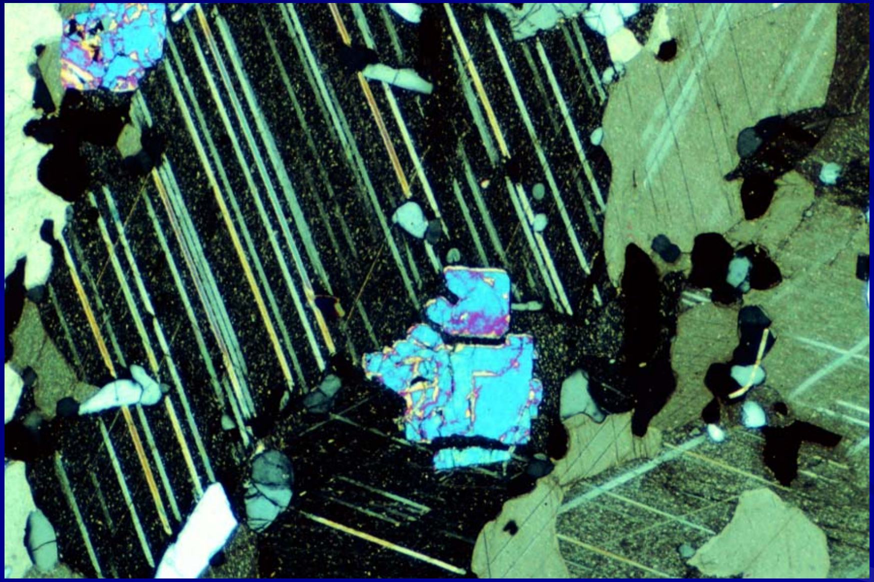
Minerals
Definition, Types, and Identification
Forensic Applications

Department Environmental, Earth, & Atmospheric Sciences

Transparent emerald, the green variety of beryl, on calcite matrix



Niocalite (blue) in sovite (calcite + apatite). Oka carbonatite complex. Crossed-polars. Width = 5.4 mm

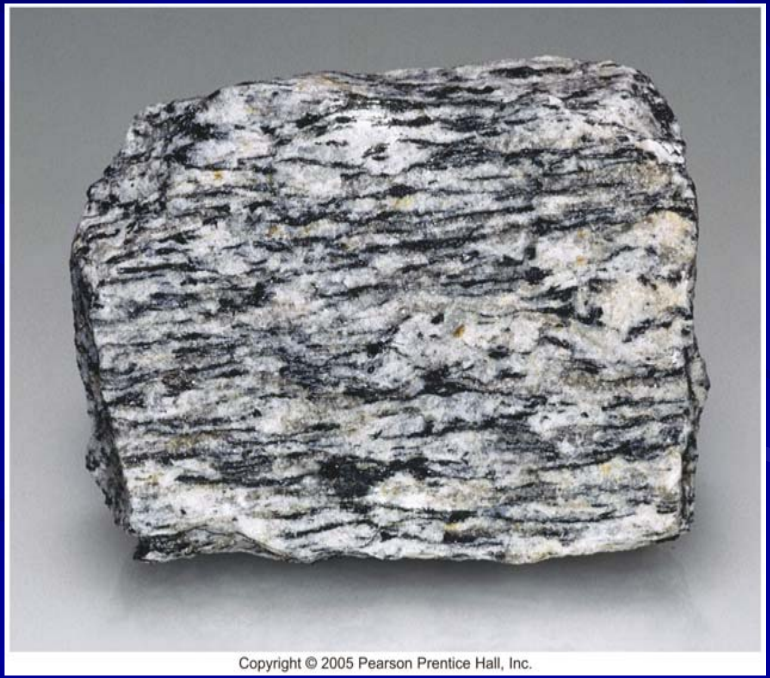
UMASS LOWELL

Department Environmental, Earth, & Atmospheric Sciences

Minerals

- **Building blocks of rocks, soil ,dirt, and mud**
- **Minerals are everywhere**
- **Rocks are aggregates of one or more minerals**

Fluorite



Gneiss

Mineral Definition

1. **Naturally Occurring**

2. **Inorganic**

3. **Crystalline – has a definite internal structure, i.e., atoms in the mineral are arranged in a regular way**

4. **Chemical composition fixed or varies within certain limits**

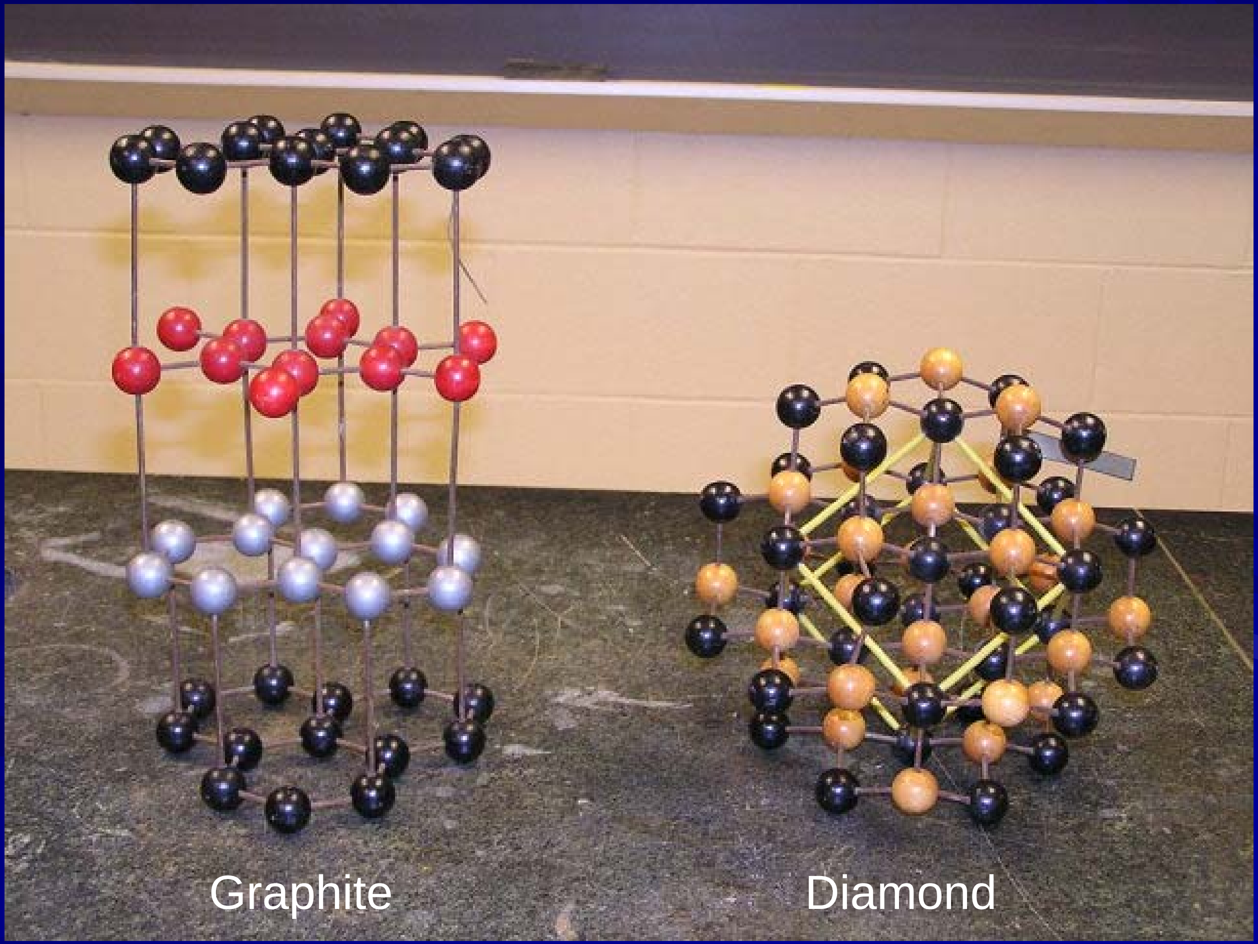
Minerals

- **Naturally Occurring** - minerals must be formed naturally - glass, concrete, synthetic diamonds, rubies and emeralds don't count
- **Inorganic** - minerals are not formed by anything that was ever alive. Therefore, materials such as: Ivory, Amber, Coal, Pearls **are not minerals!**




Minerals

- **Crystalline** - **the atoms in minerals have an orderly atomic arrangement giving them a definite structure that controls their properties.**



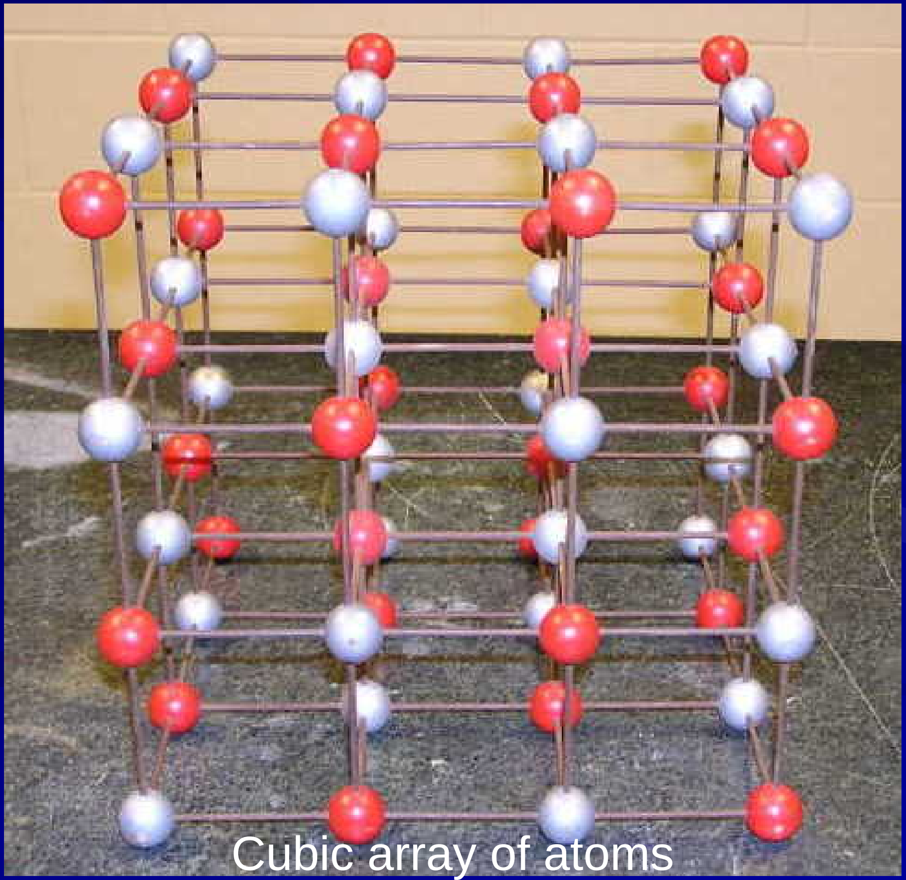
UMASS LOWELL

Department Environmental, Earth, & Atmospheric Sciences

Minerals

- **Chemistry** - **Chemical composition is fixed or varies within certain limits. Crystalline compounds with the same structure but different chemistry form different minerals.**

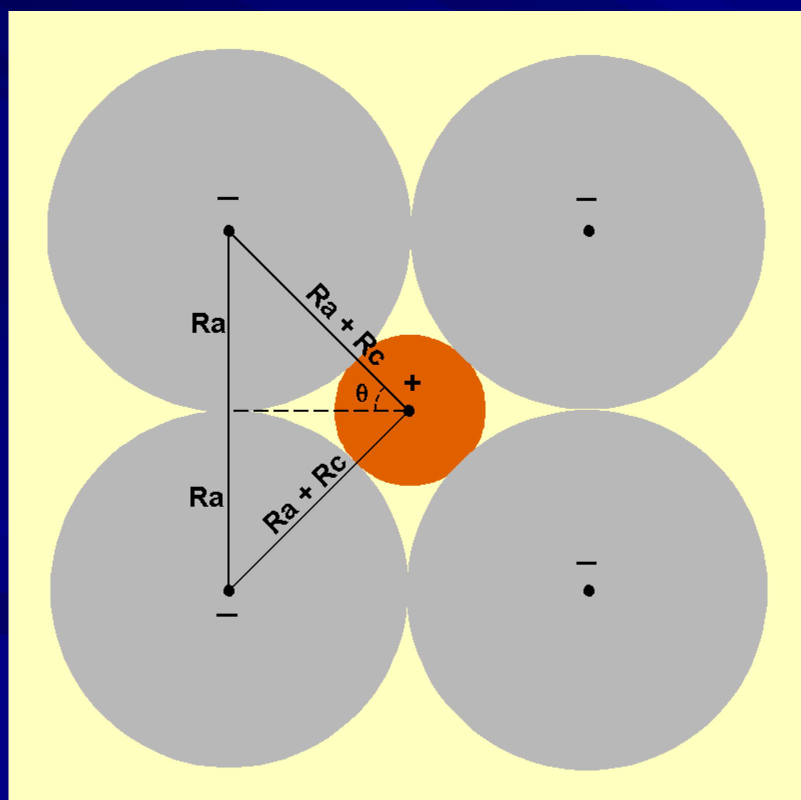
NaCl = Halite

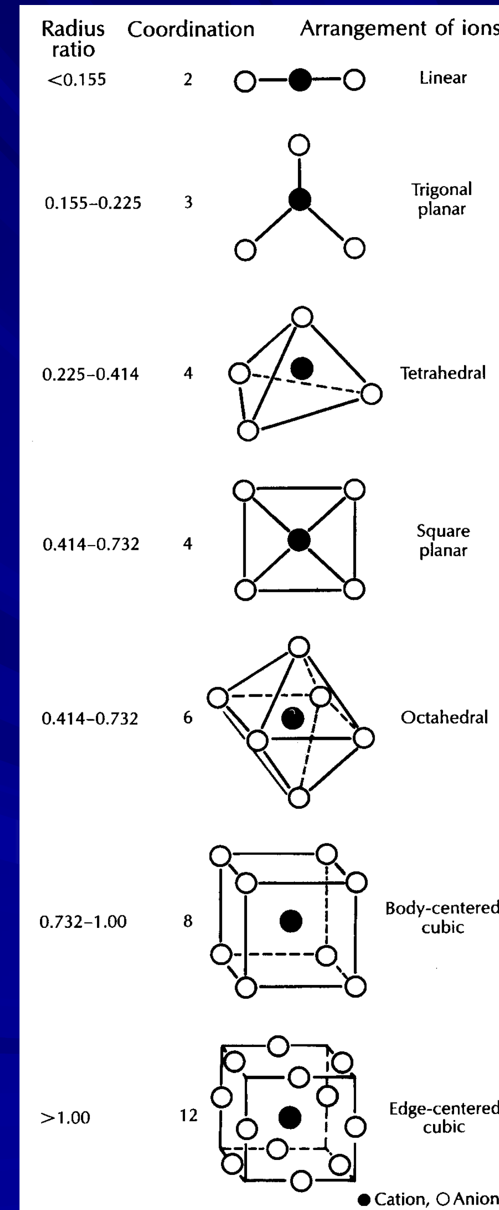

Cubic array of atoms

KCl = Sylvite

Structure of Minerals

Ions are arranged in crystal structures according to their relative sizes. This is referred to as closest packing. We usually look at this from the perspective of the cation and calculate the radius ratio = size cation/size anion. The radius ratio determines the number of anions that can be packed around a particular cation.



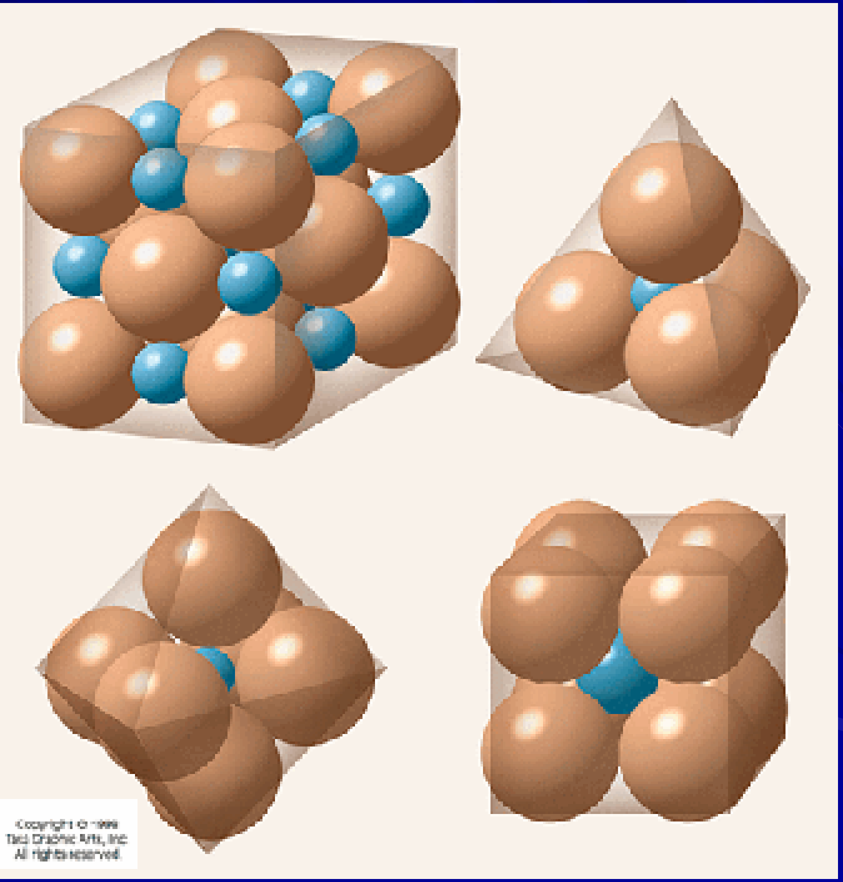


Department Environmental, Earth, & Atmospheric Sciences

Structure of Minerals

<u>Crystal Lattice</u>: the three dimensional molecular structure of a mineral. (Shape of the "unit cell.")

- Various ions make up the mineral.
- Geometry + chemistry!

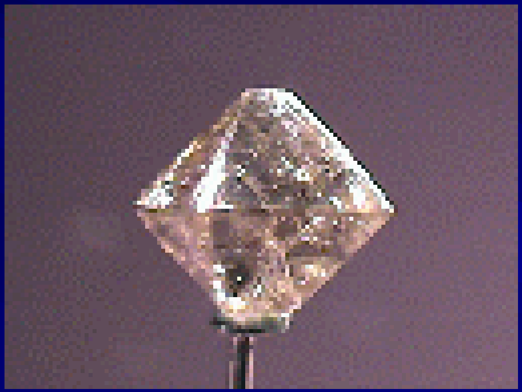


Structure of minerals

Department Environmental, Earth, & Atmospheric Sciences

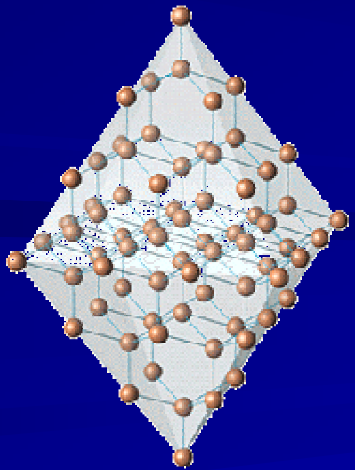
Polymorphs

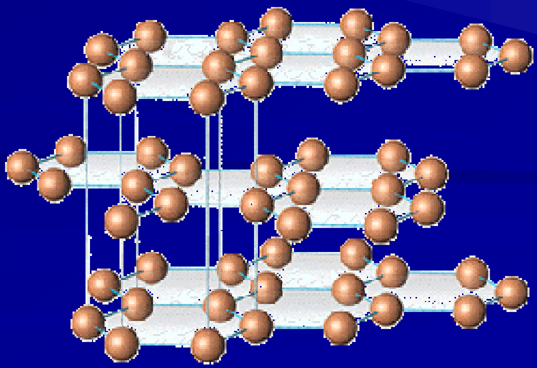
- Minerals with the same composition but different crystalline structures
- Examples include diamond and graphite
- Phase change – one polymorph changing into another



Diamond

Graphite





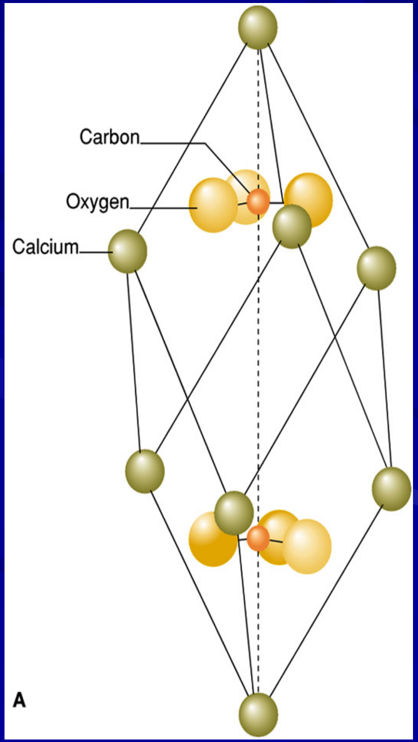
UMASS LOWELL
Department Environmental, Earth, & Atmospheric Sciences

Physical properties of minerals

Crystal Form

- **External expression of a mineral's internal structure**
- **Often interrupted due to competition for space and rapid loss of heat**

Crystals are the smallest "bits" of minerals and reflect the geometry of the mineral molecules



UMASS LOWELL

Department Environmental, Earth, & Atmospheric Sciences

Physical properties of minerals

Color

- Generally unreliable for mineral identification
- Often highly variable due to slight changes in mineral chemistry
- Exotic colorations of certain minerals produce gemstones
- Some minerals are used as pigments

Quartz (SiO_2) exhibits a variety of colors

Department Environmental, Earth, & Atmospheric Sciences

Physical properties of minerals

Streak

Color of a mineral in its powdered form

Streak is obtained on an unglazed porcelain plate

Department Environmental, Earth, & Atmospheric Sciences

Physical properties of minerals

Luster

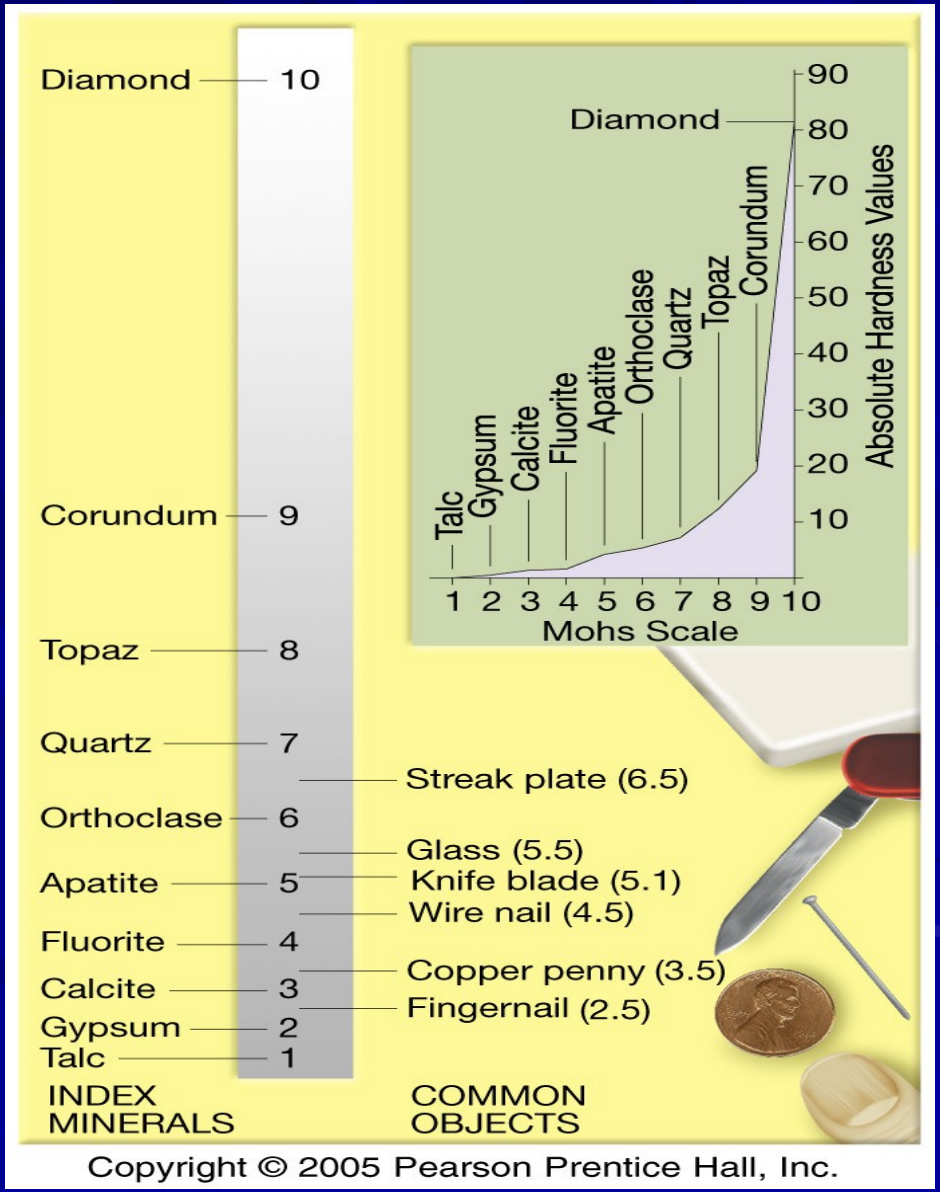
- Appearance of a mineral in reflected light
- Two basic categories
  - Metallic
  - Nonmetallic
- Other descriptive terms include vitreous, silky, or earthy

Galena (PbS) displays metallic luster

Physical properties of minerals

Hardness

- The hardness of a mineral is its resistance to scratching.
- The standard scale for measuring hardness is Moh's Hardness scale.



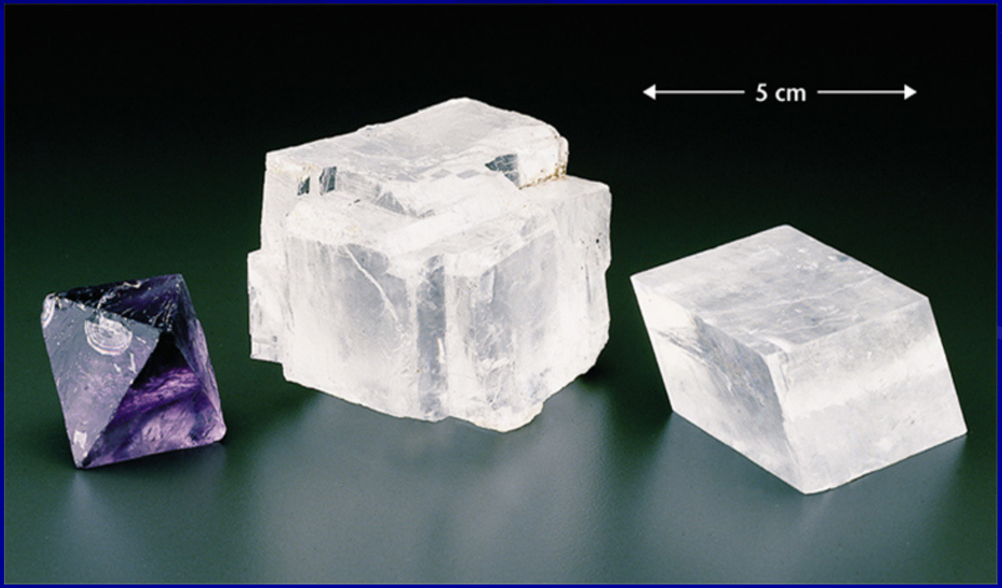
UMASS LOWELL
Department Environmental, Earth, & Atmospheric Sciences

Physical properties of minerals

Cleavage

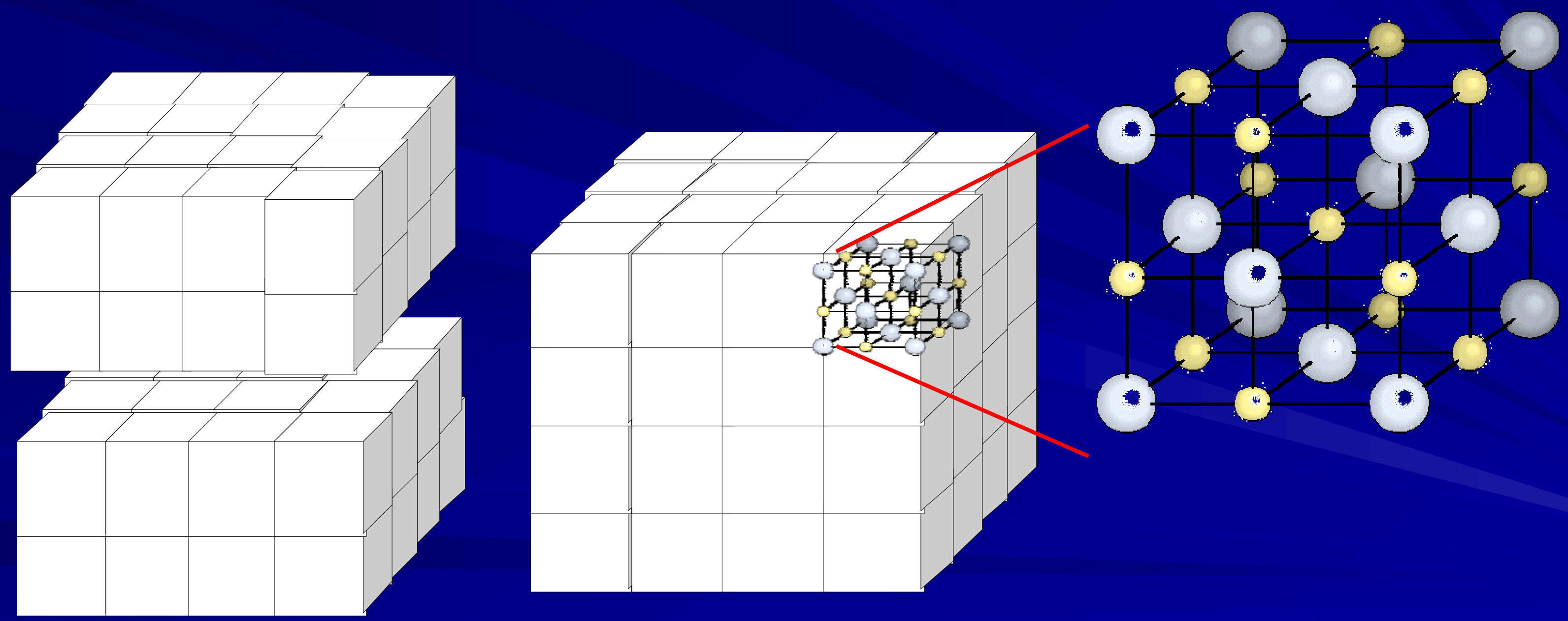
- **Tendency to break along planes of weak bonding**
- **Produces flat, shiny surfaces**
- **Described by resulting geometric shapes**
  - **Number of planes**
  - **Angles between adjacent planes**

Fluorite, halite, and calcite all exhibit perfect cleavage



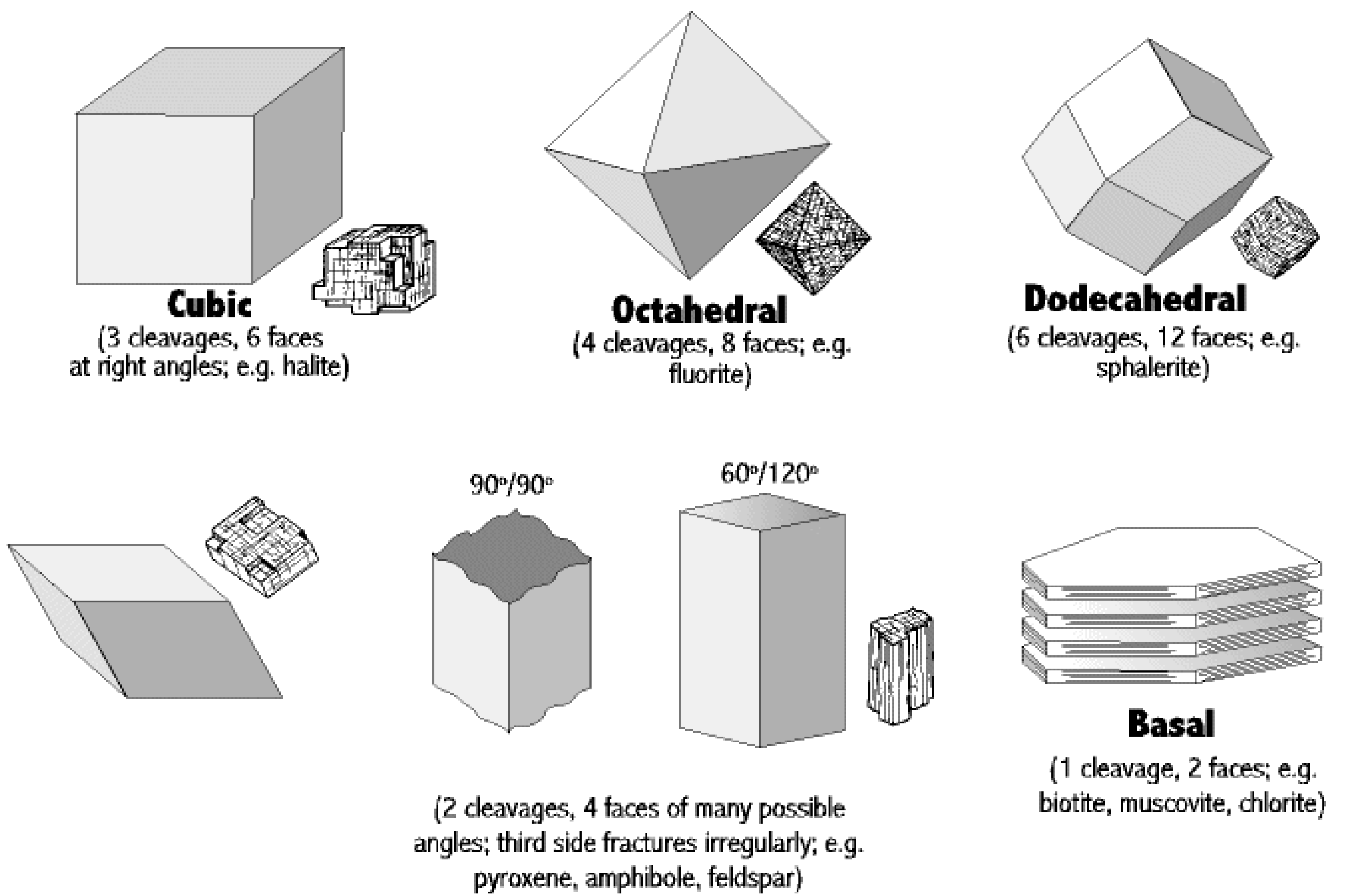
Cleavage

Due to planes of weakness caused by alignment of the common crystal faces



Department Environmental, Earth, & Atmospheric Sciences

Mineral Cleavage and Crystal Form



UMASS LOWELL
Department Environmental, Earth, & Atmospheric Sciences

Physical properties of minerals

Fracture

- Absence of cleavage when a mineral is broken

Specific Gravity

- Weight of a mineral / weight of an equal volume of water
- Average value = 2.7

Other properties

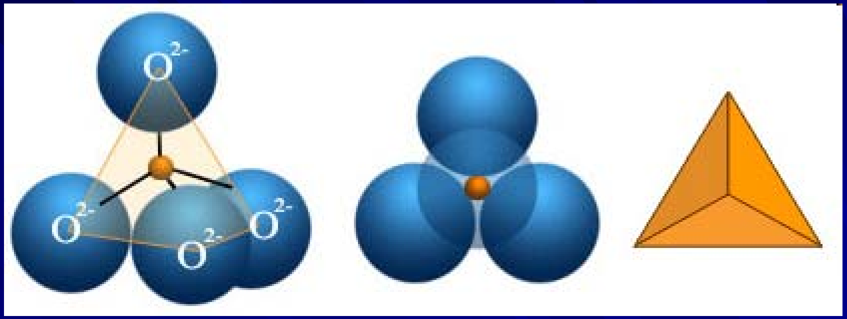
Magnetism
Reaction to hydrochloric acid
Malleability
Double refraction
Taste
Smell
Elasticity

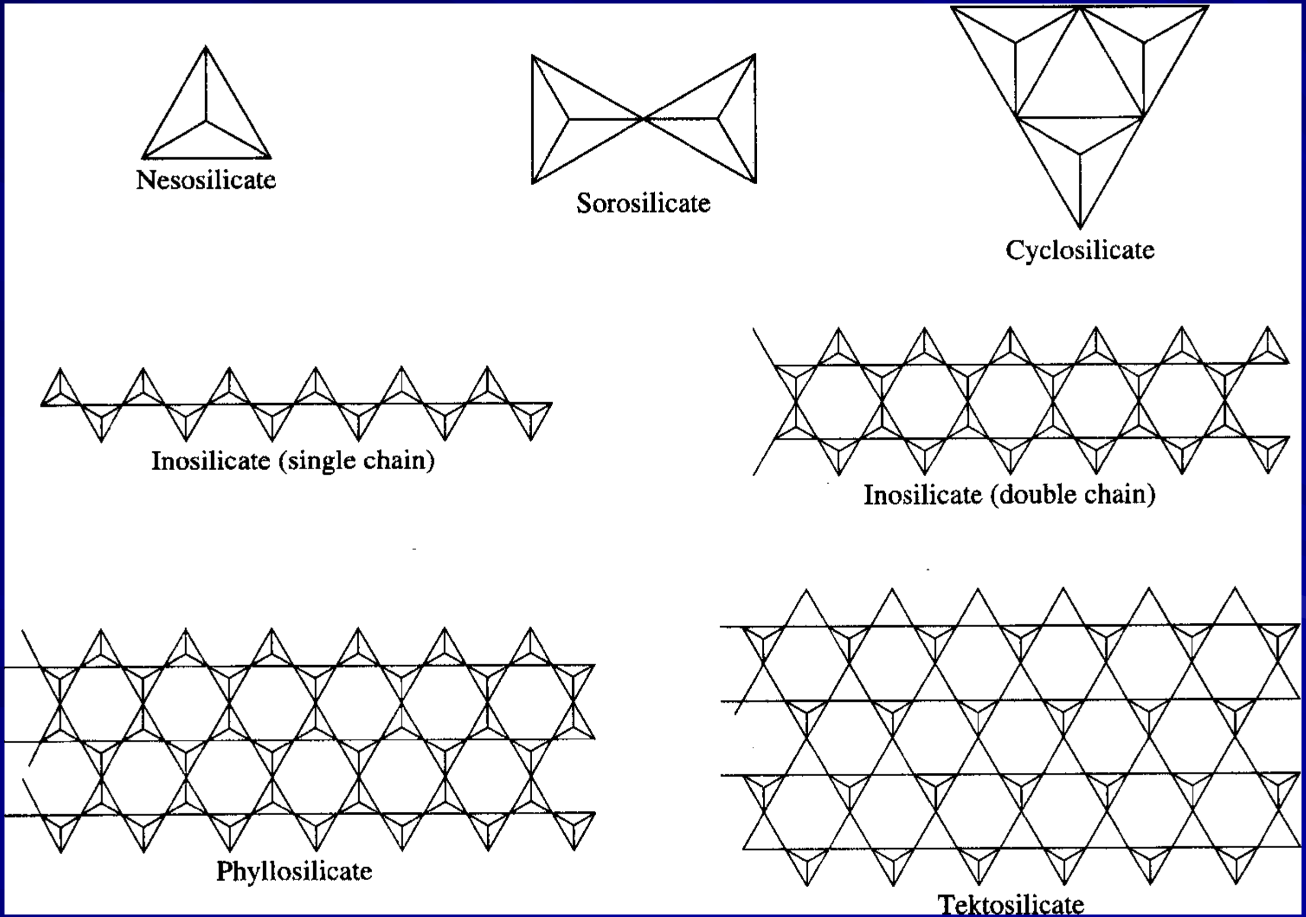
Table 7-1. Mineral classes

Class	Chemical characteristics	Examples
Borates	Various elements in combination with boron	Borax [$Na_2B_4O_7 \cdot 10H_2O$]
Carbonates	Metals in combination with carbonate (CO_3^{2-})	Calcite [$CaCO_3$] Cerrusite [$PbCO_3$]
Halides	Alkali metals or alkaline earths in combination with halogens (F, Cl, Br, I)	Halite [NaCl] Fluorite [CaF_2]
Hydroxides	Metals in combination with hydroxyls (OH^-)	Brucite [$Mg(OH)_2$]
Native elements	Pure compound of a metallic or nonmetallic element	Gold [Au] Graphite [C]
Oxides	Metals in combination with oxygen	Hematite [Fe_3O_4]
Phosphates, arsenates, vanadates, chromates, tungstates & molybdates	Various elements in combination with the ZO_4 radical where Z = P, As, V, Cr, W, Mo	Apatite [$Ca_5(PO_4)_3(F,Cl,OH)$ Carnotite [$K_2(UO_2(VO_4)_2 \cdot 3H$ Scheelite [$CaWO_4$]
Silicates	Metals in combination with silica tetrahedra (SiO_4^{4-}) forming three dimensional networks, sheets, chains and isolated tetrahedra	Quartz [SiO_2] Forsterite [$MgSiO_4$] Orthoclase [$KAlSi_3O_8$]
Sulfates	Alkaline earths or metals in combination with sulfate (SO_4^{2-})	Barite [$BaSO_4$] Epsomite [$MgSO_4 \cdot 7H_2O$]
Sulfides	One or more metals in combination with reduced sulfur or chemically similar elements (As, Se, Te)	Pyrite [FeS_2] Galena [PbS] Skutterudite [$CoAs_3$]

Department Environmental, Earth, & Atmospheric Sciences

The most common minerals in the Earth's crust are silicate minerals. The basic building block for the silicate minerals is the silica tetrahedron.





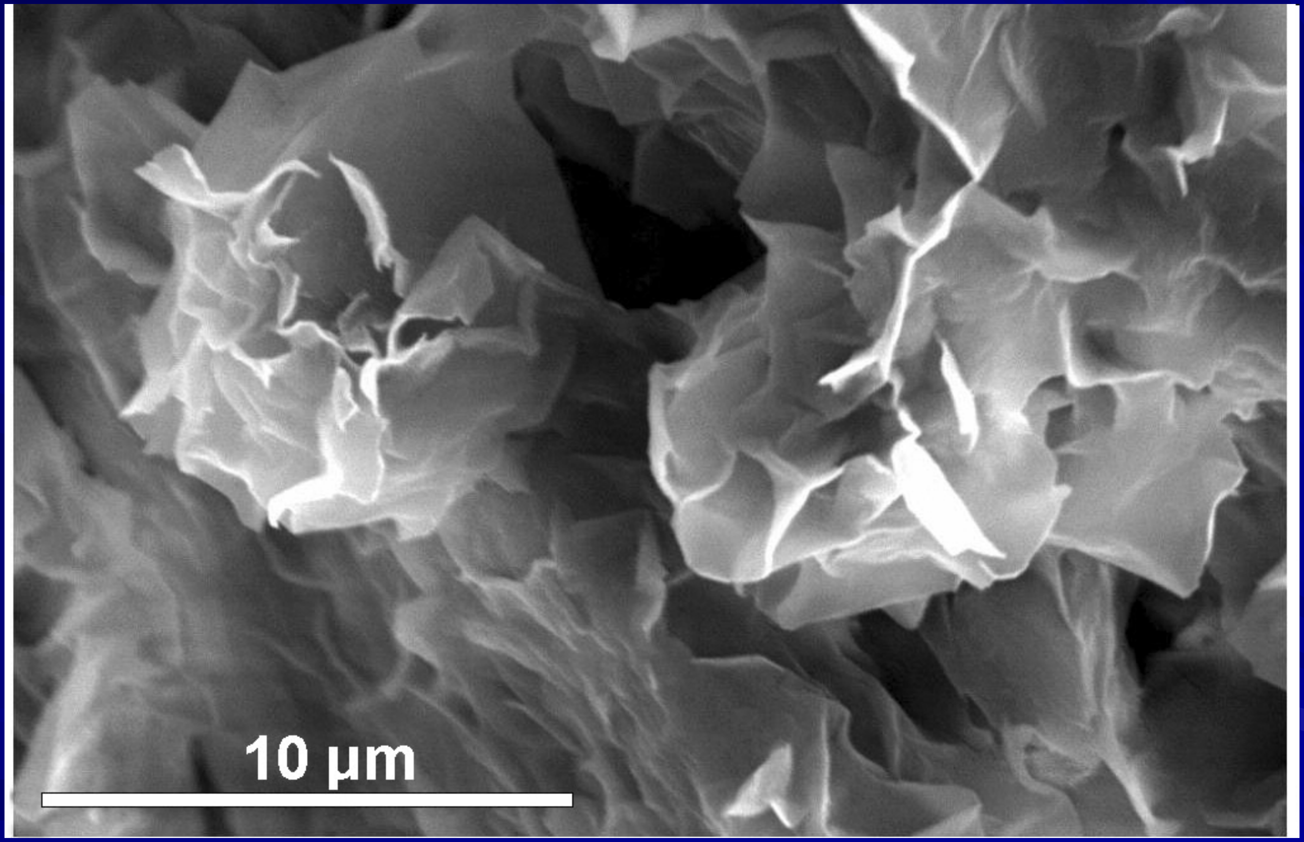
Department Environmental, Earth, & Atmospheric Sciences

Table 7-4. Properties of the silicate crystal classes

Class	Tetrahedral arrangement	# shared corners	Chemical unit	Si:O	Example
Nesosilicate	Independent tetrahedra	0	SiO_4^{4-}	1:4	Olivine
Sorosilicate	Two tetrahedra sharing a corner	1	$Si_2O_7^{6-}$	1:3.5	Melilite
Cyclosilicate	Three or more tetrahedra sharing two corners, forming a ring	2	SiO_3^{3-}	1:3	Beryl
Inosilicate	Single chain of tetrahedra sharing two corners	2	SiO_3^{3-}	1:3	Augite
	Double chain of tetrahedra alternately sharing two or three corners	2.5	$Si_4O_{11}^{6-}$	1:2.75	Hornblende
Phyllosilicate	Sheet of tetrahedra sharing three corners	3	$Si_2O_5^{2-}$	1:2.5	Kaolinite
Tektosilicate	Framework of tetrahedra sharing all four corners	4	SiO_2	1:2	K-feldspar

Clay Minerals

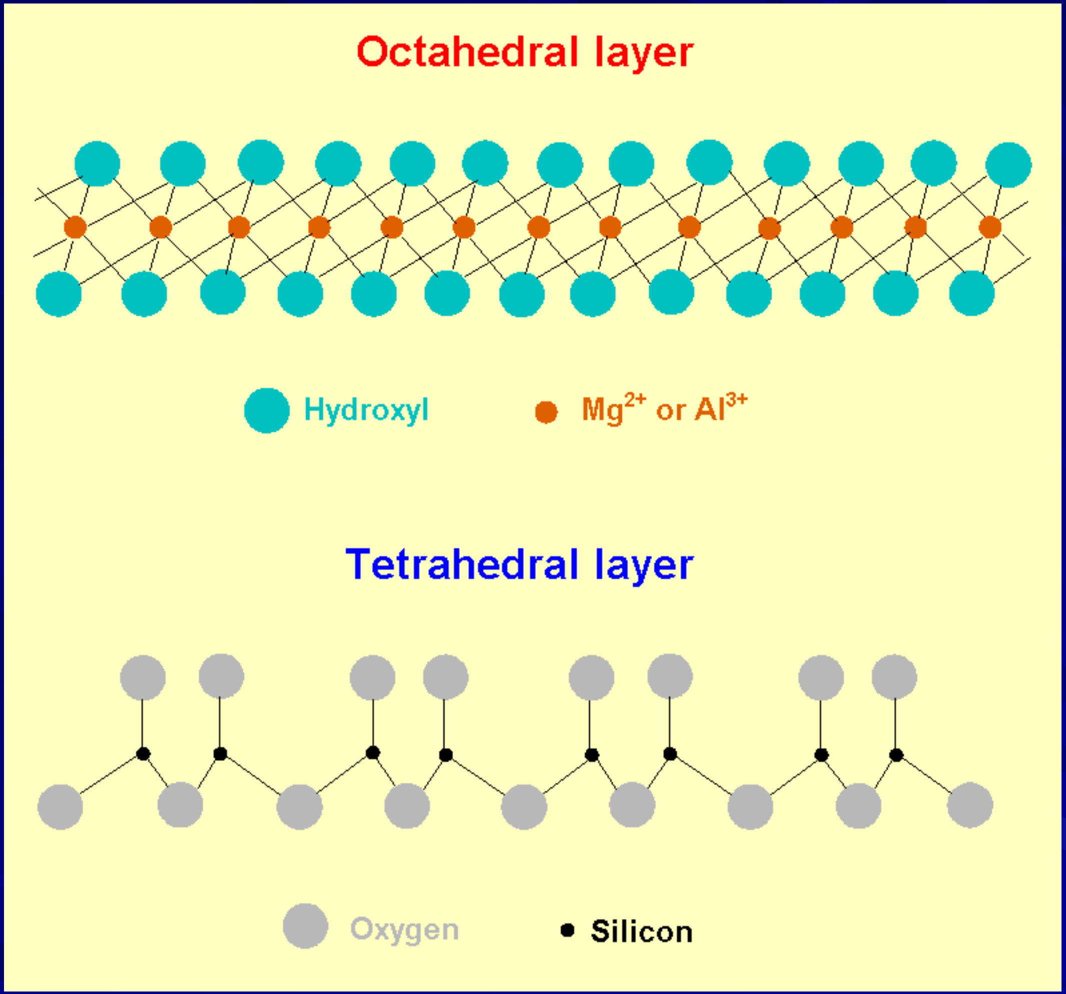
Quartz (SiO_2) and the clay minerals are the most common components of soil.



Montmorillonite showing a rose like texture, Miocene arkose, Madrid Basin, Spain.

Department Environmental, Earth, & Atmospheric Sciences

Clay minerals are built by combining tetrahedral and octahedral layers.

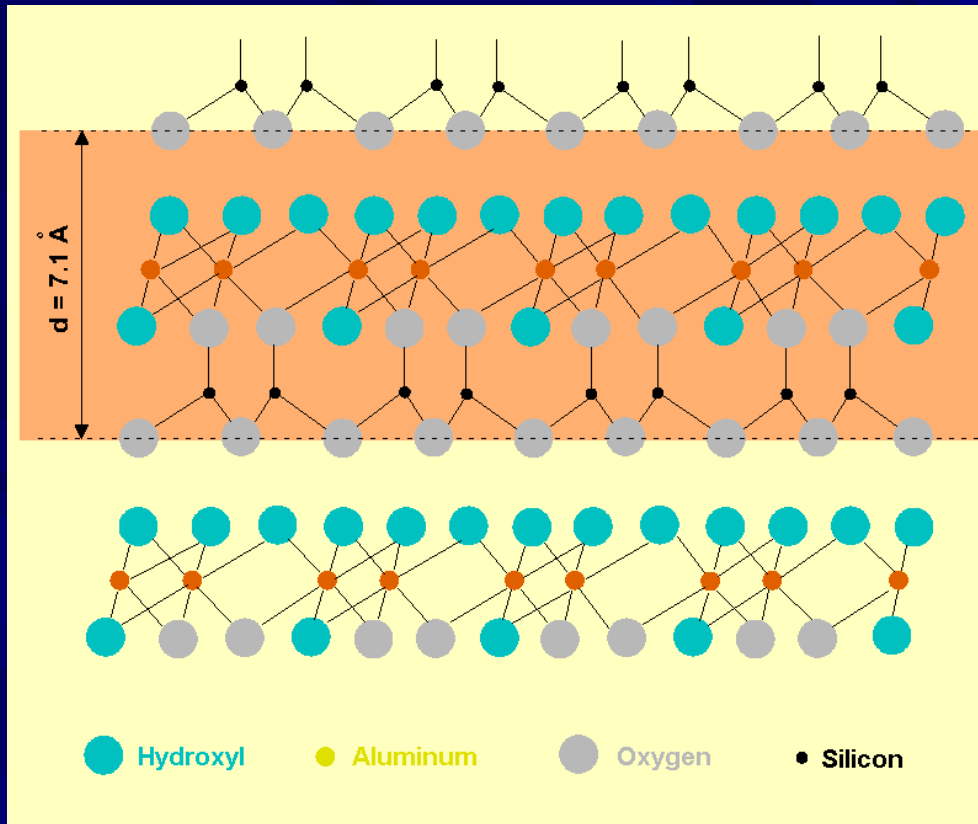


Structure of the octahedral and tetrahedral layer. Mg2+ in the octahedral layer = brucite. Al3+ in the octahedral layer = gibbsite. Al3+ can substitute for Si4+ in the tetrahedral layer.

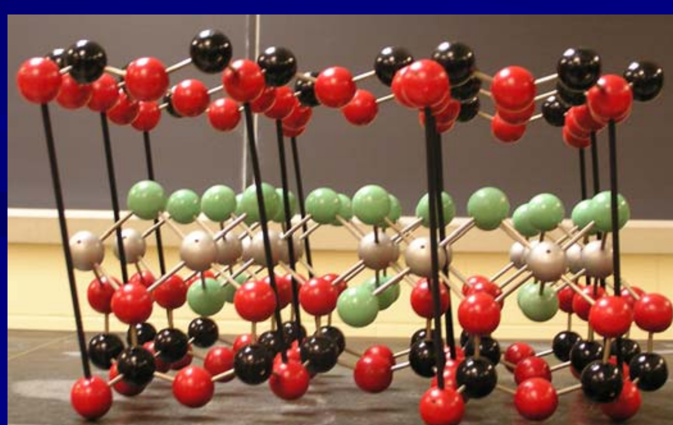
Table 7-5. Summary of the principal characteristics of the layered clay mineral groups

	Kaolinites	Illites	Smectites	Vermiculites
Structure Tetrahedral: Octahedral	1:1	2:1	2:1	2:1
Octahedral layer	Di-octahedral	Mostly di-octahedral	Di- or tri-octahedral	Mostly tri-octahedral
Interlayer cations	Nil	K	Ca, Na	Mg
Interlayer water	Only in halloysite	Some in hydromuscovite	Ca, two layers Na, one to many layers	Ca, two layers K, one layer to nil
Basal spacing	7.1 Å	10 Å	Variable most ~15 Å	Variable 14.4 Å when fully hydrated
Ethylene glycol	Only taken up by halloysite	No effect	Two glycol layers, 17 Å	One glycol layer, 14 Å
Cation exchange capacity (CEC) in meq/100 g clay	Nil 3 - 15	Low 10 - 40	High 80 - 150	High 100 - 150
Formula	$Al_2Si_2O_5(OH)_2$, little variation	$K_{0.5-0.75}Al_2(Si,Al)_2O_{10}(OH)_2$	$M^{+}_{0.7}(Y^{3+},Y^{2+})_{4-6}(Si,Al)_8O_{20}(OH)_4 \cdot nH_2O$	$M^{2+}_{0.66}(Y^{2+},Y^{3+})_6(Si,Al)_8O_{20}(OH)_4 \cdot 8H_2O$
Dilute acids	Scarcely soluble	Readily attacked	Attacked	Readily attacked
Heating 200 °C	Except halloysite, unchanged	No marked change	Collapse to approximately 10 Å	Exfoliation, shrinkage of layer spacing
Examples	Kaolinite, dickite, nacrite, halloysite	Illite, hydrous micas, phengite, brammallite, glauconite, celadonite	Montmorillonite, beidellite, nontronite, hectorite, saponite, sauconite	Vermiculite

Structure of kaolinite a 1:1 layer clay



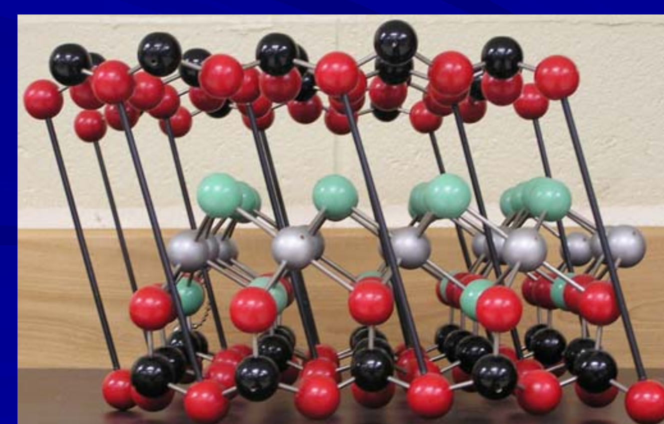
Structure of kaolinite. Each structural unit consists of a gibbsite layer and a tetrahedral layer. Note that only two out of three octahedral sites in the octahedral layer are occupied.



T

O

T

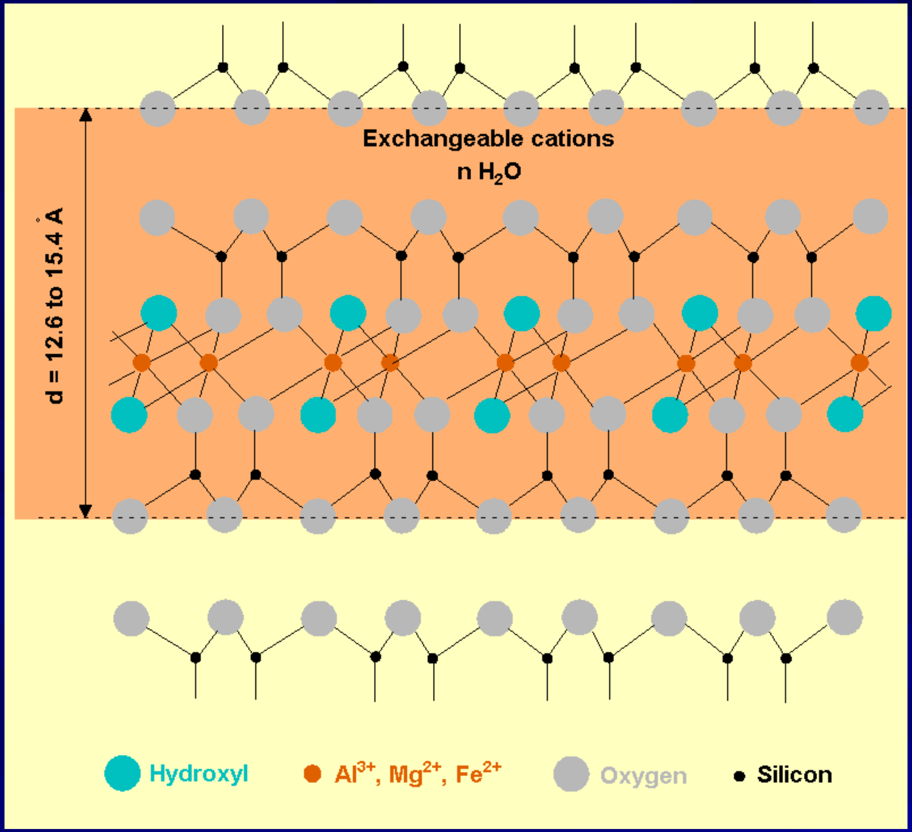


Department Environmental, Earth, & Atmospheric Sciences

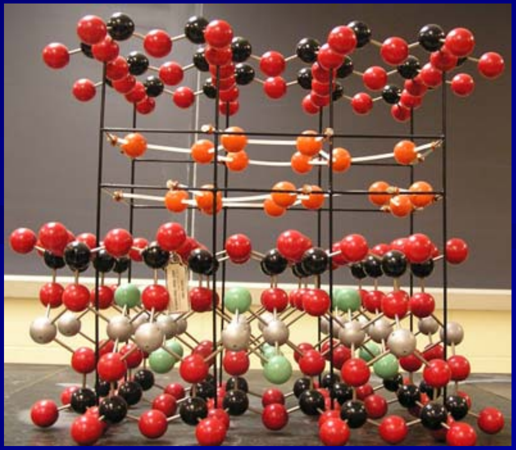
Table 7-6. Substitutions for smectite group clay minerals

Mineral	Tetrahedral cations	Octahedral cations	Exchangeable cations
		Di-octahedral	
Montmorillonite	Si_8	$Al_{3.3}Mg_{0.7}$	$(0.5Ca,Na)_{0.7}$
Beidellite	$Si_{7.3}Al_{0.7}$	Al_4	$(0.5Ca,Na)_{0.7}$
Nontronite	$Si_{7.3}Al_{0.7}$	Fe_4^{3+}	$(0.5Ca,Na)_{0.7}$
		Tri-octahedral	
Saponite	$Si_{7.2}Al_{0.8}$	Mg_6	$(0.5Ca,Na)_{0.8}$
Hectorite	Si_8	$Mg_{5.3}Li_{0.7}$	$(0.5Ca,Na)_{0.7}$
Sauconite	$Si_{6.7}Al_{1.3}$	$Zn_{4-6}(Mg,Al,Fe^{3+})_{2-0}$	$(0.5Ca,Na)_{0.7}$

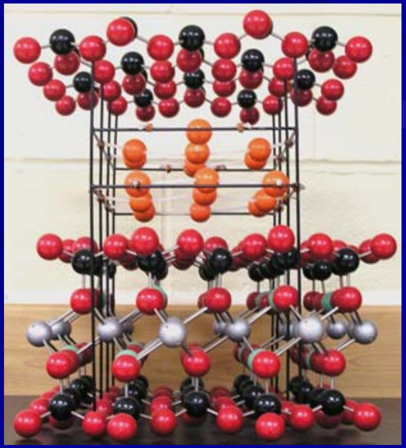
Structure of montmorillonite a 2:1 layer clay



Structure of montmorillonite, a 2:1 clay. The octahedral layer is a gibbsite layer. Substitution of Mg^{2+} for Al^{3+} in the octahderal layer is charge balanced by the addition of Na^{+} or Ca^{2+} cations (exchangeable cations) in the interlayer position.



T
IL
T
O
T



Tools for Identification and Characterization of Minerals

Stereomicroscope

PLM

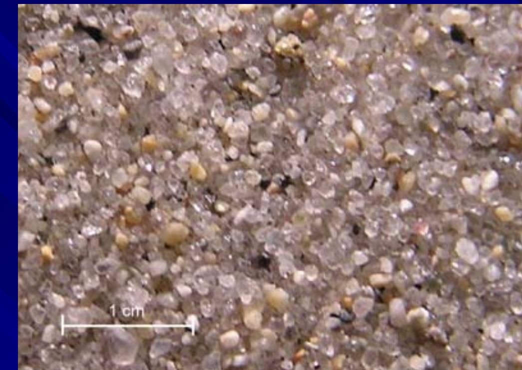
XRD

SEM

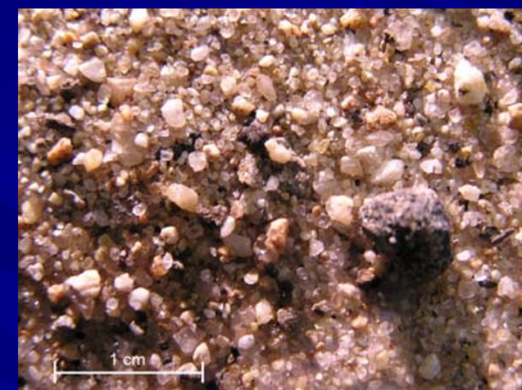
EMP

Stereomicroscopy

Mineralogy and texture



Beach sand



Stream sand

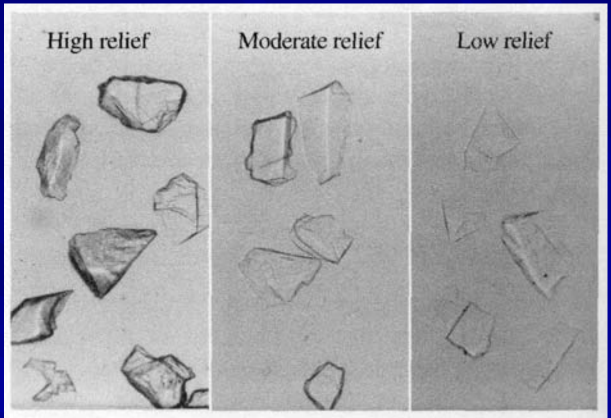
Carbonate sand

Polarizing Light Microscopy (PLM) – a forensic workhorse

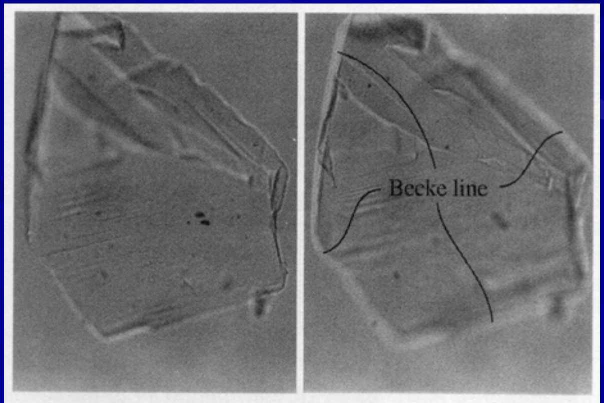
Use various optical properties to characterize materials

Index of refraction

Higher relief means higher refractive index relative to the mounting media or index oil.



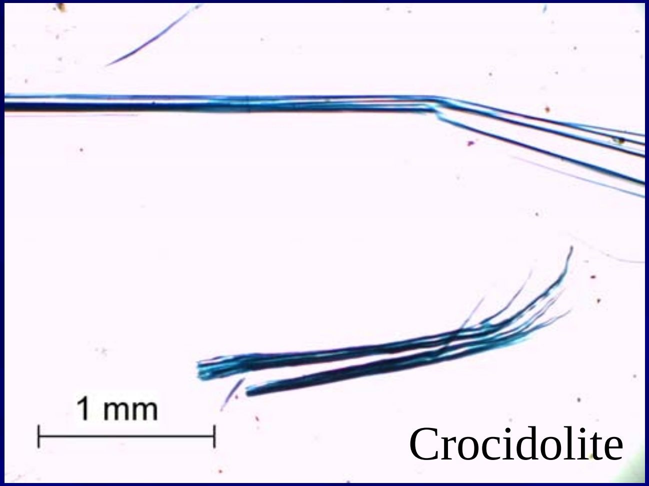
The Becke line method is used to determine if material has a higher or lower refractive index then the mounting media or index oil.

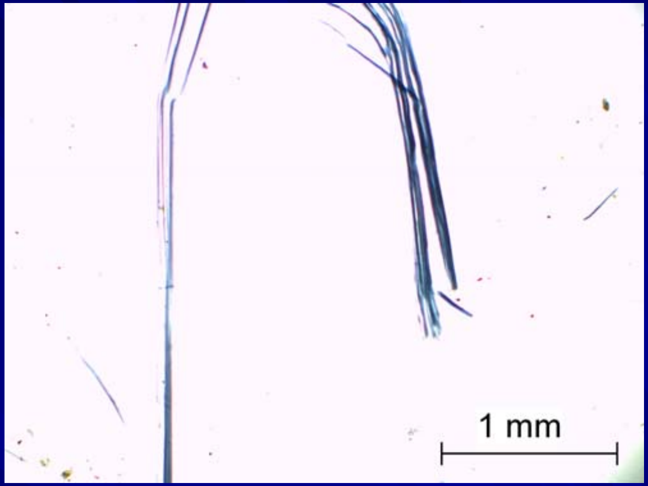


Department Environmental, Earth, & Atmospheric Sciences

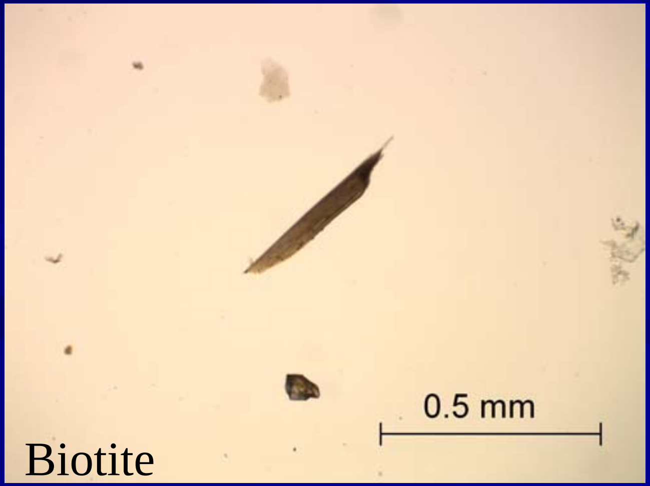
Polarizing Light Microscopy (PLM) – a forensic workhorse

Pleochroism – color changes as stage is rotated – polarized light





Birefringence – color changes under crossed-polars due to retardation



Plane polarized light

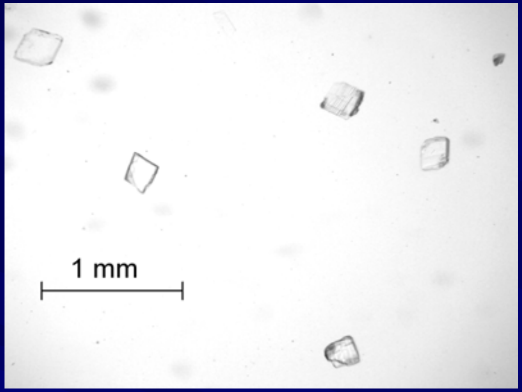
Crossed-polars

UMASS LOWELL
Department Environmental, Earth, & Atmospheric Sciences

Polarizing Light Microscopy (PLM) – a forensic workhorse

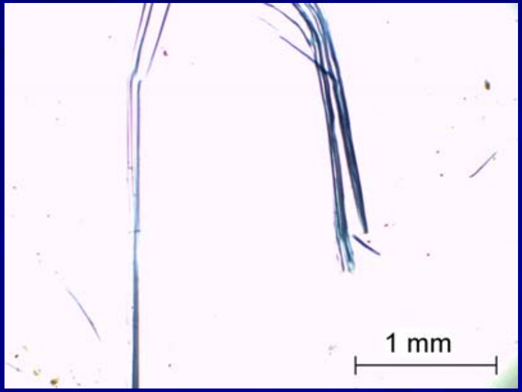
Department Environmental, Earth, & Atmospheric Sciences

Morphology and "habit"



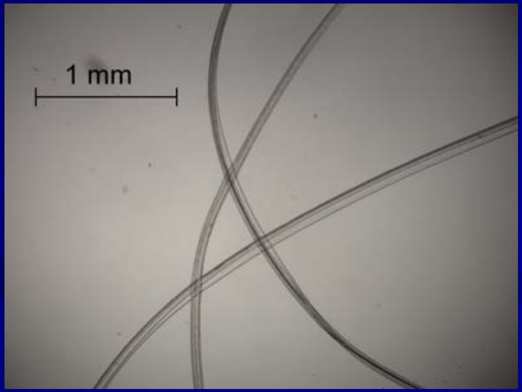
Calcite - rhombohedral

Biotite flake

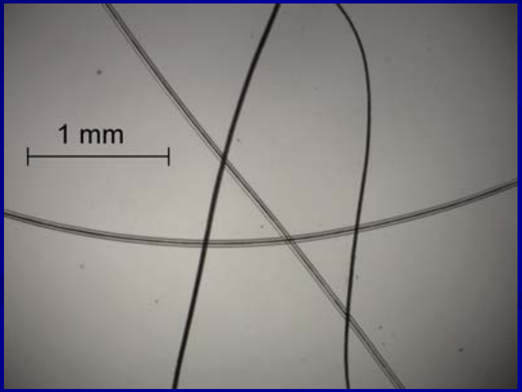


Crocidolite fiber

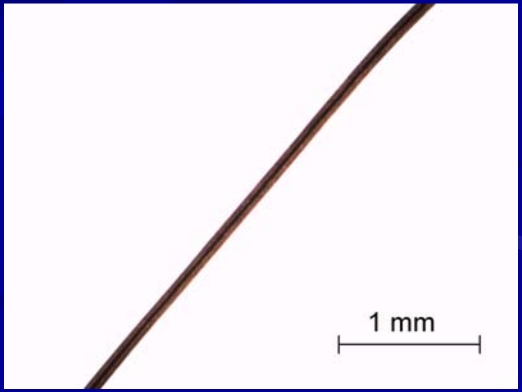
Fiber characteristics



Dynel



Dog's hair



Human hair (mongoloid)

X-ray Diffraction (XRD)

Department Environmental, Earth, & Atmospheric Sciences

A powerful way to identify crystalline materials. The physical basis is Bragg's Law (a Nobel prize for simple trigonometry). The angles required for diffraction and the intensity of the diffracted wavelengths can be used to identify the material.

X-ray diffractometer

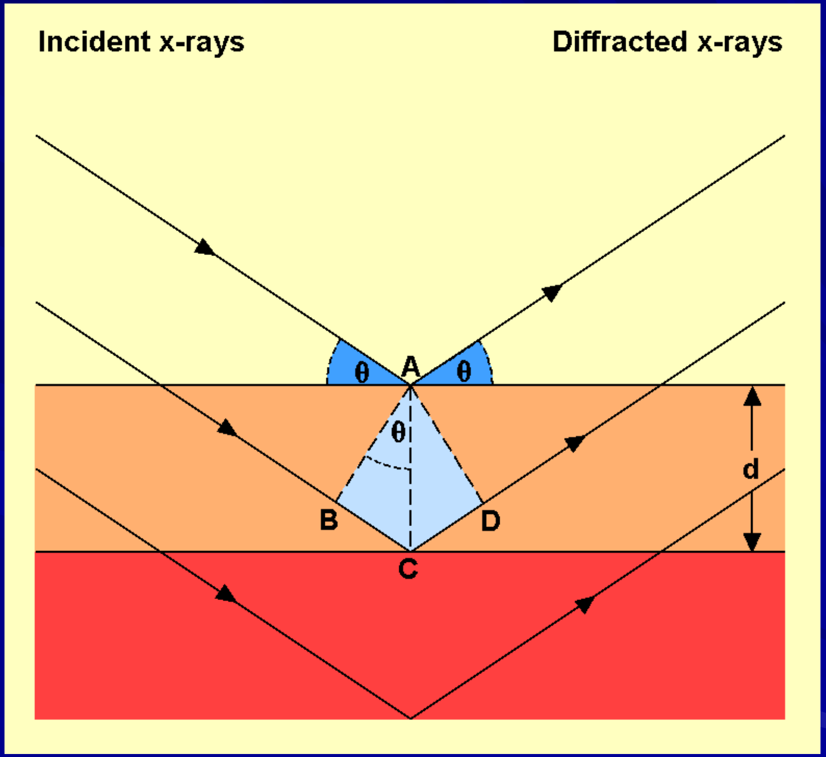
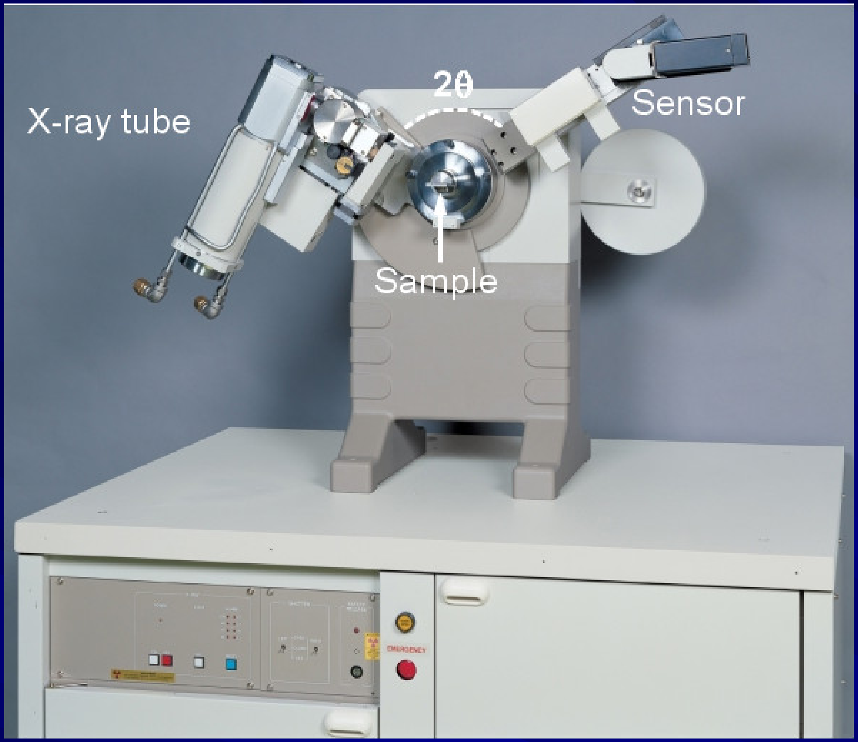
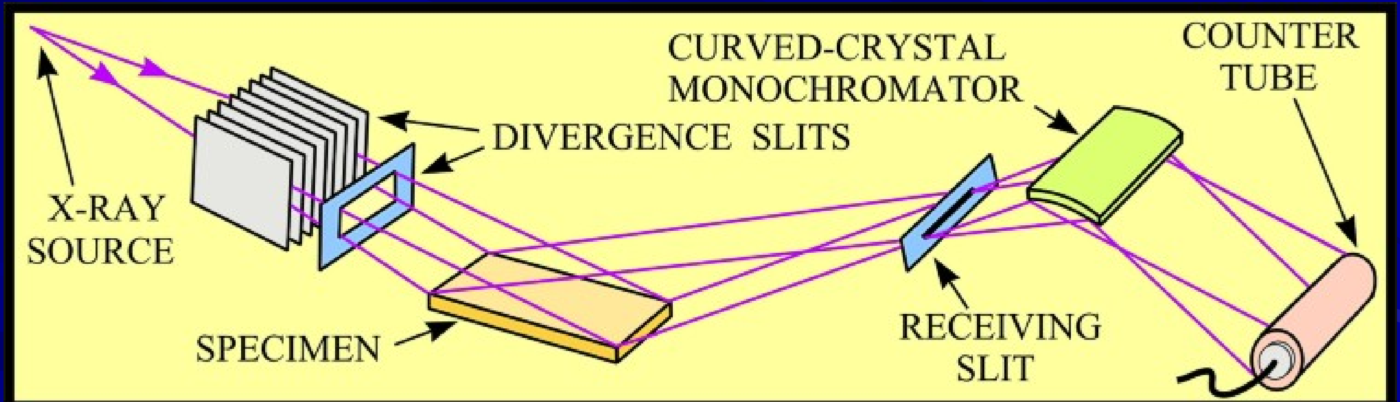


Diagram illustrating Bragg's law. θ = angle of incidence and diffraction when Bragg's law conditions are met. *d* = inter-planar spacing.

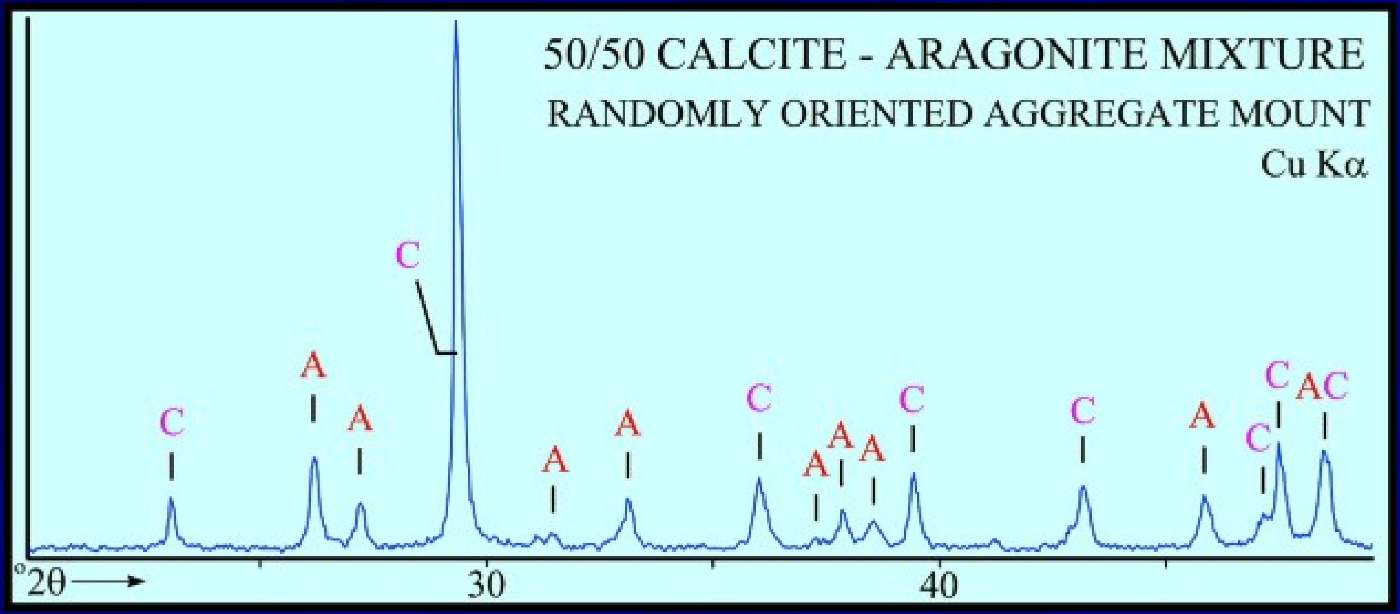


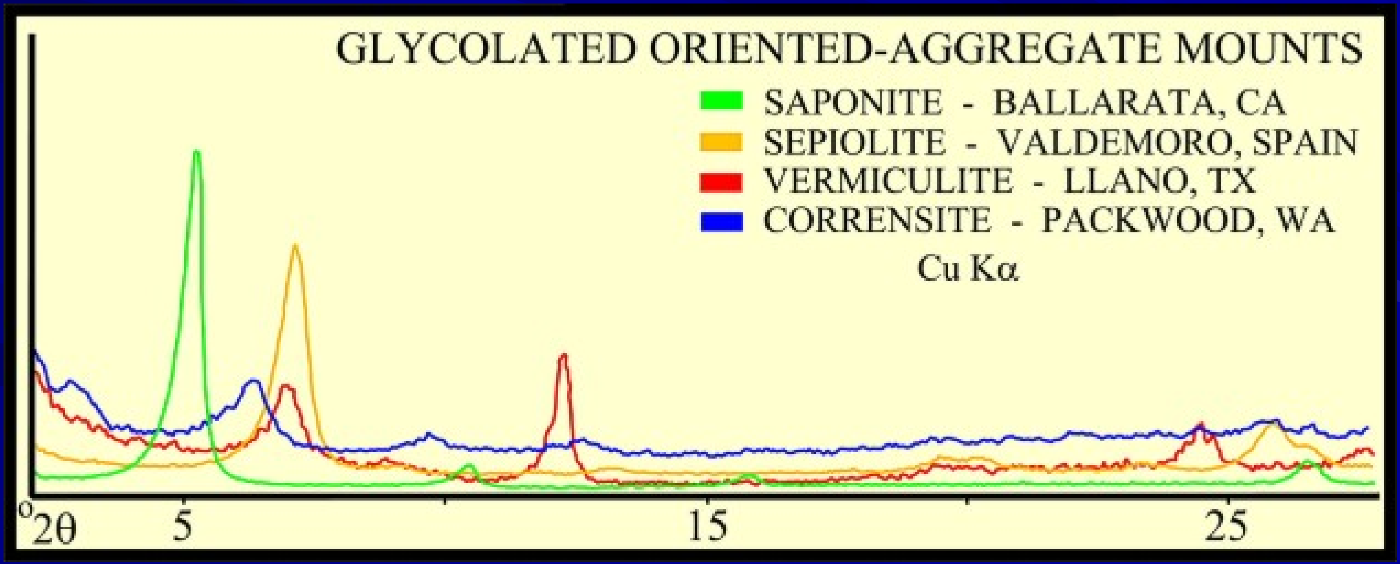
Configuration for a typical X-ray powder diffractometer.



OPTICAL ARRANGEMENT FOR A PHILLIPS X-RAY DIFFRACTOMETER

Mineral X-ray diffraction patterns



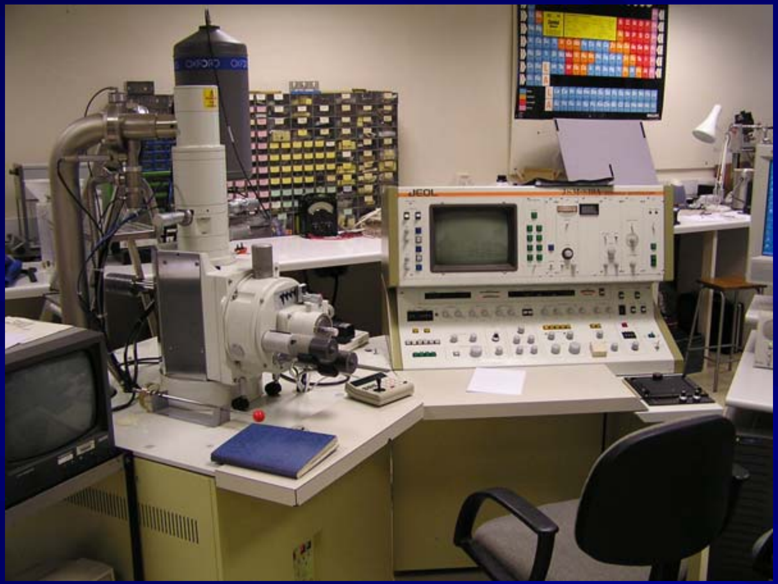


Department Environmental, Earth, & Atmospheric Sciences

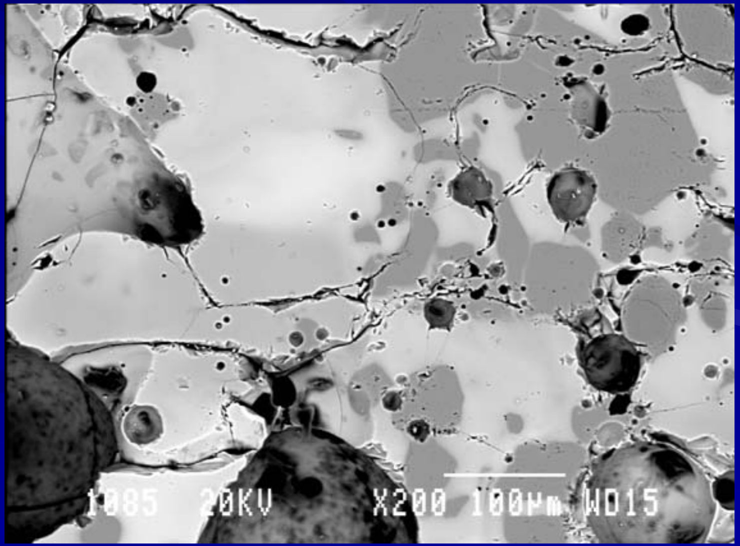
UMASS LOWELL
Department Environmental, Earth, & Atmospheric Sciences

Scanning Electron Microscopy (SEM) with EDAX

Can be used to characterize materials at the micron level.



The material illustrated here is tinitite, the glass formed from the desert sand at Alamogordo when the first atomic bomb was detonated. The shades are related to the atomic number of the elements. Areas with lower atomic number elements are darker. Using EDAX, quantitative elemental abundances can be determined.



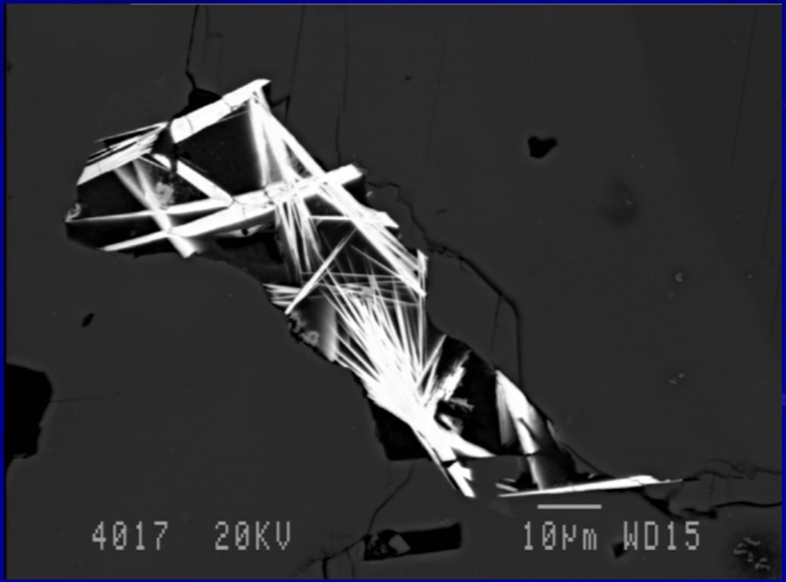
Back scatter electron image

Department Environmental, Earth, & Atmospheric Sciences

The Electron Microprobe (EMP)

This instrument is not commonly used in forensic investigations, but it can be used to determine the abundance of a variety of elements on areas as small as one micron in diameter. There may be specific cases where such data would be useful.

Rare-earth carbonate minerals in carbonatite. Analyses were done on 1 micron diameter spots.



First Forensic Geology Case

Department Environmental, Earth, & Atmospheric Sciences

- In October of 1904 the strangled body of Eva Disch was found near Frankfurt, Germany
- When Georg Popp was called in he examined a filthy handkerchief found at the scene that contained bits of hornblende, snuff and, coal

First Forensic Geology Case

Department Environmental, Earth, & Atmospheric Sciences

- A suspect, Karl Laubach, used snuff, worked at the coal-burning local gas works and at a quarry that had hornblende bearing rocks
- The suspect also had mica in the cuffs of his trousers that matched mica at the murder scene

Junger Case

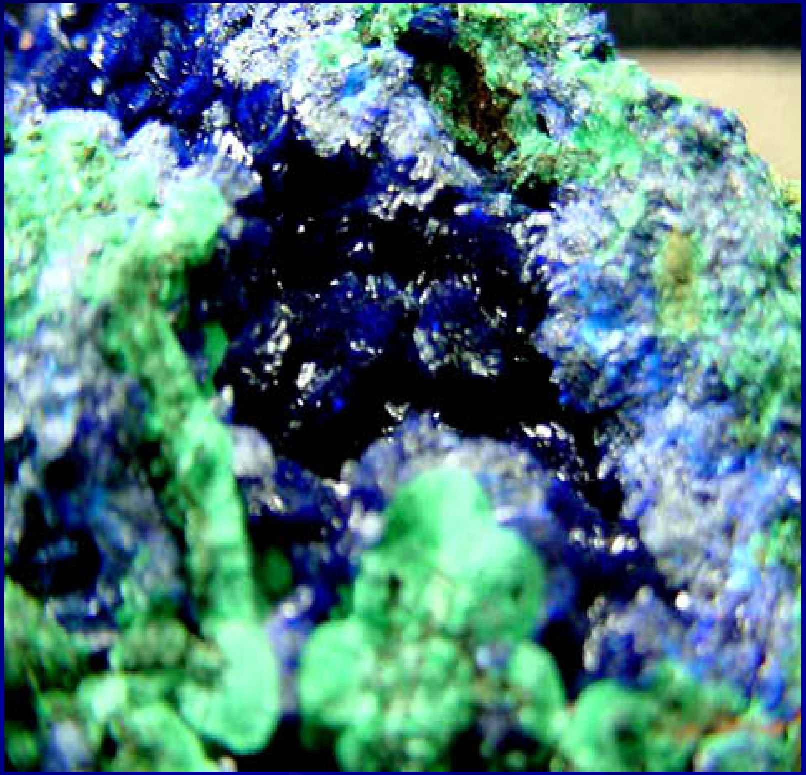
Department Environmental, Earth, & Atmospheric Sciences

***Location: Front Royal, Va*.**

***Crime*: Homicide**

***Evidence*: Soil on the Suspect's vehicle compared with soil from the crime scene at a river crossing. Samples contained Malachite and Azurite from an abandoned copper mine just up stream. The soft copper minerals were not found a short distance downstream.**

(thanks to Ray Murary)



The Reeves Murder Case

In September of 1958 a woman's body was found at the edge of the Anacostia River in Washington, D.C. A peculiar black sand was found on the victim, in a suspects car, and at the murder scene. Geologic investigation showed that the sand was blast furnace slag that had been spread on a small section of highway to test it for use in the control of snow and ice.

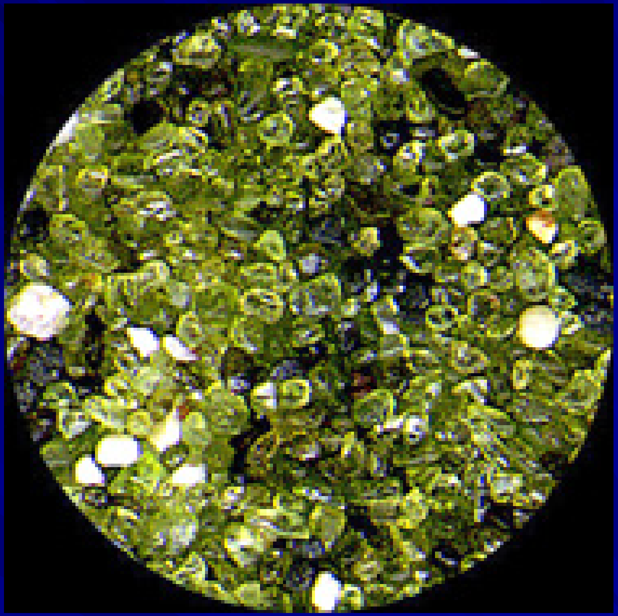
(Block, 1979 p.149-152)

Sand from a Construction Site

In another example, in southern Ontario a man was arrested and charged with the beating death of the young girl. The scene of the crime was a construction site adjacent to a newly poured concrete wall. The soil was sand that had been transported to the scene for construction purposes. As such, the sand had received additional mixing during the moving and construction process and was quite distinctive. The glove of the suspect contained sand that was similar to that found at the scene and significantly different in composition and particle size from the area of the suspect's home. This was important because the suspect claimed the soil on the gloves came from his garden.
(Murray and Tedrow, 1992 , p. 16)

Commercial Foundry Sand

- Sands of heavy minerals, olivine, zircon, etc. are used in foundry work
- In a breaking and entering case at a foundry in Toronto, Canada a suspect's shoes had grains of olivine sand
- Because olivine sand is not found in place in that part of Canada the sand on the shoes indicated that the suspect had been at the foundry. *(Murray and Tedrow, 1992 , p. 79)*



Department Environmental, Earth, & Atmospheric Sciences

Acknowledgements

Case studies and some of the graphics used in this talk were graciously provided by Jack Crelling, Southern Illinois University

Other tables and graphics are from:

Eby, G.N. (2004) Principles of Environmental Geochemistry. Thomson.