uses talc as a principal ingredient***.**

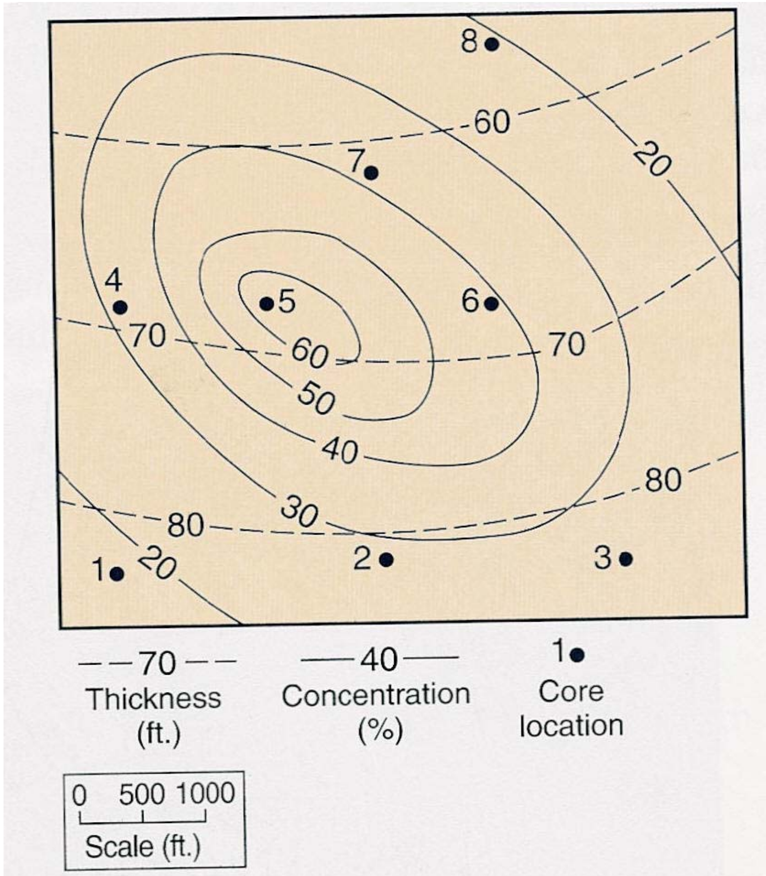
Problem 2: The concentration of gold in the oceans is estimated to be only 0.011 μg (10^{-6} g) per liter. If it could be mined, how much total amount of gold would you then find in the oceans? How does it compare to the amount of gold in continental ore deposits? Mass of oceans is 3 x 10^{21} kg. Mass of Earth is 5.98 x 10^{24} kg.

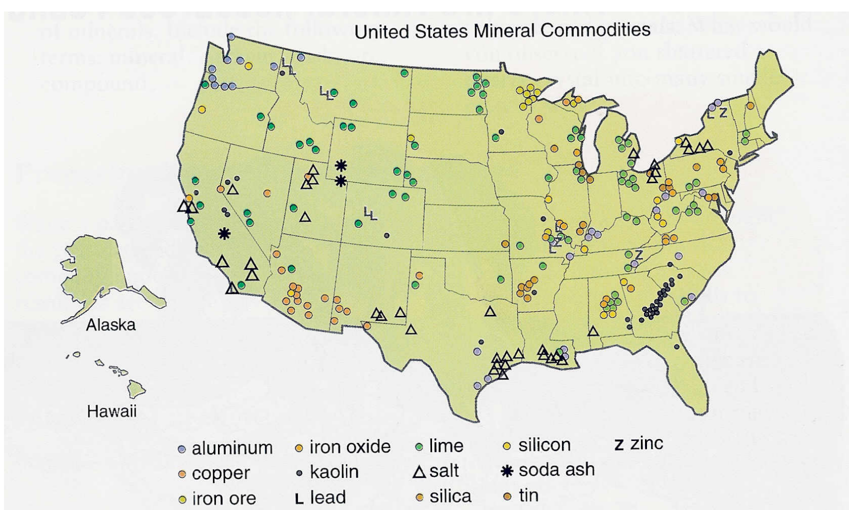
Problem 3: (from EarthComm – Earth's Natural Resources, 2002, pp. R125)

The map below shows the thickness of a rock formation consisting of limestone and dolostone. The data from the map come from the drilling of eight boreholes, taking core samples, and measuring the thickness of the formation in each core. The map also shows the percentage of dolostone in the formation at each location. The dolostone contains the highest percentage of lead-zinc ore.

Answer the following questions:

1. Areas where dolostone exceeds 50% have profitable ore. Color these areas green
2. What is the thickness range of dolostone in the profitable area?
3. What is the approximate surface area (in ft^2) of dolostone in the profitable area?
4. If the average profit on the dolostone is $0.30 per cubic yard, what is the approximate company gain?





United States Mineral Commodities
(from EarthComm – Earth's Natural Resources, 2002, pp. R112)