

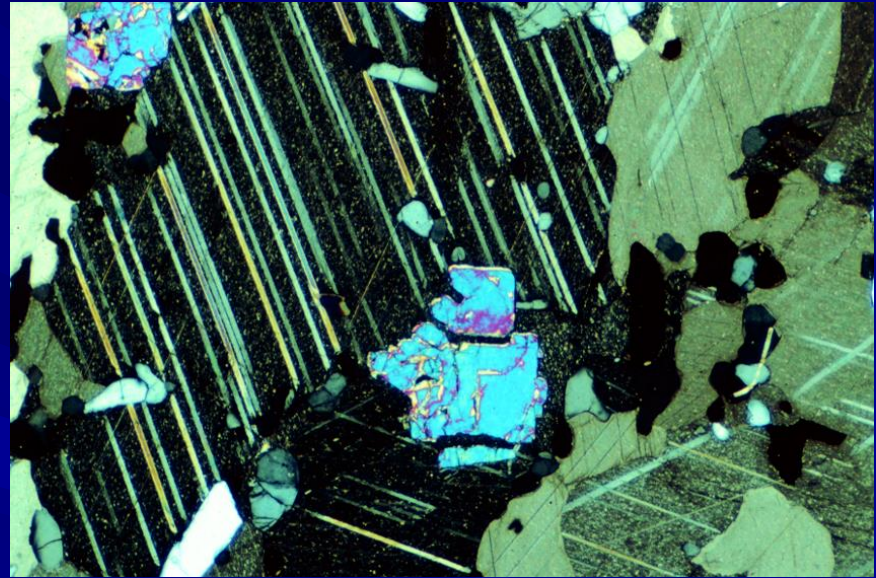
Forensic Geology - Minerals

Definition, Types, and Identification

Forensic Applications



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



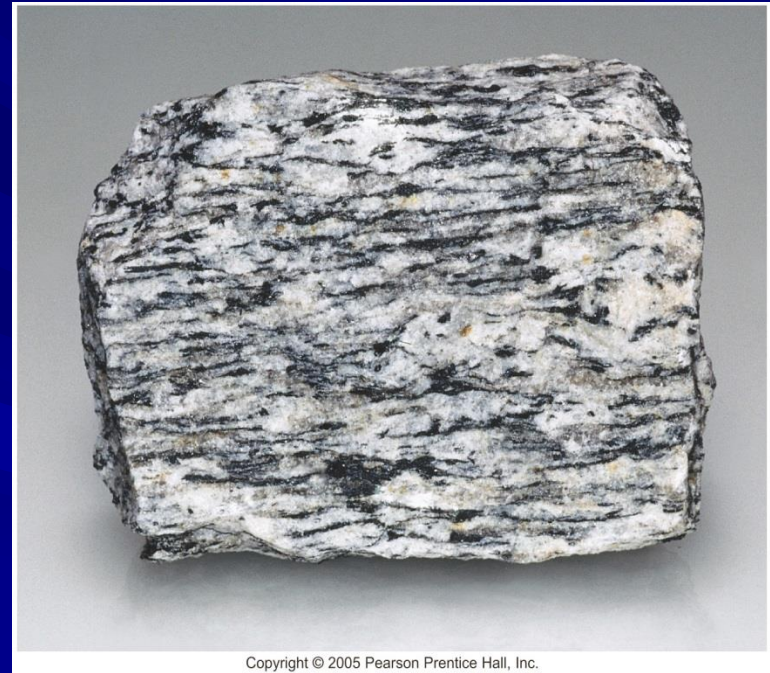
Niocalite (blue) in sovitite (calcite + apatite). Oka carbonatite complex. Crossed-polars. Width = 5.4 mm

Minerals

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



Fluorite



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Gneiss

Mineral Definition

- Naturally occurring - minerals must be formed naturally - glass, concrete, **synthetic** diamonds, rubies and emeralds don't count
- Crystalline – has a definite internal structure, i.e., atoms in the mineral are arranged in a regular way
- Chemical composition fixed or varies within certain limits



Quartz



Orthoclase



Biotite



Amphibole



Pyroxene

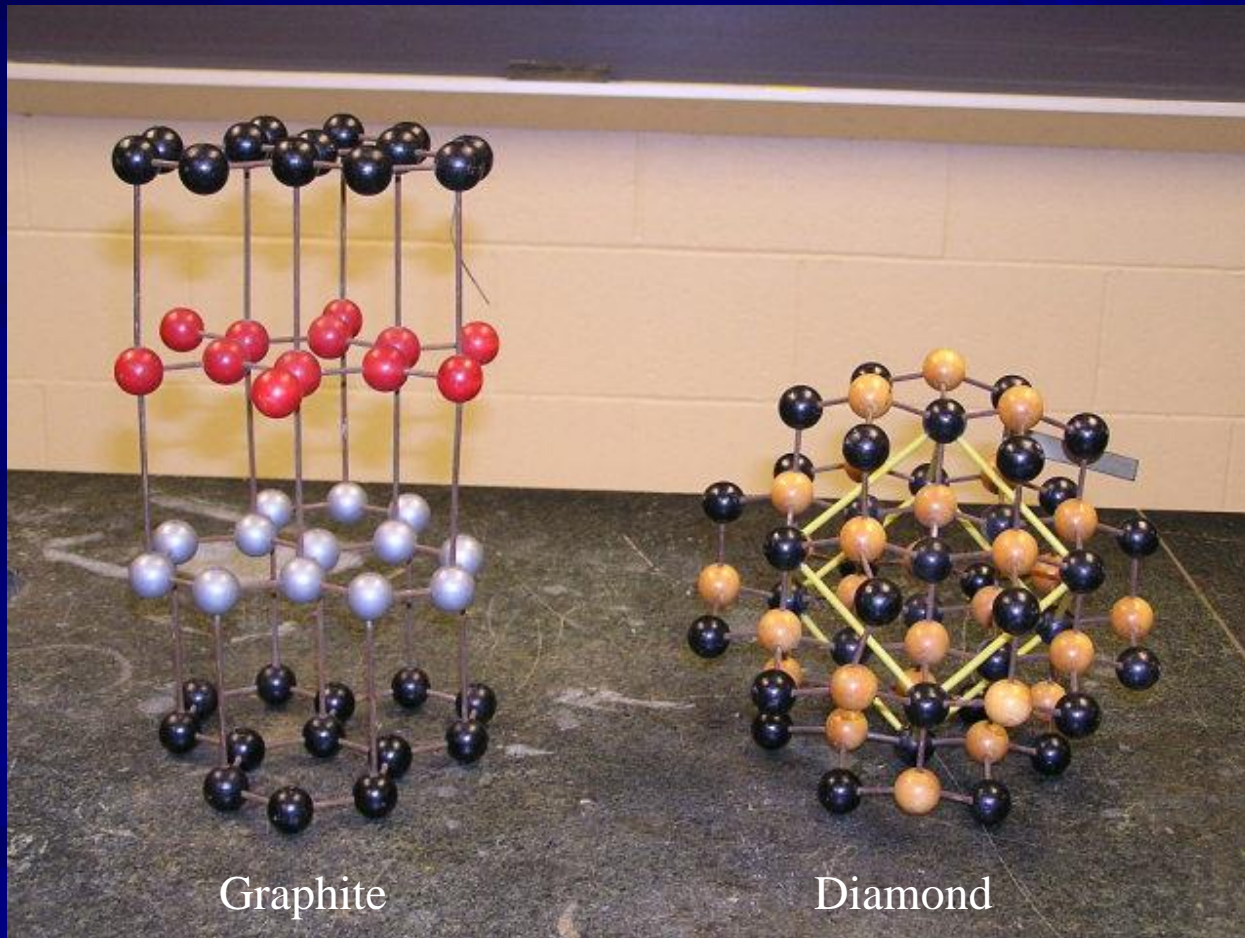
(C) Chazotte & Matton 2010



Olivine

Minerals

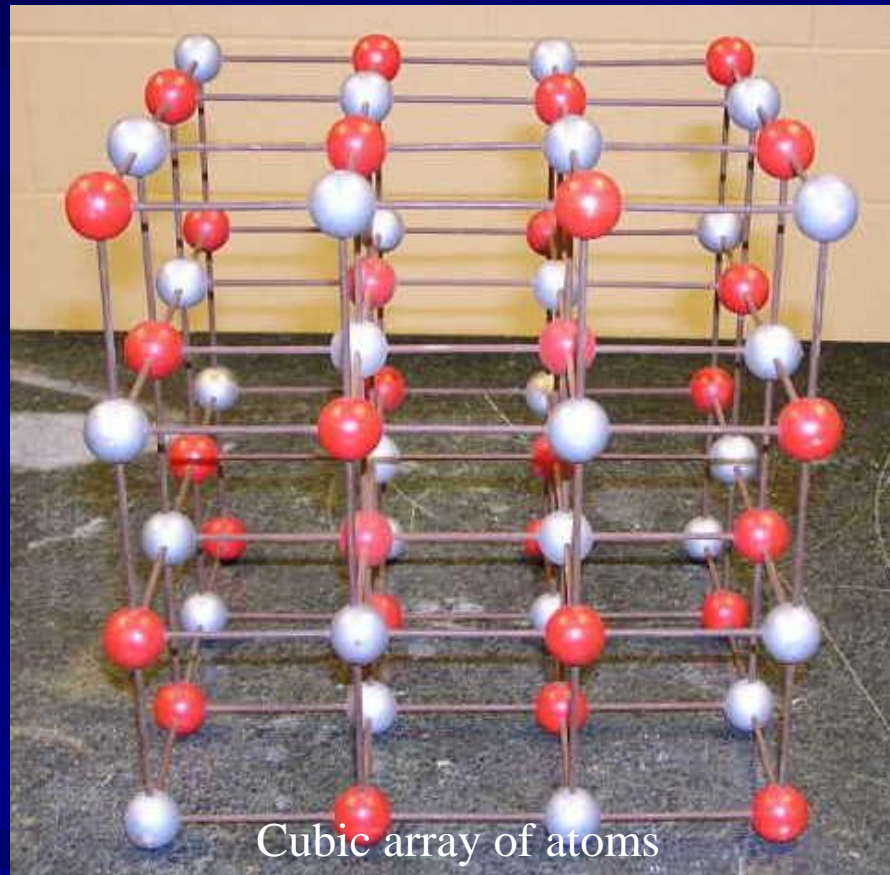
Crystalline - the atoms in minerals have an orderly atomic arrangement giving them a definite structure that controls their properties.



Minerals

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

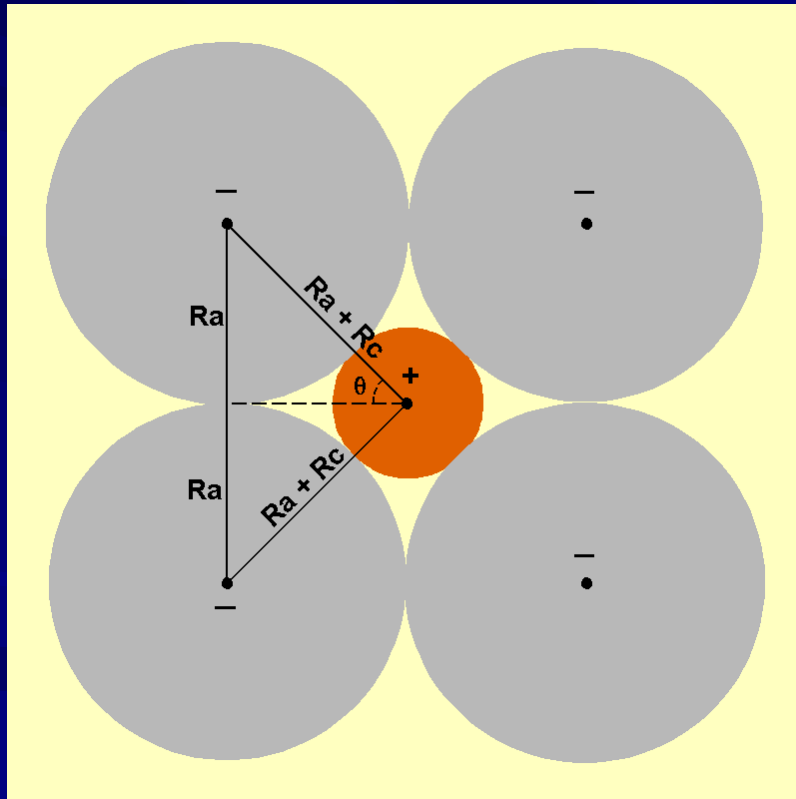
NaCl = Halite



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.



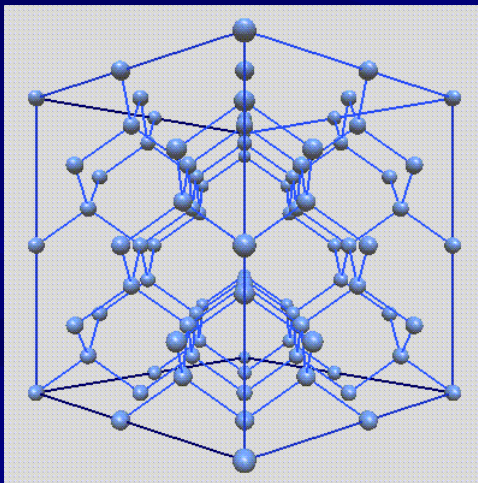
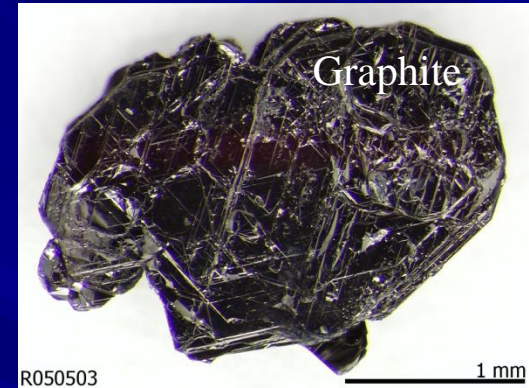
Radius ratio	Coordination	Arrangement of ions	
<0.155	2		Linear
0.155–0.225	3		Trigonal planar
0.225–0.414	4		Tetrahedral
0.414–0.732	4		Square planar
0.414–0.732	6		Octahedral
0.732–1.00	8		Body-centered cubic
>1.00	12		Edge-centered cubic

● Cation, ○ Anion

Structure of minerals

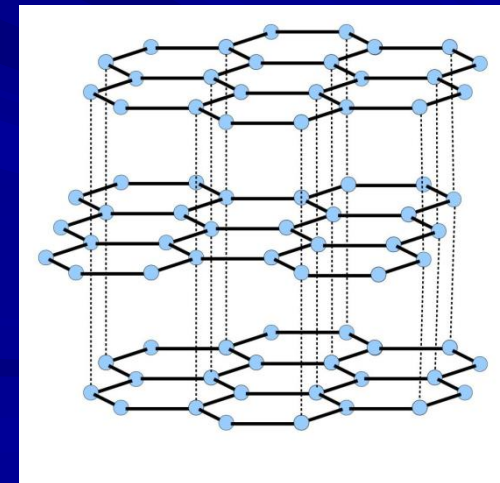
Polymorphs

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



Puckered
six-sided
carbon
rings

Carbon rings
in sheets held
together by
van der Waal
forces



Physical properties of minerals

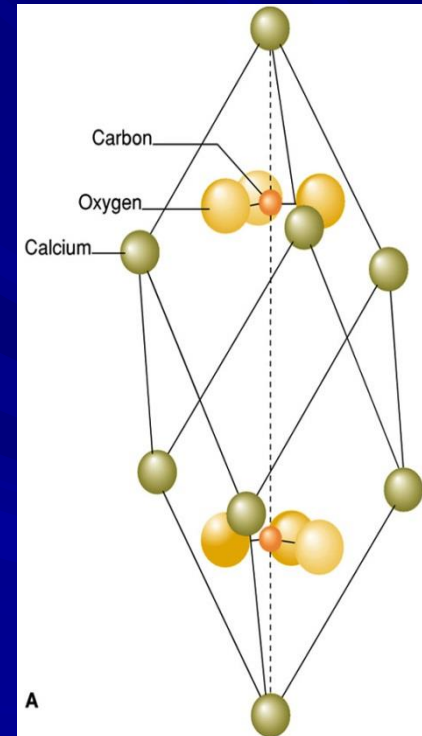
Crystal Form

- 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



Calcite crystals and calcite structure



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



Physical properties of minerals

Streak

Color of a mineral in its powdered form

Streak is obtained on
an unglazed porcelain
plate

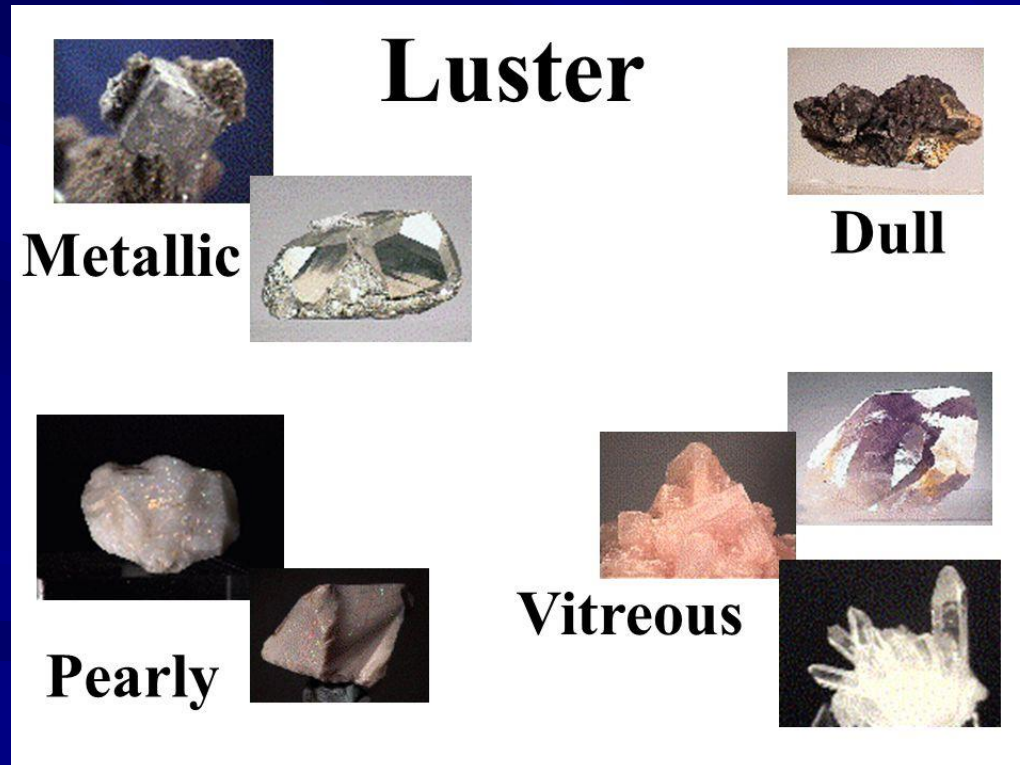


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Physical properties of minerals

Luster

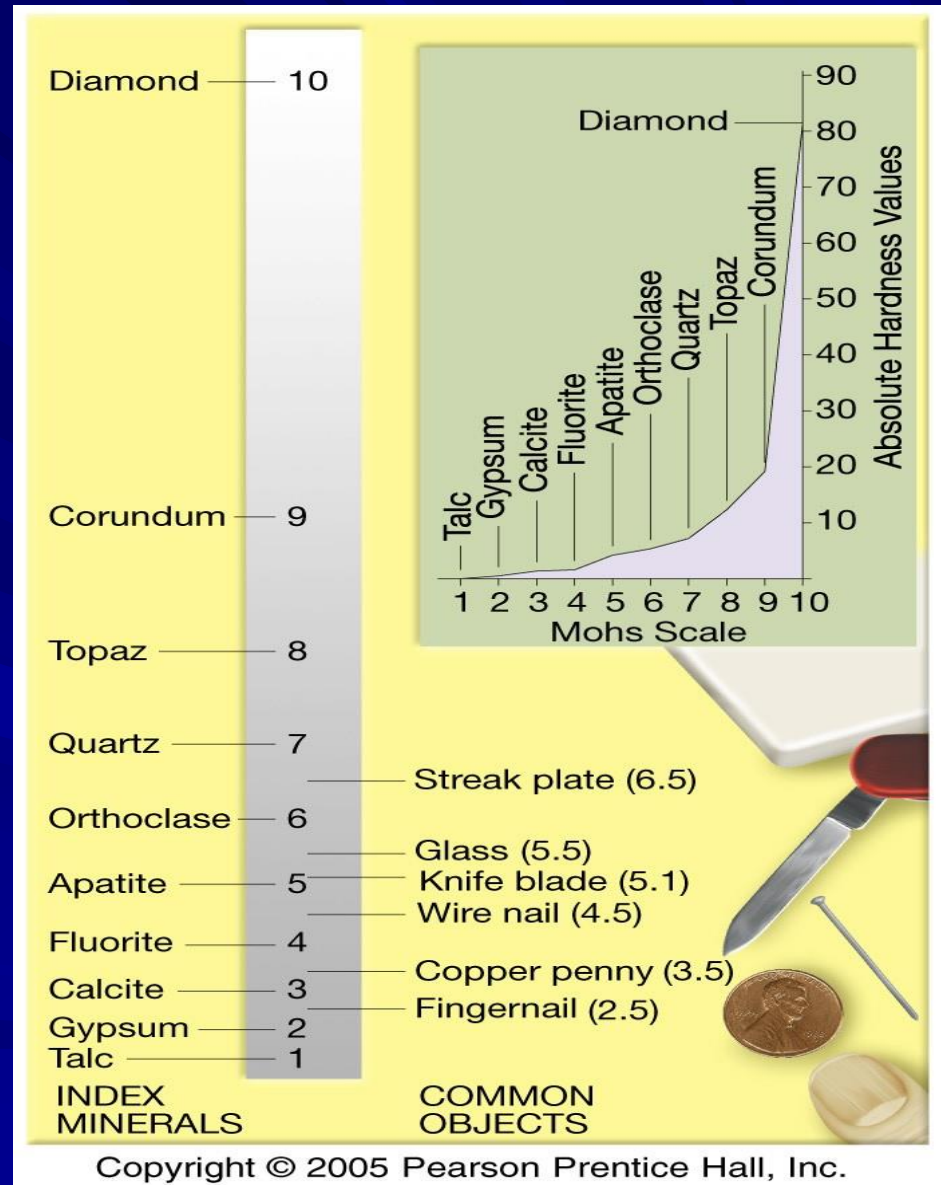
- Appearance of a mineral in reflected light
- Two basic categories
 - Metallic
 - Nonmetallic
- Other descriptive terms include vitreous, silky, or earthy



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.

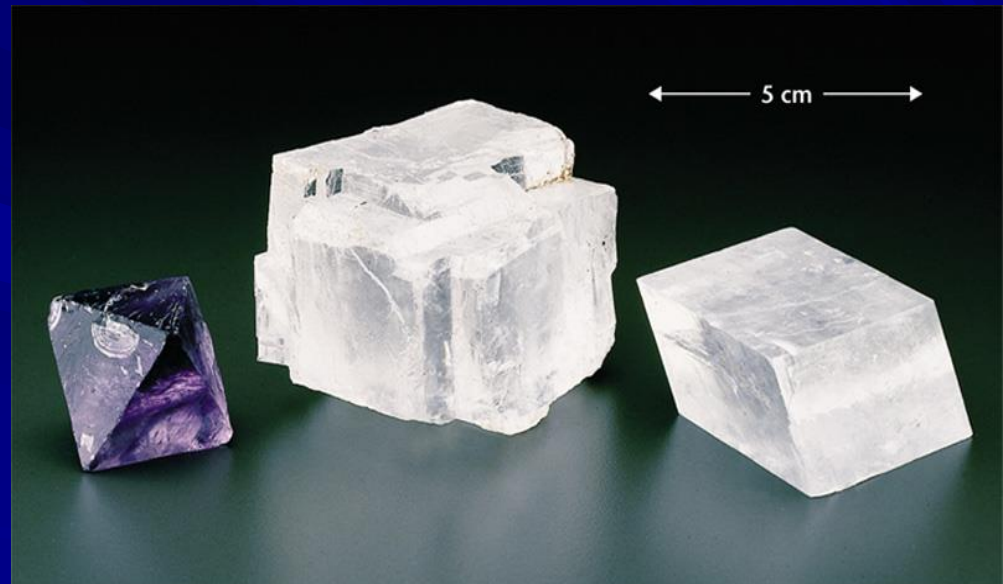


Physical properties of minerals

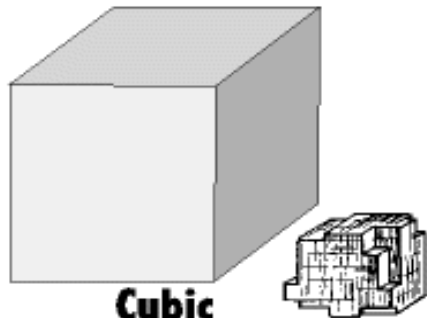
Cleavage

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

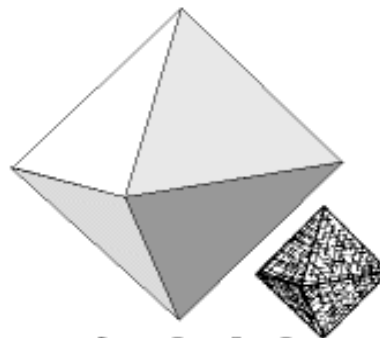
Fluorite, halite, and calcite
all exhibit perfect cleavage



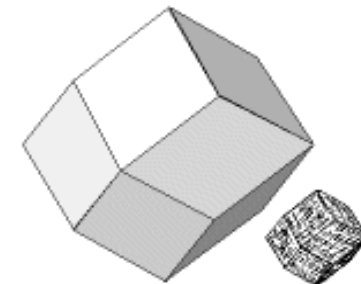
Mineral Cleavage and Crystal Form



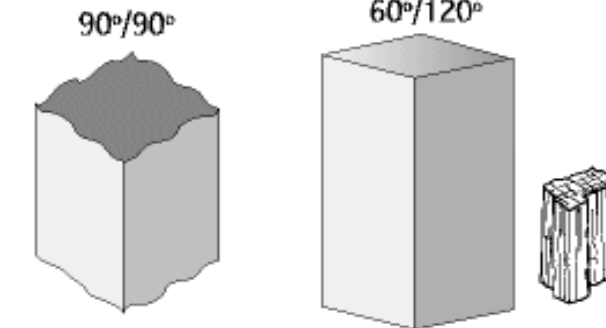
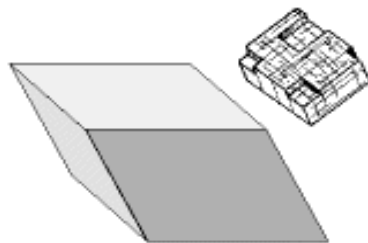
Cubic
(3 cleavages, 6 faces
at right angles; e.g. halite)



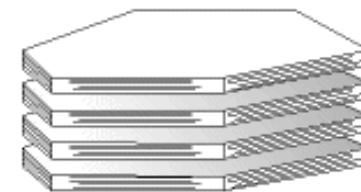
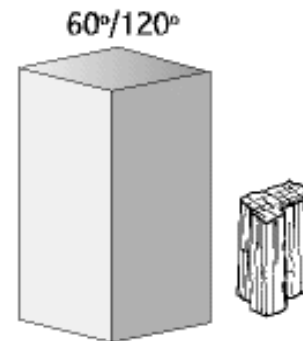
Octahedral
(4 cleavages, 8 faces; e.g.
fluorite)



Dodecahedral
(6 cleavages, 12 faces; e.g.
sphalerite)



(2 cleavages, 4 faces of many possible
angles; third side fractures irregularly; e.g.
pyroxene, amphibole, feldspar)



Basal
(1 cleavage, 2 faces; e.g.
biotite, muscovite, chlorite)

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 – magnetite and pyrrhotite (weak)
 - Reaction to hydrochloric acid – calcite fizzes
 - Malleability – generally pure metals
 - Double refraction – any mineral that isn't isometric
 - Taste – example halite versus sylvite
 - Smell – rotten egg smell if you put HCl on a sulfide mineral
 - Elasticity

Table 7-1. Mineral classes

Class	Chemical characteristics	Examples
Borates	Various elements in combination with boron	Borax [$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$]
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 [$\text{Mg}(\text{OH})_2$]
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 [$\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})$] Carnotite [$\text{K}_2(\text{UO}_2(\text{VO}_4)_2 \cdot 3\text{H}_2\text{O})$] 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 [$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$]
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]

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

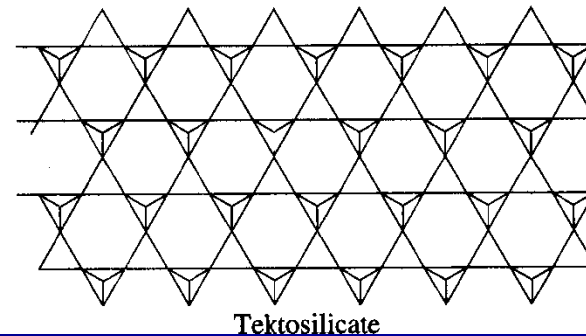
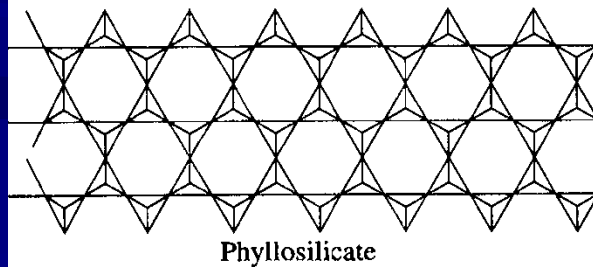
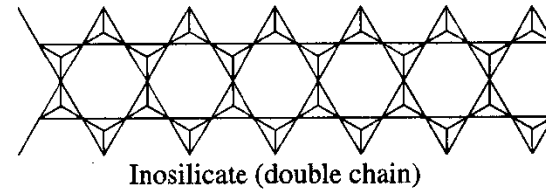
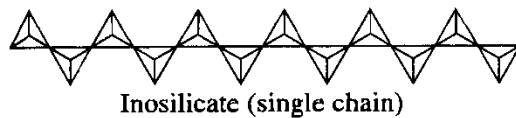
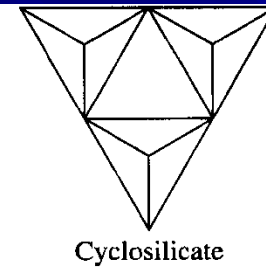
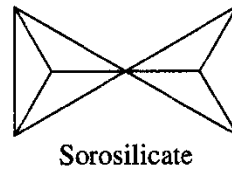
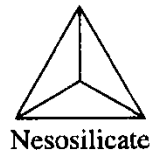
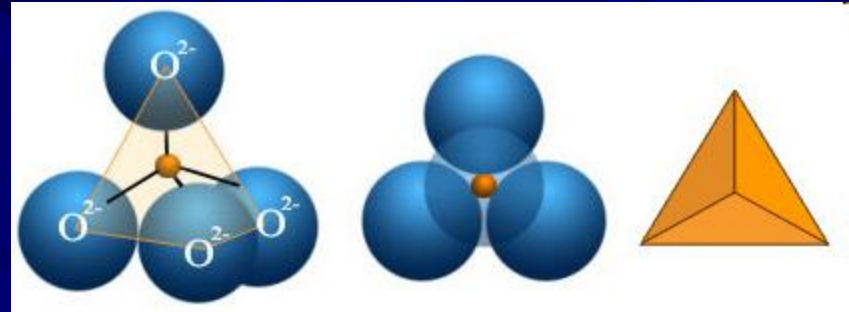
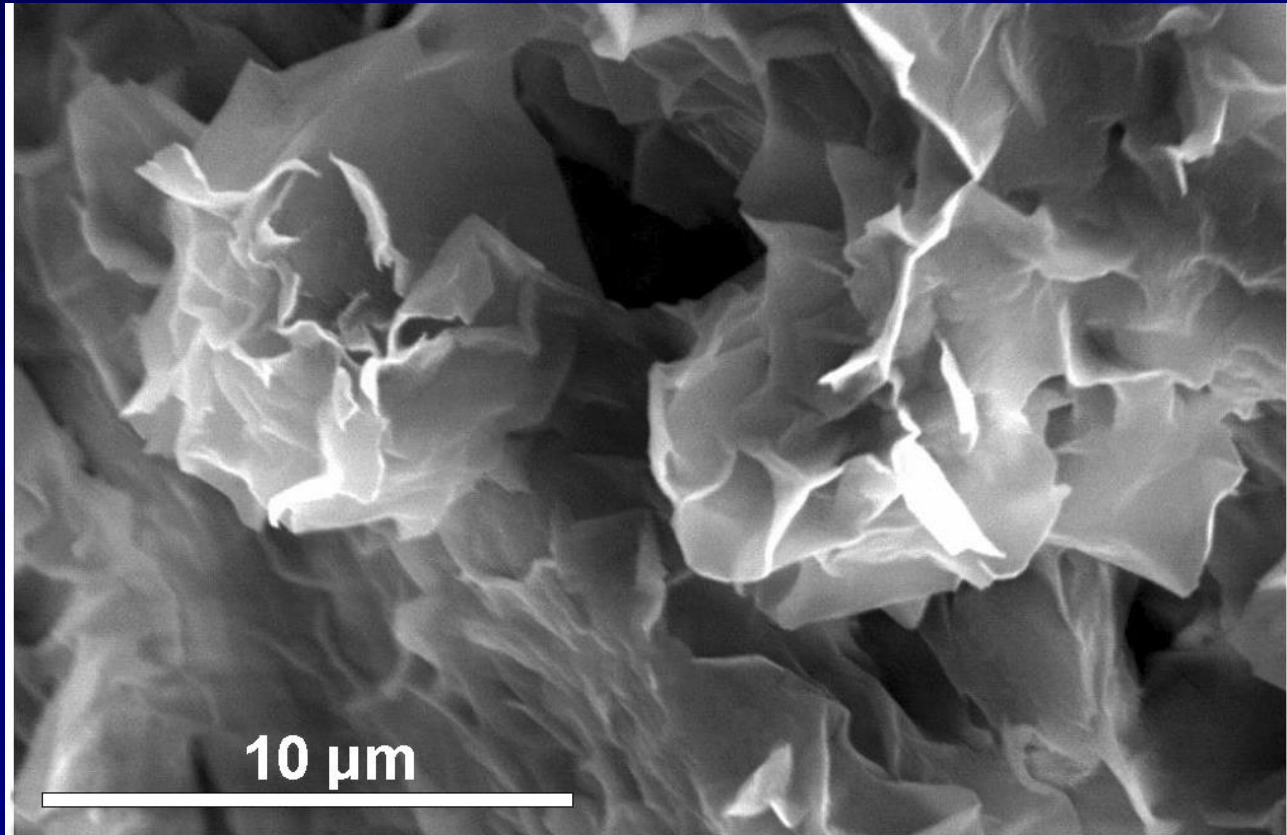


Table 7-4. Properties of the silicate crystal classes

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	$\text{Si}_2\text{O}_7^{6-}$	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	$\text{Si}_4\text{O}_{11}^{6-}$	1:2.75	Hornblende
Phyllosilicate	Sheet of tetrahedra sharing three corners	3	$\text{Si}_2\text{O}_5^{2-}$	1:2.5	Kaolinite
Tektosilicate	Framework of tetrahedra sharing all four corners	4	SiO_2	1:2	K-feldspar

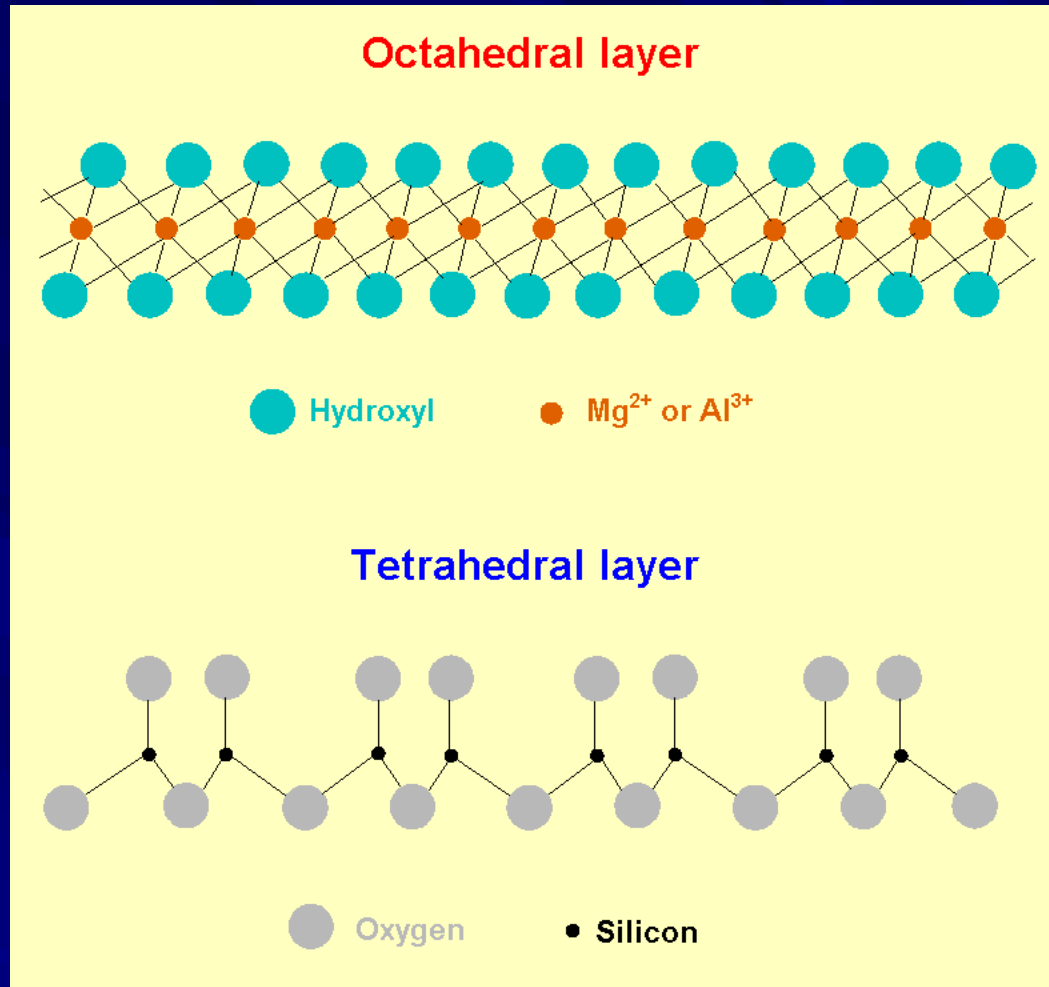
Clay Minerals

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



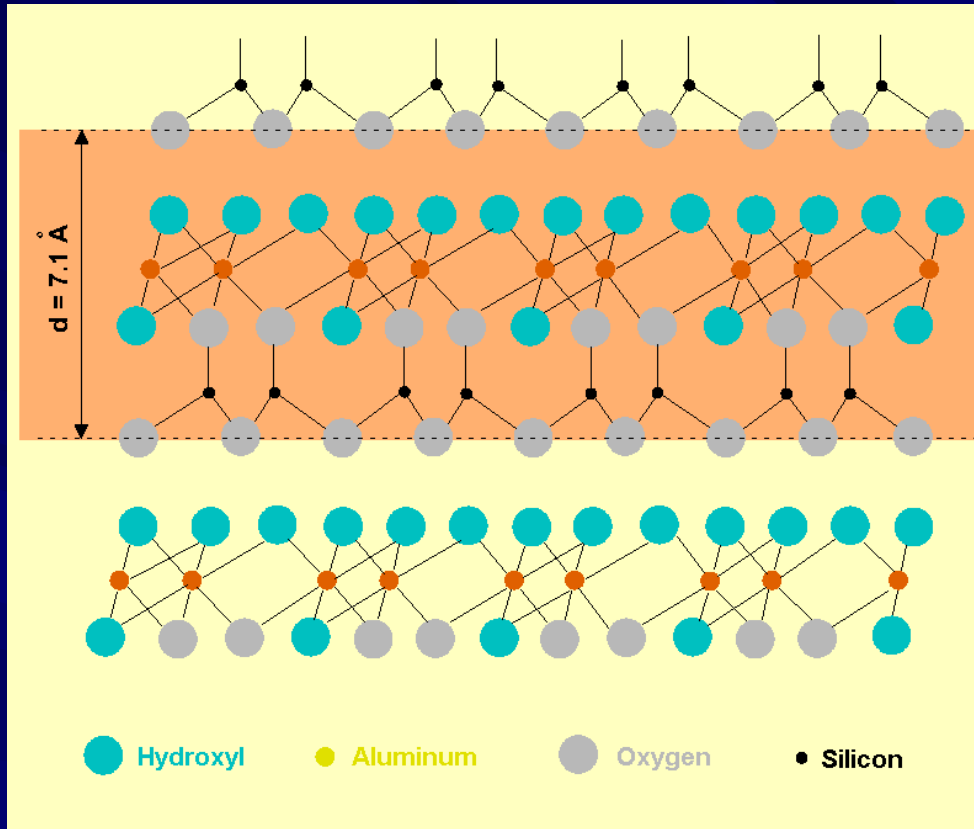
Montmorillonite showing a rose like texture, Miocene arkose, Madrid Basin, Spain.

Clay minerals are built by combining tetrahedral and octahedral layers.

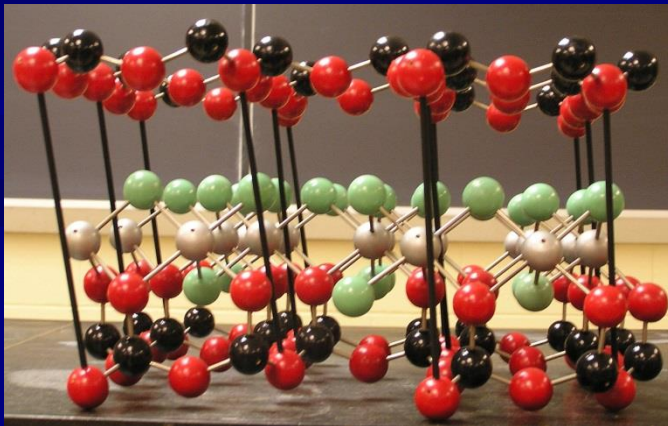


Structure of the octahedral and tetrahedral layer.
 Mg^{2+} in the octahedral layer = brucite. Al^{3+} in the octahedral layer = gibbsite. Al^{3+} can substitute for Si^{4+} in the tetrahedral layer.

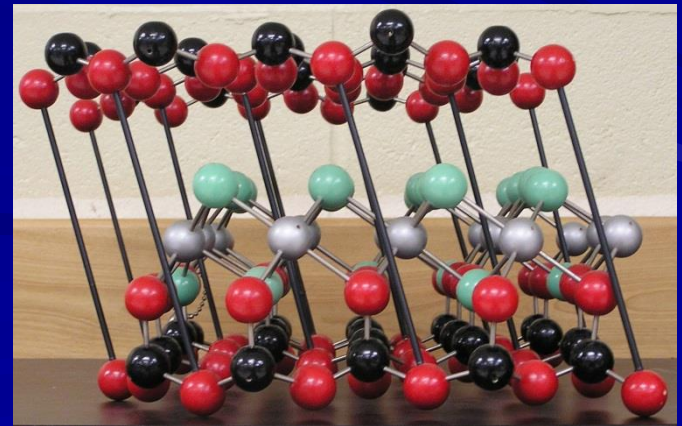
Structure of kaolinite a 1:1 layer clay



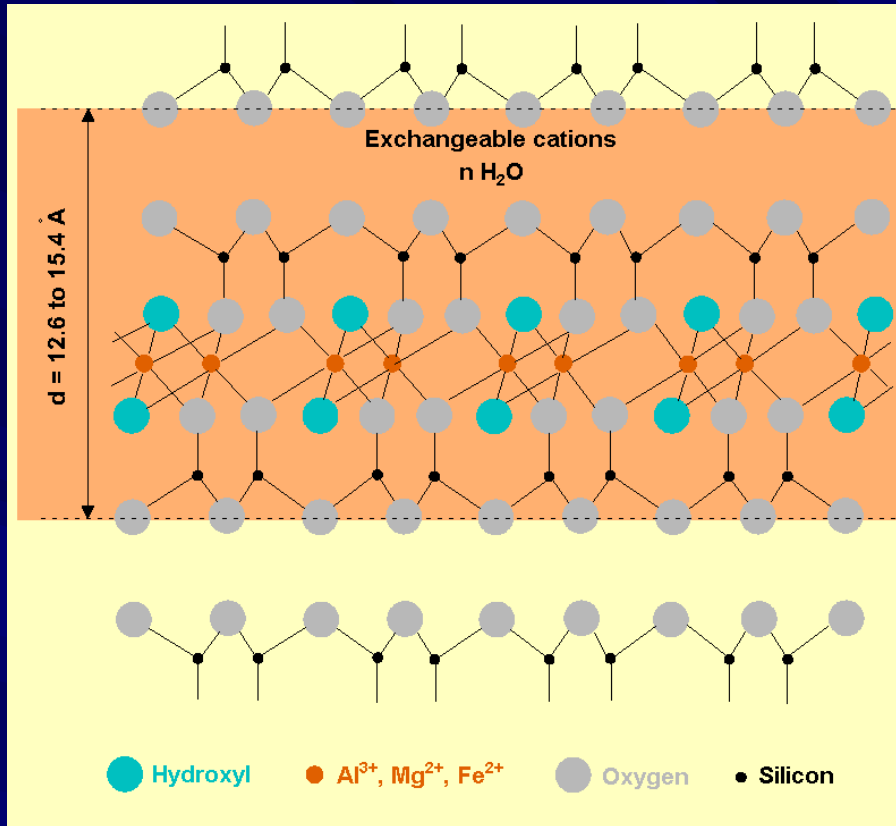
Structure of kaolinite. Each structural unit consists of a gibbsite layer and a tetrahedral layer. Note that only two out of three octahedral sites in the octahedral layer are occupied.



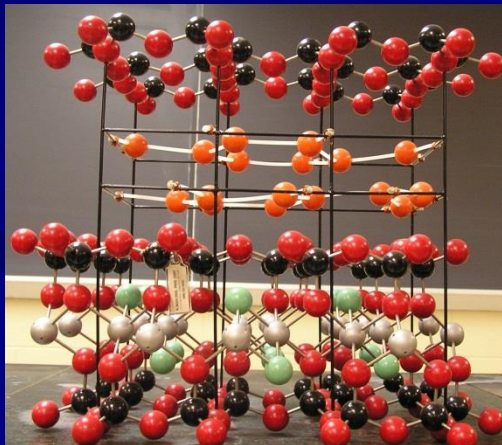
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Structure of montmorillonite a 2:1 layer clay



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



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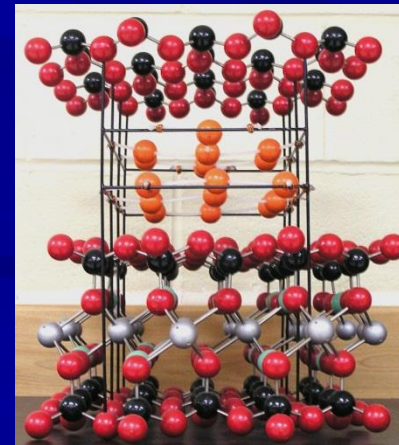


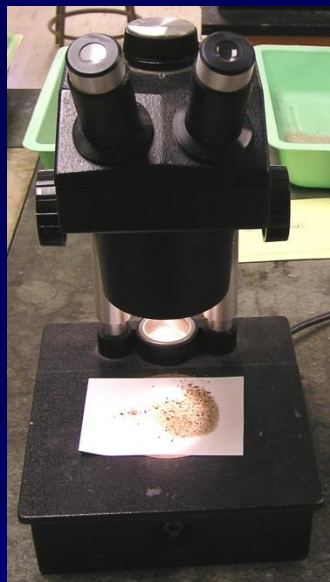
Table 7-5. Summary of the principal characteristics of the layered clay mineral groups

	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 layers
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	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_2$, little variation	$\text{K}_{0.5-0.75}\text{Al}_2(\text{Si},\text{Al})_2\text{O}_{10}(\text{OH})_2$	$\text{M}^{+0.7}(\text{Y}^{3+}, \text{Y}^{2+})_{4-6}(\text{Si},\text{Al})_8\text{O}_{20}(\text{OH})_4 \cdot n\text{H}_2\text{O}$	$\text{M}^{2+0.66}(\text{Y}^{2+}, \text{Y}^{3+})_6(\text{Si},\text{Al})_8\text{O}_{20}(\text{OH})_4 \cdot 8\text{H}_2\text{O}$
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

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}	(0.5 Ca, Na) _{0.7}
Beidellite	Si _{7.3} Al _{0.7}	Al ₄	(0.5 Ca, Na) _{0.7}
Nontronite	Si _{7.3} Al _{0.7}	Fe ₄ ³⁺	(0.5 Ca, Na) _{0.7}
Tri-octahedral			
Saponite	Si _{7.2} Al _{0.8}	Mg ₆	(0.5 Ca, Na) _{0.8}
Hectorite	Si ₈	Mg _{5.3} Li _{0.7}	(0.5 Ca, Na) _{0.7}
Sauconite	Si _{6.7} Al _{1.3}	Zn ₄₋₆ (Mg, Al, Fe ³⁺) ₂₋₀	(0.5 Ca, Na) _{0.7}

Tools for Identification and Characterization of Minerals



Stereomicroscope



PLM



XRD



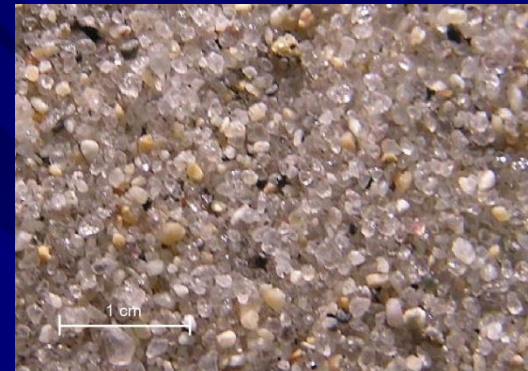
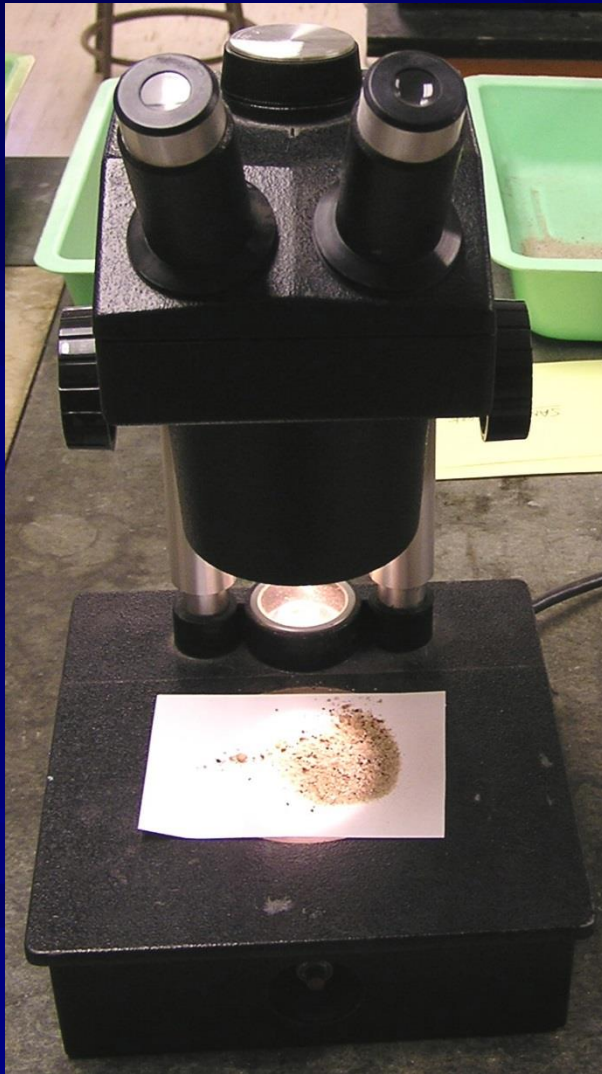
SEM



EMPA

Stereomicroscopy

Mineralogy and texture



Beach sand



Stream sand



Carbonate sand

Polarizing Light Microscopy (PLM) – a forensic workhorse

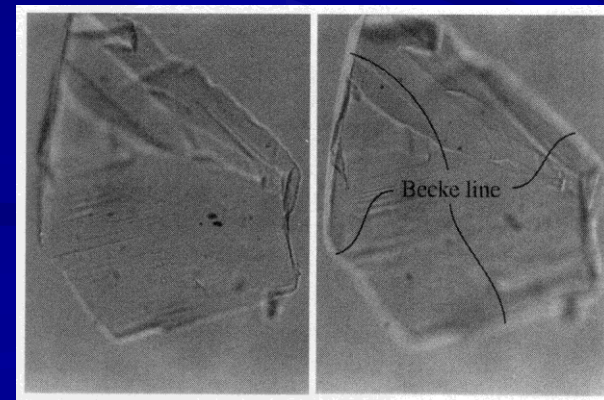
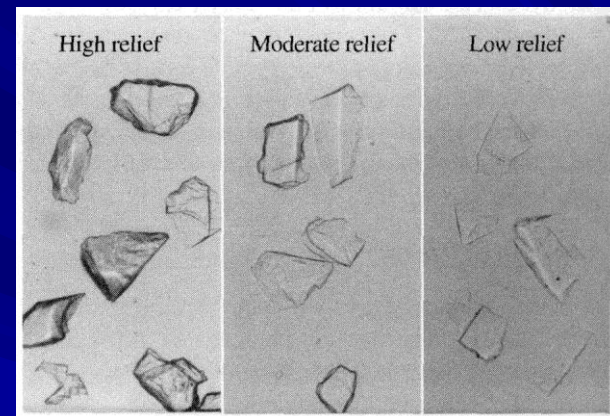
Use various optical properties to characterize materials

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 than the mounting media or index oil.

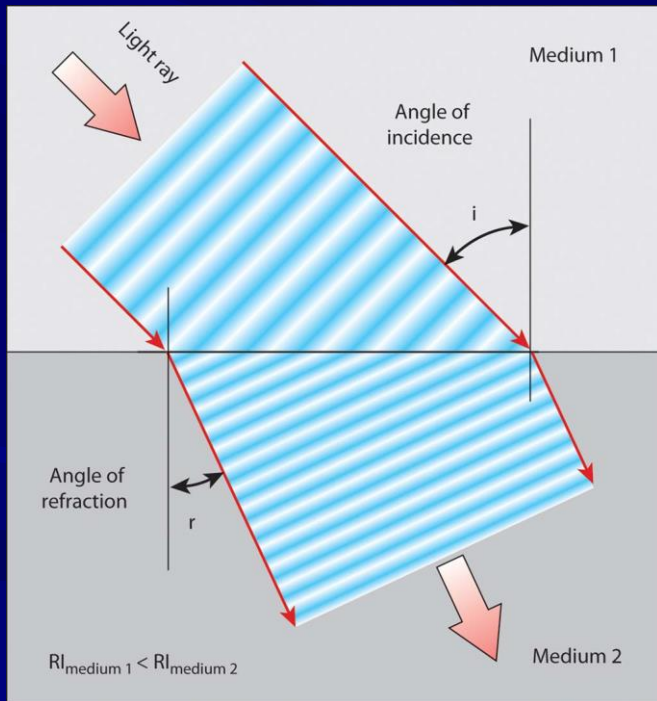


Refractive Index and Angle of Refraction

$$\text{Refractive Index}(R.I.) = \frac{\text{velocity of light in a vacuum}}{\text{velocity of light in a medium}}$$

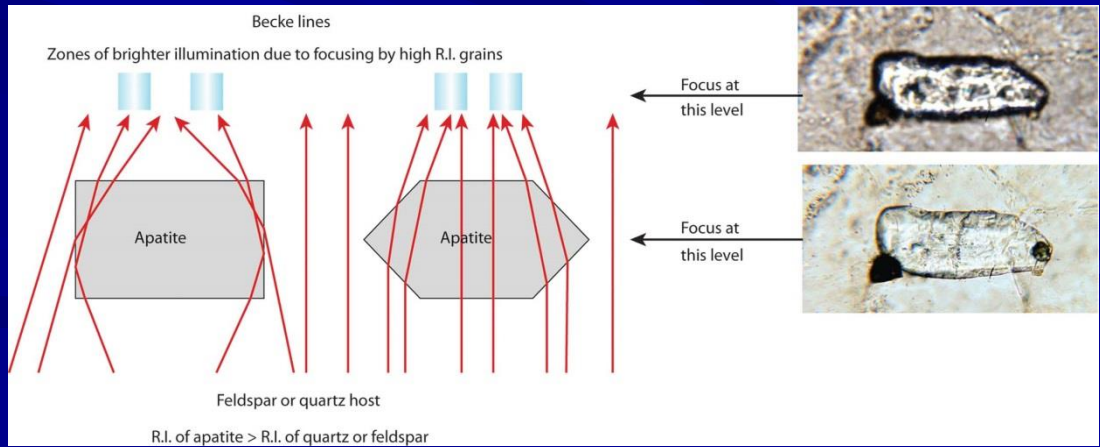
The refractive index varies with the wavelength of light.

Becke Lines – Super Important

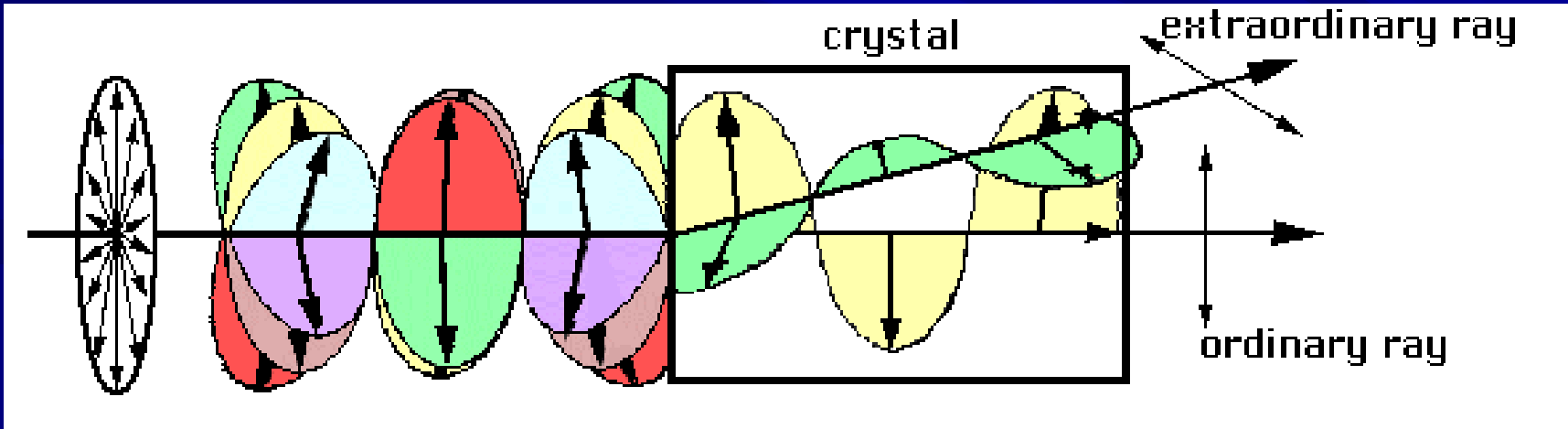
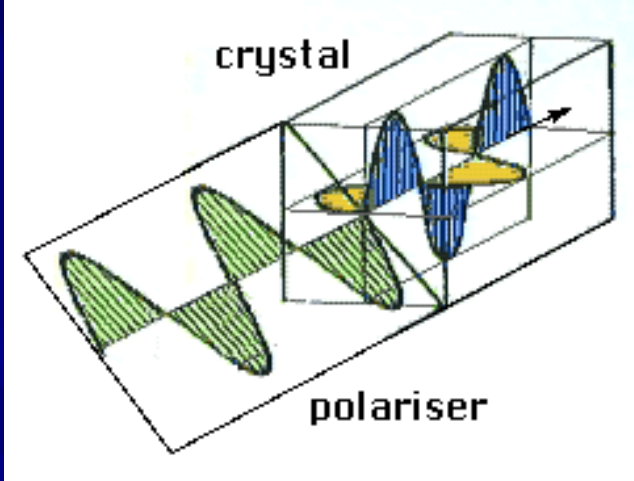
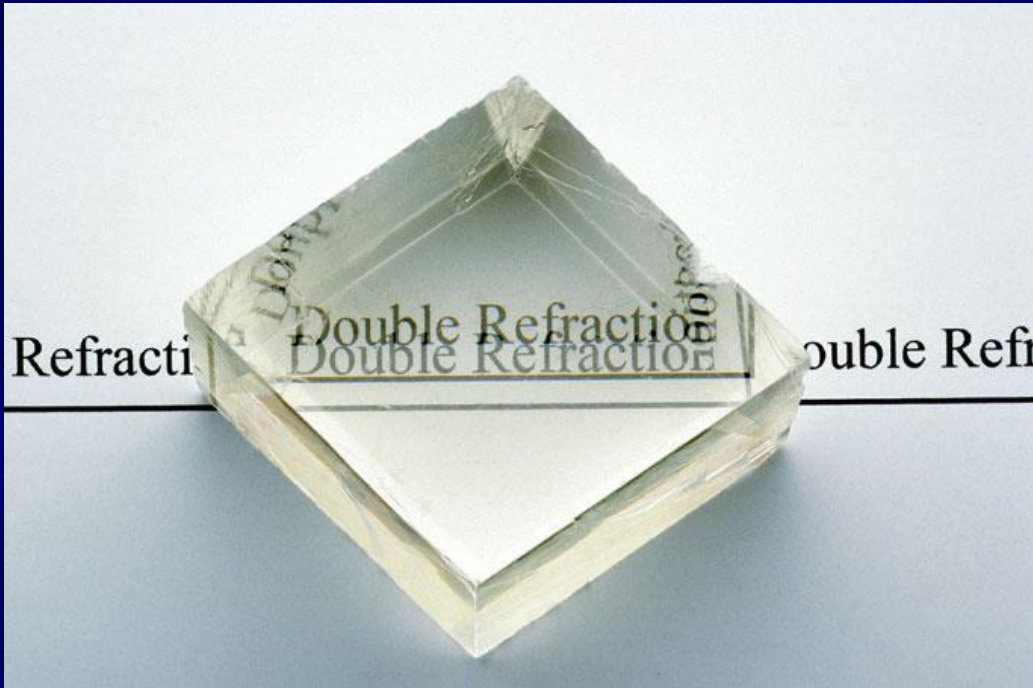


Refraction – Snell's Law

$$\frac{\sin i}{\sin r} = \frac{R.I.2}{R.I.1}$$

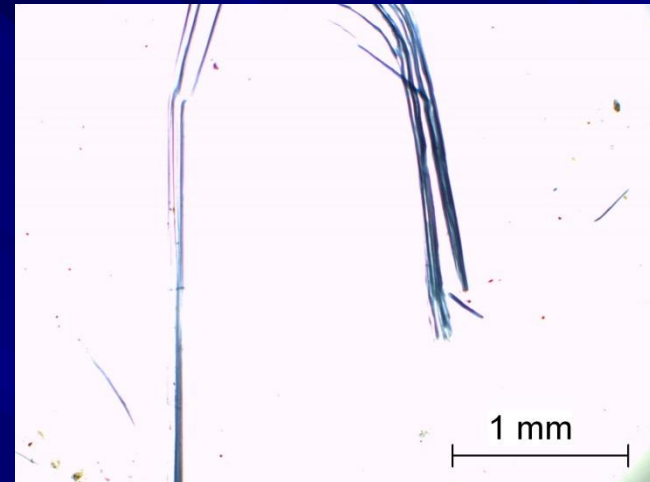
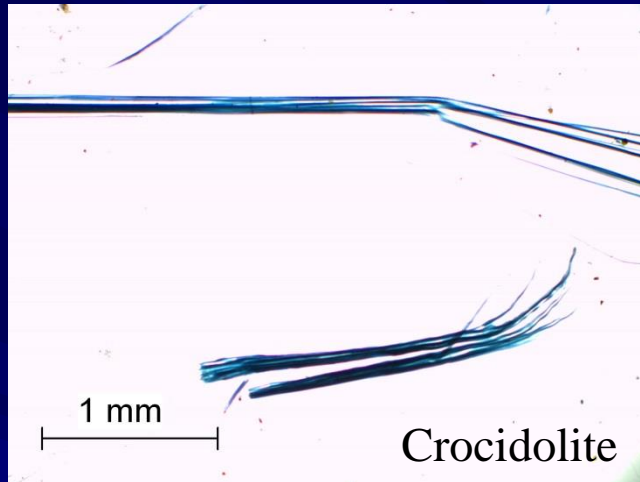


Double Refraction

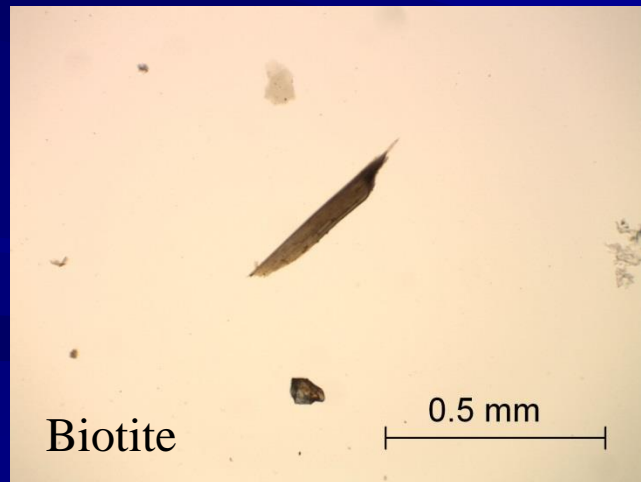


Polarizing Light Microscopy (PLM) – a forensic workhorse

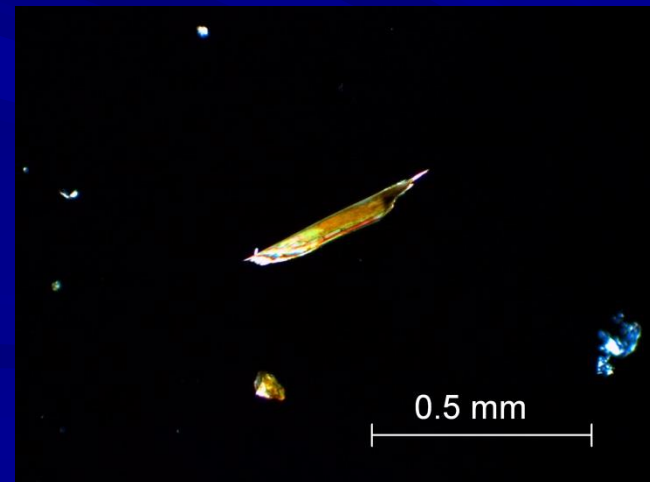
Pleochroism – color changes as stage is rotated – polarized light



Birefringence – color changes under crossed-polars due to retardation



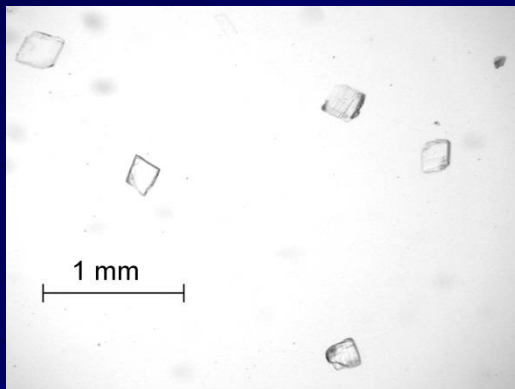
Plane polarized light



Crossed-polars

Polarizing Light Microscopy (PLM) – a forensic workhorse

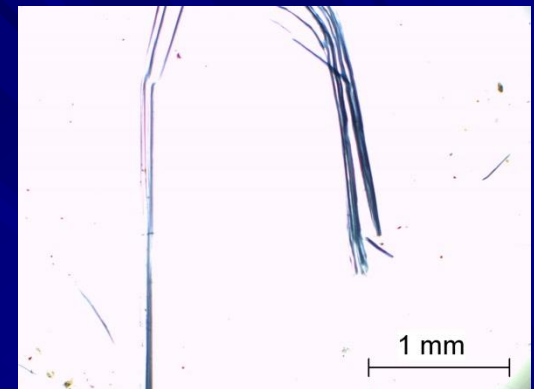
Morphology and “habit”



Calcite - rhombohedral

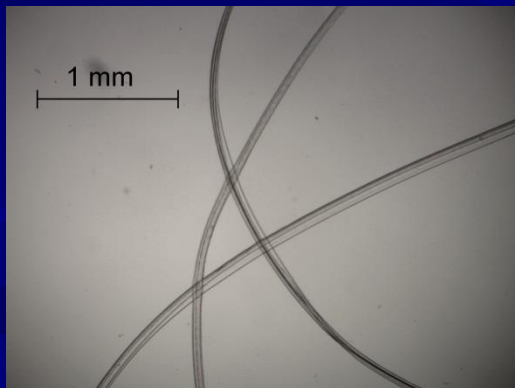


Biotite flake

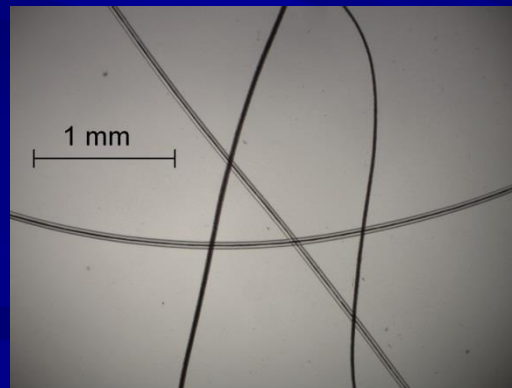


Crocidolite fiber

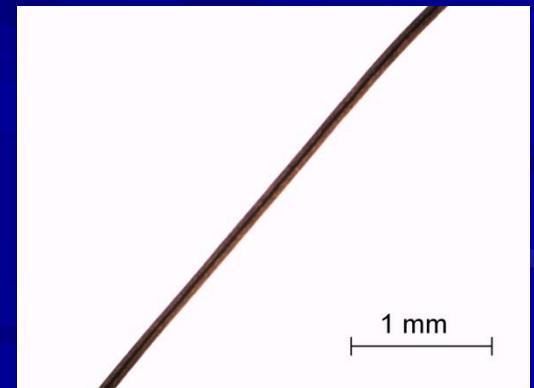
Fiber characteristics



Dynel



Dog's hair



Human hair (mongoloid)

X-ray Diffraction (XRD)

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

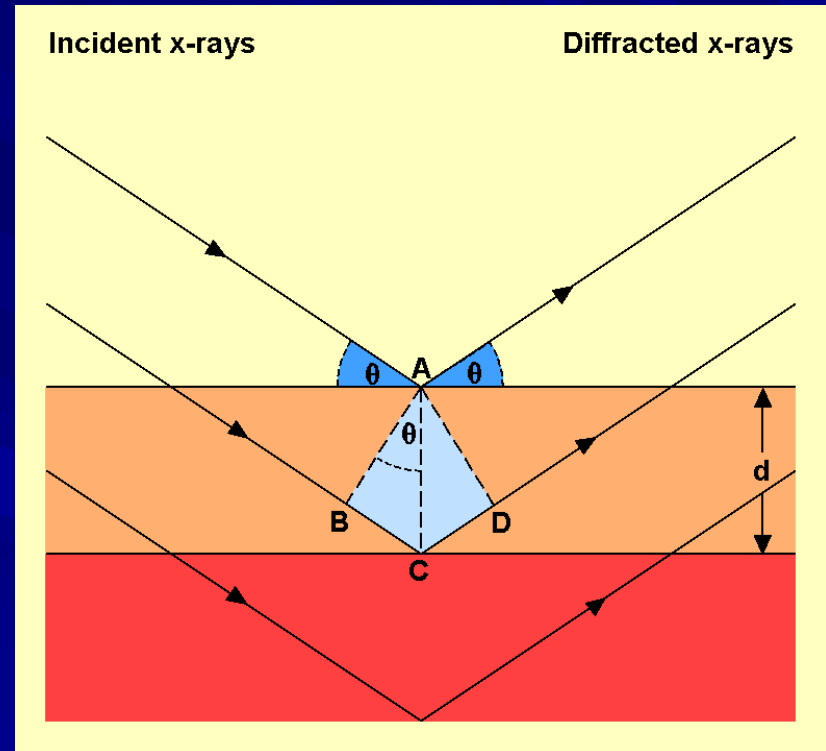
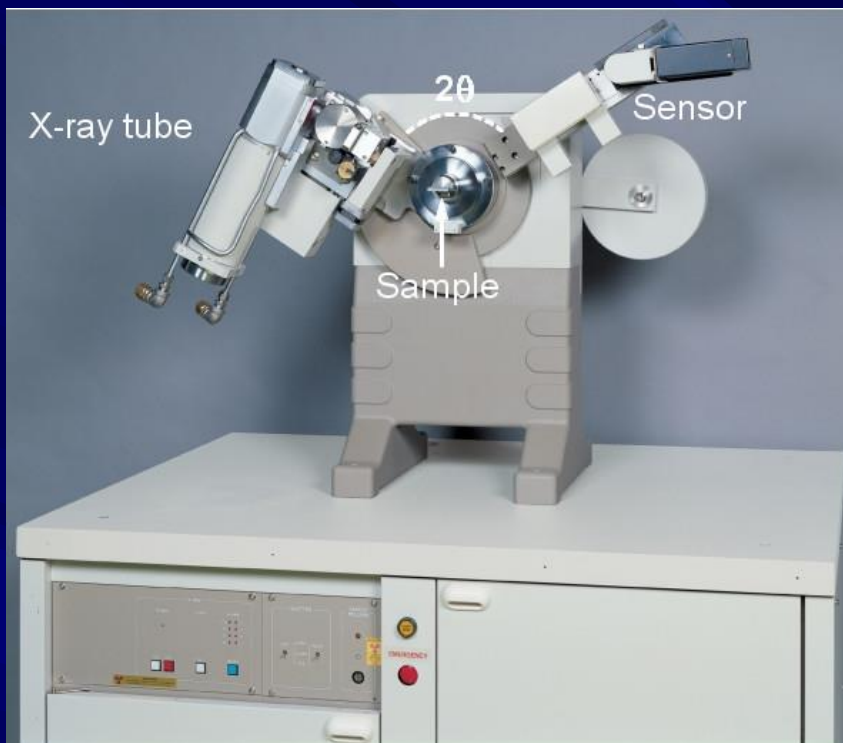
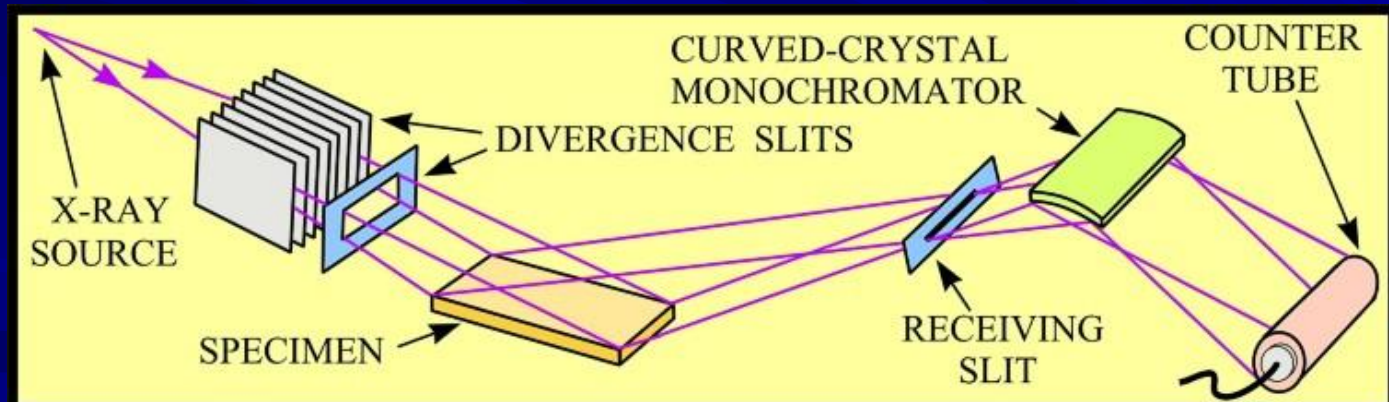


Diagram illustrating Bragg's law. $\lambda = 2d \sin \theta$ where θ = angle of incidence and diffraction when Bragg's law conditions are met and d = inter-planar spacing.

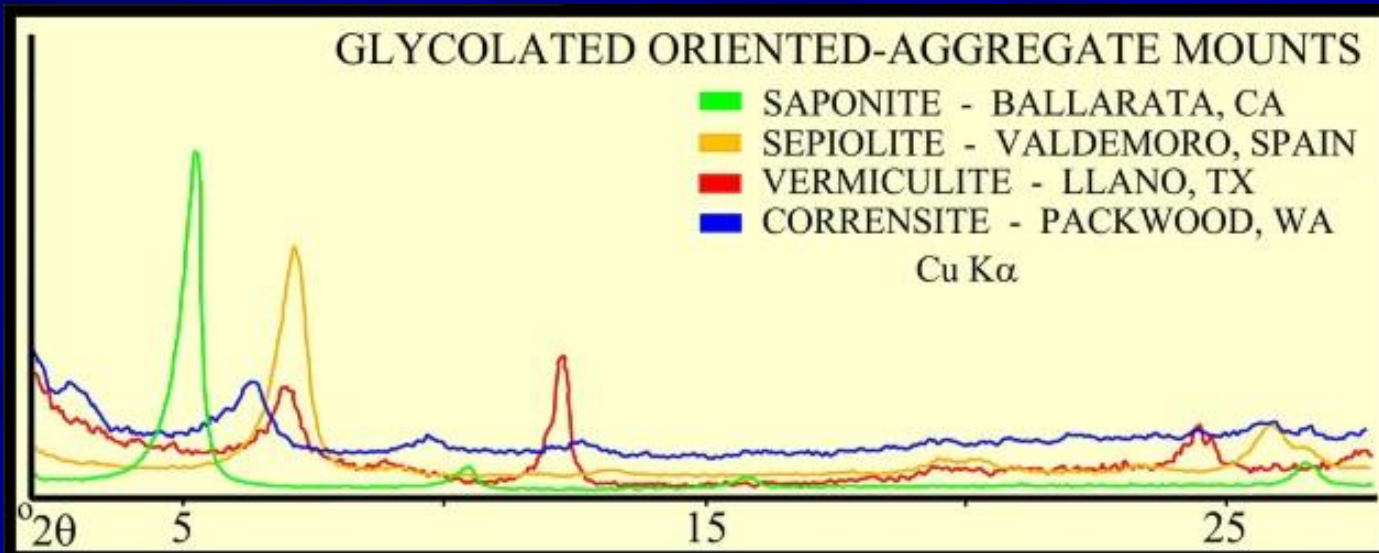
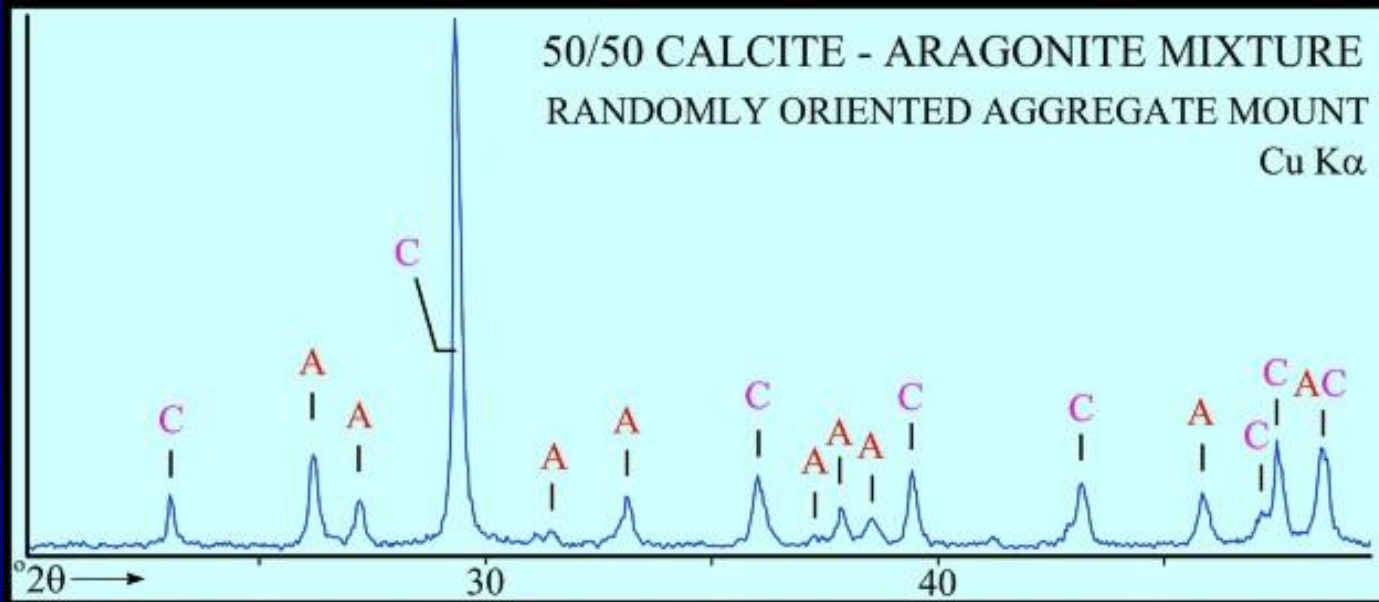


Configuration for a typical X-ray powder diffractometer.

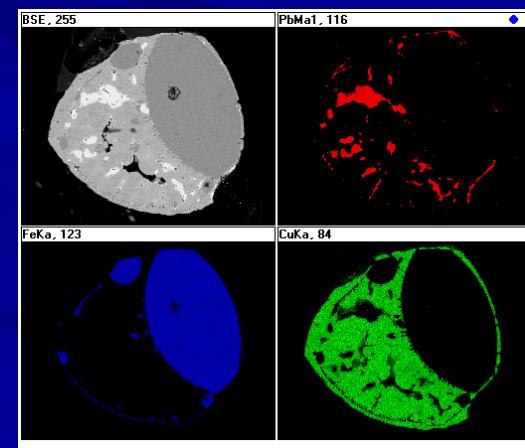
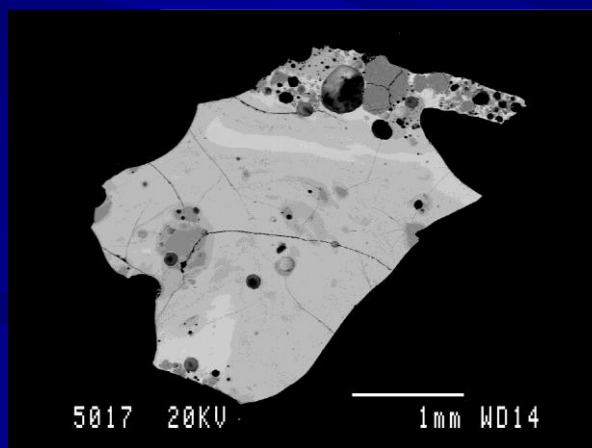
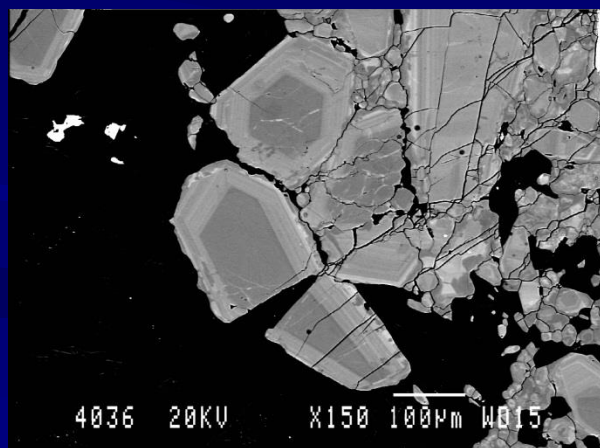
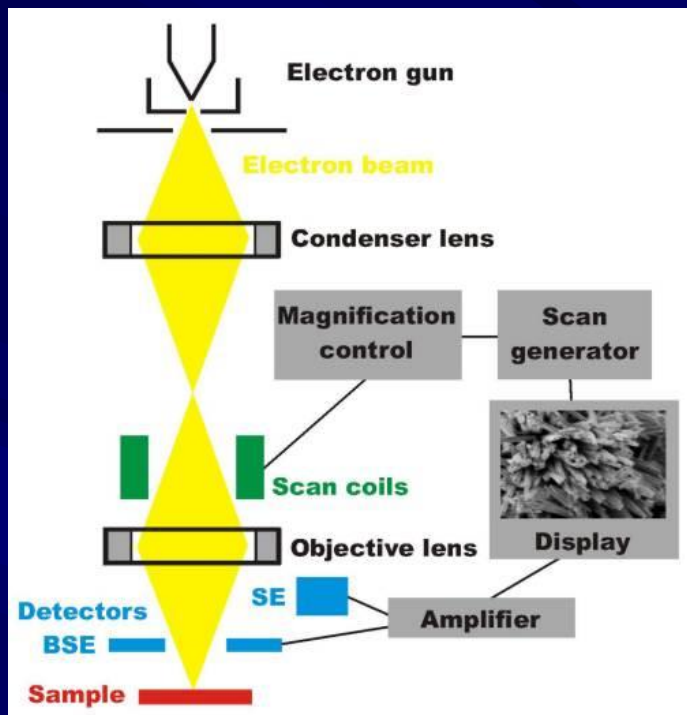


OPTICAL ARRANGEMENT FOR A PHILLIPS X-RAY DIFFRACTOMETER

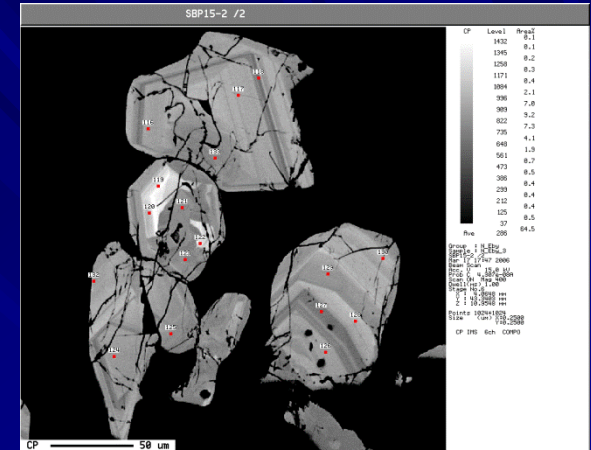
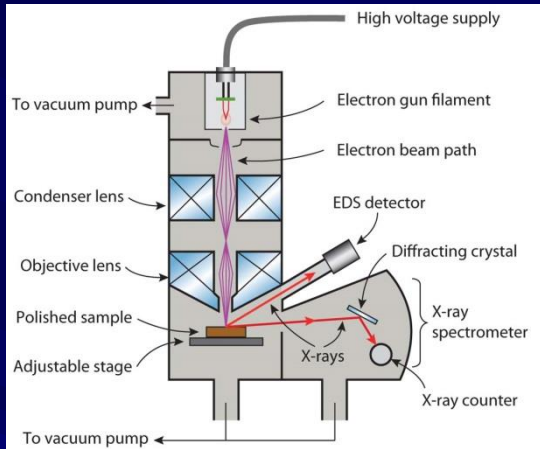
Mineral X-ray diffraction patterns



Scanning Electron Microscope (SEM)



Electron Microprobe Analyzer (EMPA)



No.	SiO2	TiO2	Al2O3	FeO	MnO	CaO	P2O5	V2O3	La2O3	Ce2O3	Pr2O3	Nd2O3	Sm2O3	Eu2O3	Gd2O3	Tb2O3	Dy2O3	Ho2O3	Er2O3	Tm2O3	Yb2O3	Lu2O3	Y2O3	Nb2O5	PbO	ZrO2	ThO2	UO2
116	1.9	0	0.004	0	0	0.195	27.559	0	14.72	31.043	3.12	10.051	0.974	0.088	1.183	0.073	0.344	0	0.031	0.046	0	0.06	1.191	0	0.126	0.043	7.589	0.296
117	2.078	0	0	0	0	0.174	27.147	0	13.95	30.607	3.09	10.537	1.116	0.086	1.274	0.125	0.271	0.032	0.123	0.141	0.066	0.065	1.418	0.057	0.112	0.017	8.45	0.33
118	1.065	0	0.019	0.015	0	0.178	28.744	0	14.704	33.228	3.372	10.905	0.998	0.089	1.177	0.105	0.434	0	0.097	0.129	0.141	0.169	1.746	0.007	0.096	0.064	3.936	0.325
119	4.321	0	0.015	0.004	0	0.238	23.928	0	11.036	26.526	2.775	10.056	1.319	0.195	1.062	0.089	0.329	0.107	0.091	0.007	0.009	0.056	1.573	0.007	0.293	0.039	17.49	0.588
120	4.9	0	0	0.058	0	0.221	22.894	0	11.211	25.178	2.742	9.962	0.996	0.075	1.042	0.04	0.405	0.017	0.198	0.042	0.078	0.018	1.373	0.042	0.318	0.088	19.277	0.679
121	1.499	0	0.004	0.027	0	0.325	28.174	0	13.629	31.073	3.103	10.644	1.225	0.087	1.348	0.176	0.429	0	0.16	0.079	0.204	0.133	1.749	0	0.113	0.047	6.842	0.232
122	3.627	0	0.011	0.044	0	0.265	24.925	0	11.756	27.256	2.932	10.618	1.231	0.048	1.303	0.056	0.47	0.246	0.142	0.134	0	0	1.572	0.003	0.253	0.003	14.541	0.514
123	1.451	0	0	0	0.014	0.176	28.232	0	15.186	32.484	3.095	10.142	1.006	0.068	1.098	0.076	0.354	0.1	0.014	0.048	0.02	0.109	1.078	0.057	0.085	0.007	5.817	0.2
124	1.661	0	0	0.008	0	0.129	27.924	0	15.045	32.451	3.197	10.447	0.861	0.072	1.019	0.153	0.255	0.135	0.122	0.168	0.09	0	1.235	0.01	0.106	0.04	6.629	0.247
125	1.433	0	0.004	0.011	0.025	0.153	28.19	0	14.987	32.457	3.289	10.557	0.806	0	1.181	0.121	0.259	0.063	0.197	0.118	0	0	1.102	0	0.088	0.027	5.704	0.197
126	1.907	0	0.001	0.04	0.004	0.147	27.454	0	14.344	31.682	3.187	10.534	1.102	0.162	1.082	0.105	0.304	0	0.039	0.006	0.03	0.094	1.269	0.02	0.117	0	7.444	0.278
127	0.857	0	0.006	0	0.01	0.182	29.241	0	15.73	33.814	3.268	10.563	1.144	0.094	1.134	0.145	0.379	0.195	0.073	0	0.035	0.065	1.464	0	0.052	0.104	3.06	0.299
128	2.343	0	0	0	0	0.158	26.773	0	14.964	30.944	2.904	9.904	0.87	0.051	1.03	0.081	0.304	0.106	0	0.115	0	0	1.162	0	0.13	0.03	9.334	0.304
129	1.54	0	0	0	0	0.186	27.958	0	15.017	32.512	3.169	10.347	0.826	0.13	1.015	0.154	0.378	0.144	0.146	0.029	0.009	0	1.337	0	0.096	0.09	6.07	0.313
130	2.06	0	0	0.061	0	0.232	27.154	0	14.523	31.369	3.065	10.002	0.861	0	1.111	0	0.334	0	0.126	0.073	0.14	0.059	1.098	0.05	0.129	0	8.094	0.232
131	1.818	0	0.007	0.039	0	0.349	27.781	0	14.702	31.238	3.299	10.411	1.119	0.015	1.317	0.153	0.514	0.139	0.142	0.089	0.08	0.002	1.255	0	0.111	0.11	7.014	0.264
132	1.839	0	0	0.019	0	0.327	27.376	0	14.735	31.676	3.28	10.54	1.125	0.096	1.237	0.154	0.395	0.037	0.096	0.03	0	0.082	1.304	0	0.11	0.053	7.174	0.272
133	1.349	0	0.001	0.007	0	0.121	28.336	0	14.824	33.301	3.138	10.859	1.108	0.135	1.079	0.093	0.306	0.004	0.043	0	0.039	0.167	1.175	0.084	0.082	0.06	5.364	0.192

The analyzed mineral is monazite
 monazite-Ce (Ce, La, Pr, Nd, Th, Y)PO₄



First Forensic Geology Case

- 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

- 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



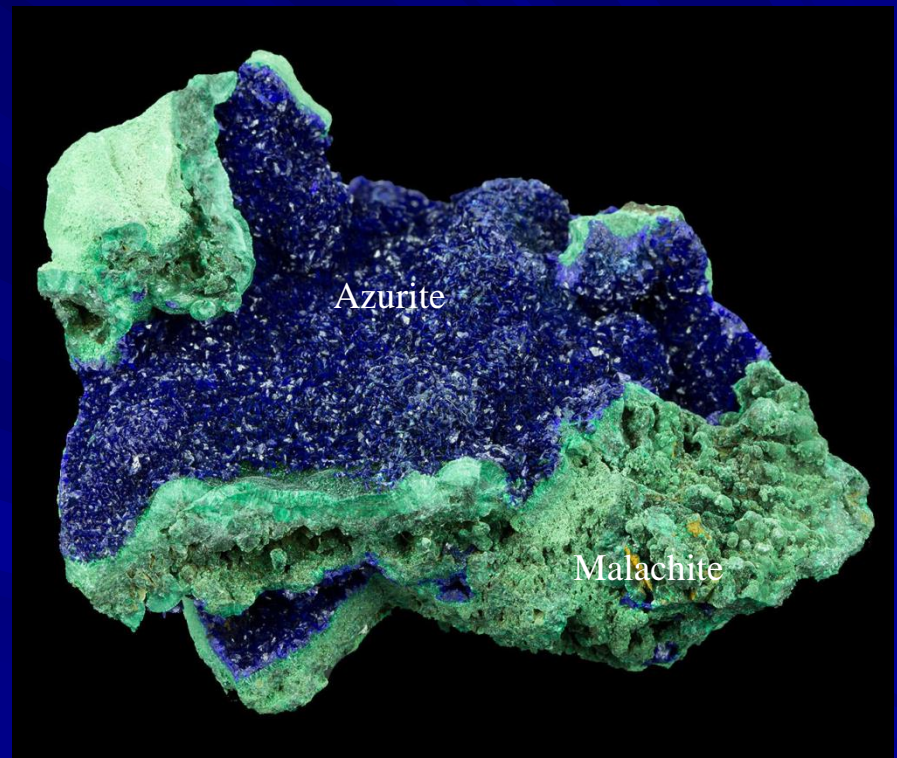
Junger Case

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.

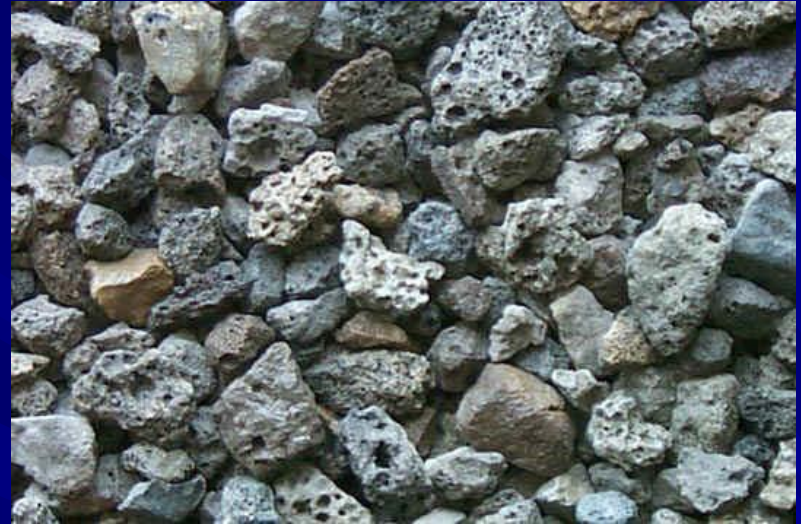
(thanks to Ray Murary)



The Reeves Murder Case

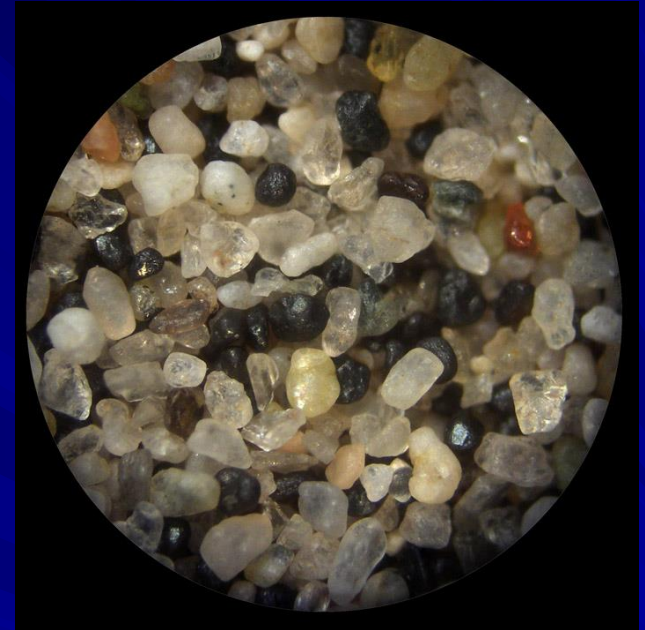
In September of 1958 a woman's body was found at the edge of the Anacostia River in Washington, D.C. A peculiar black sand was found on the victim, in a suspect's car, and at the murder scene. Geologic investigation showed that the sand was blast furnace slag that had been spread on a small section of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

(Block, 1979 p.149-152)



Sand from a Construction Site

In 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*)

