Teaching MPG - in Context: The Earth, Rocks, and Society

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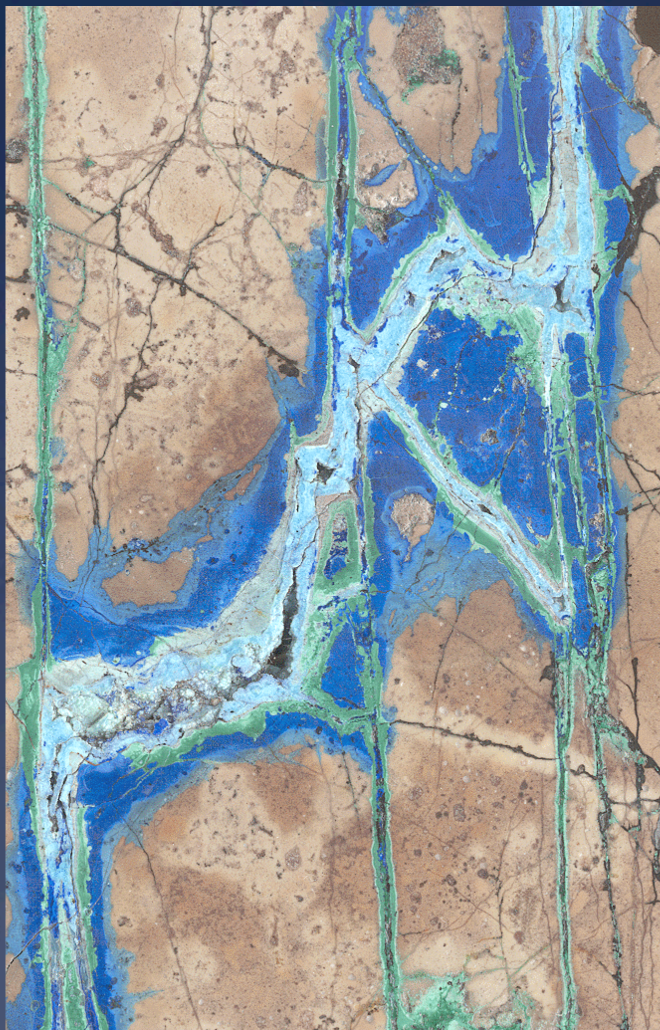
Presentation Outline



Fracture sets filled with Cu-bearing minerals. Scan - 20 cm high, Bisbee, AZ. *Photo: B. Dutrow*

Describes 3 integrated MPG courses (focus on minerals):

- **heighten course relevancy**
  - **Engage students**
- **teach basics, emerging topics**
  - **Philosophical discussion**
- **modify for other themes.**

- **Emphasis in Each**
- **Expected Outcomes**

Connections to Minerals

Spinel-twinned copper crystals, Ray Mine, AZ. 7.5 inches. *Photo: Stuart Wilensky*

Used in our everyday life

- *e.g.*, laundry detergent, cat litter, paper – pencils, toothpaste, duct tape, makeup

Necessary for our standard of living

- *e.g.*, transfer electricity, provide building materials for our homes and schools

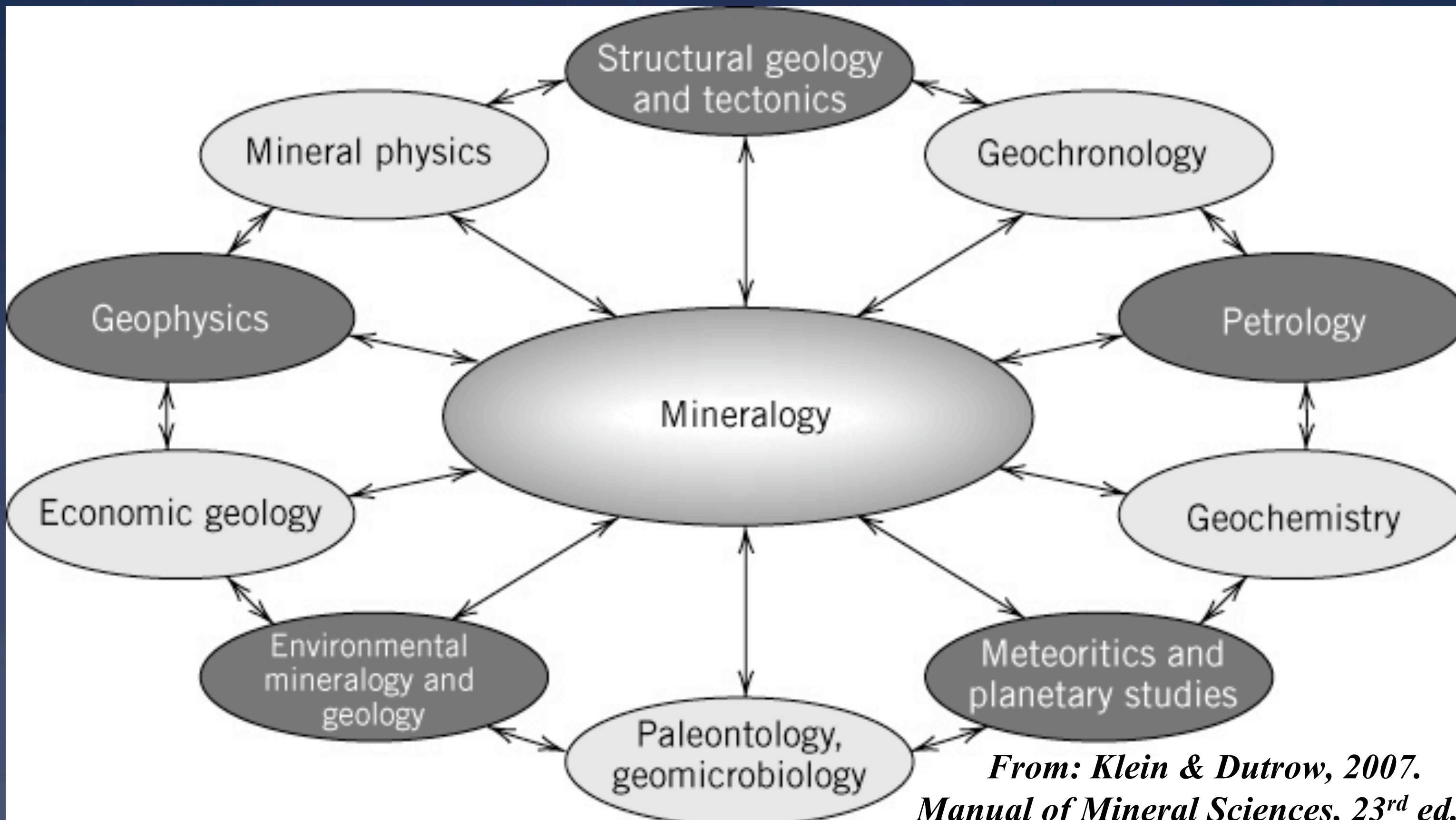
Without minerals, we would not have an Earth!

The Study of Minerals:

Fundamental components from which rocks and the solid Earth are comprised; play critical role as sources and sinks for geochemical cycles

Fluor-tremolite in folded metamorphic rocks, Campolungo, Switzerland
Photo: B. Dutrow

Mineralogy: The Center of Geosciences



From: Klein & Dutrow, 2007. Manual of Mineral Sciences, 23rd ed.

- **Related fields rely on the foundation of mineralogy**
- **Easily linked to other geosciences disciplines and life on Planet Earth**

The Study of Minerals

Tourmaline with albite and fluorite.
10.6 cm high, Stak Nala, N.A., Pakistan. *Photo: © Jeff Scovil*

"Minerals are the basic stuff of the Earth, and their study will always remain at the core of the Earth Sciences."

- Frank Hawthorne (1993, Can. Min.)
2010 IMA medalist

Yes, but does Mineralogy remain at the core of geologic study?

The Teaching of MPG: *Problems (Motivation)*

In the U.S., mineralogy (petrology) has suffered.

- **classes combined or shortened**

  ***e.g.*, 14-week Minerals and Rocks course! reduced credit hours**

- **positions, classes eliminated**

  ***e.g.*, Optical Mineralogy, Crystallography, Metamorphic Petrology**

- **Relevance questioned**

  Traditional, basic = bad

Mineralogy has a perception problem! We need a gimmick!

The Teaching of MPG: *Solutions* *(Gimmicks)*

Students with their pet minerals and rocks for semester-long, project-based project at LSU. *Photo: D. Henry*

Improve/provide context and make connections

Relate to societal issues

e.g., methane-hydrate thermodynamics, oil-well explosion

Provide active, project-based learning

Positive environment

One possible solution..
framework readadjustment…

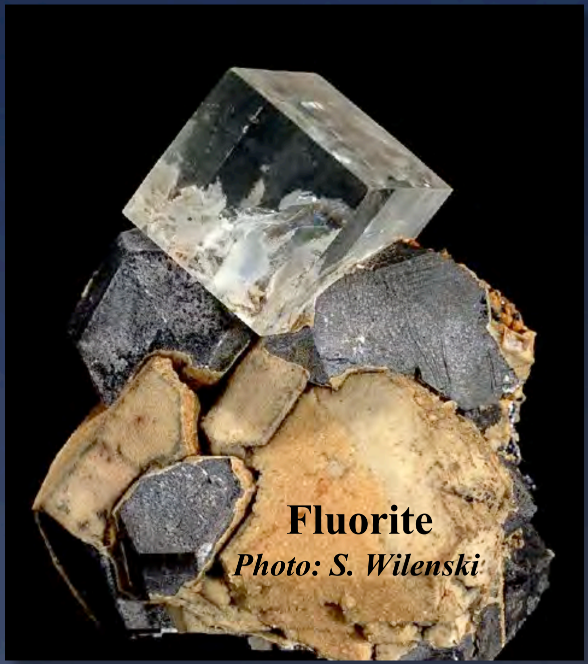
Teaching in the field, Sawtooth Mtns, Idaho.
Photo: P. Bergeron

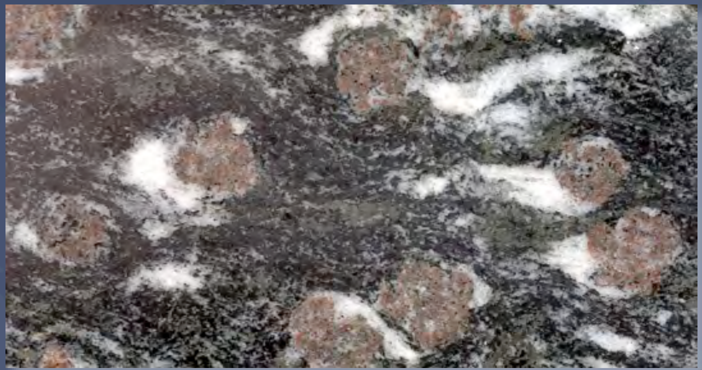
Three example courses:

- *Mineralogy – Core to Crust*
- *Petrologic Mineralogy*
- *Earth Materials and the Environment*

Tailor to any MPG suite

Mineralogy - Planet Earth





Garnet amphibolite 6cm polished slab.

Photo. D. Henry

Typical Course Goals:

- **Provide conceptual understanding of mineral structure, growth, behavior *f (T, P)*, uses;**
- **Classification and identification of ~90 minerals;**
- **Foundation for advanced geology courses.**

Mineralogy - Planet Earth

Recent and Eocene pinecone (Patagonia).
Photo: D. Henry

Additional Goals:

- Links to other Disciplines

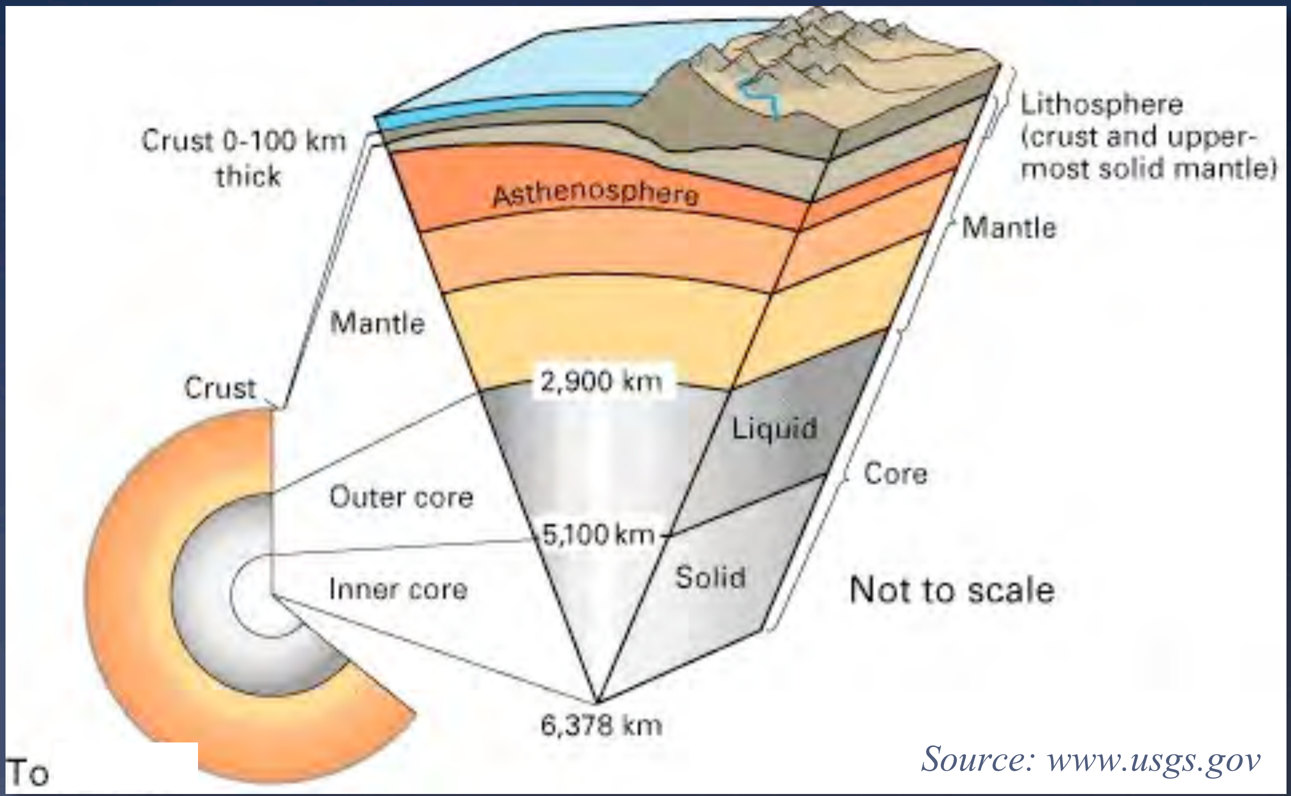
  e.g., materials science, chemistry, geomicrobiology, paleontology, inorganic chemistry, gemology, art, archaeology, biomineralization;

- Links to our standard of living, including hobbies

  e.g., size of tailings pile

Titanium mountain bike.
Photo: Marlin Bikes

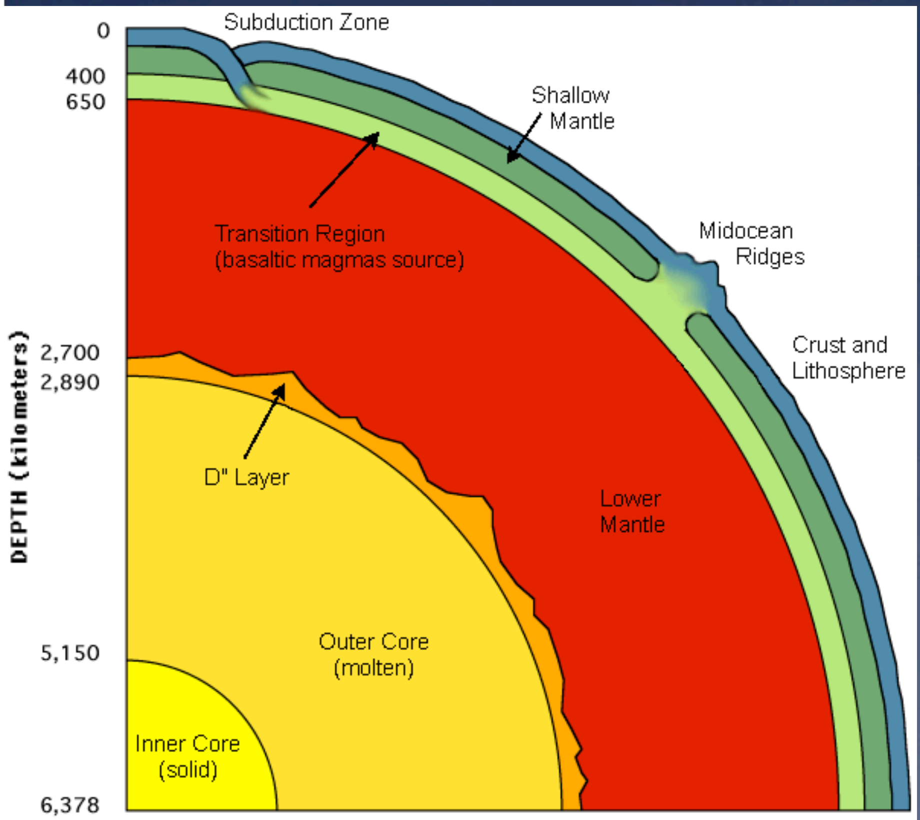
Mineralogy in Context: *Planet Earth*



"Earth System or Whole Earth" approach

Systematic mineralogy taught in terms of Earth's divisions from the core to the crust, simple to complex minerals.

Minerals from Core to Crust



Source: www.iitaka.org

Review of physical properties

Basics of crystallography

- Symmetry
- Pauling's Rules

Review of Earth's Structure

- Direct and indirect methods of investigation

  Geophysics, experimental petrology

Minerals from Core to Crust

Region		(km)	Mineralogy Covered
	crust	100	Other Silicates (tectosilicates, phyllosilicates, etc) + Non-Silicates
mantle	upper mantle	410	Olivine, Pyroxene, Amphiboles, Diamonds, Garnet
mantle	transition zone	670	Spinels, Garnet (majorite), Oxides, polymorphic transitions: ol→sp→per, pyx→gt→ilm
mantle	lower mantle	2900	Perovskite, Oxides (Magnesio-Wustite, Ilmenite, Rutile, Stishovite structures) D”
core	outer core	5200	Native Elements (Liquid Iron + Ni + S)
core	inner core		Native Elements (Solid Iron + Ni)

Fig. 1: from Dutrow, B. 2004. Teaching Mineralogy from the Core to the Crust. *J. Geoscience Ed. 52: 81-86*

Systematic Mineralogy

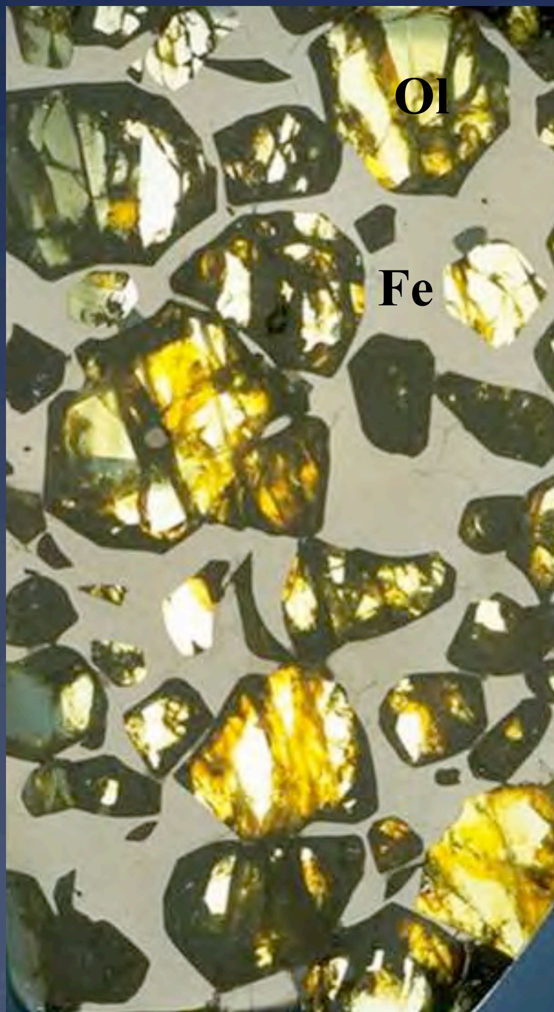
- ***Crust***
- ***Upper to lower mantle***
- ***D’’***
- ***Core***

Mineral chemistry, structural features on a *“need to know”* basis

- ***‘Just in time learning’***

Syllabus: http://www.geol.lsu.edu/dutrow/mingy

Minerals in Context: *Earth's Core*



Pallasite meteorite (olivine and iron metal).
Photo: Smithsonian Institution

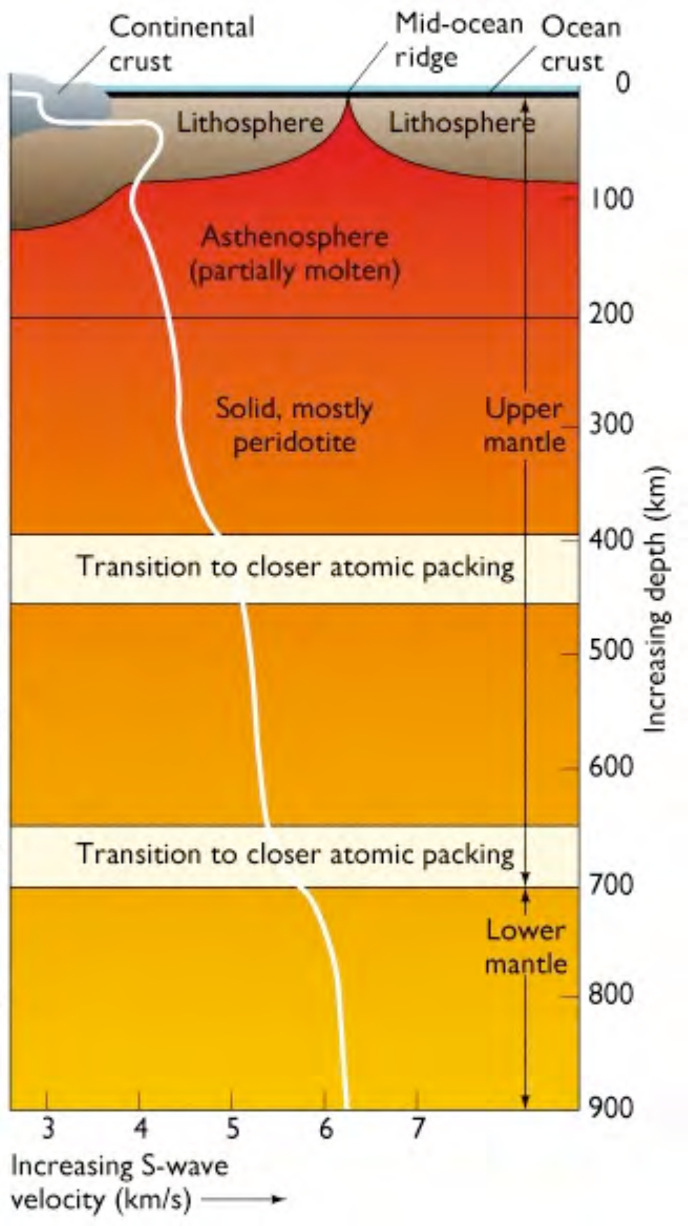
Inner Core

- Native Elements
  - Fe group
  - S
  - Precious metals with crust
- Simple packing and structures
- Meteorites as natural analogs

Outer core

- Reexamine definition of a mineral

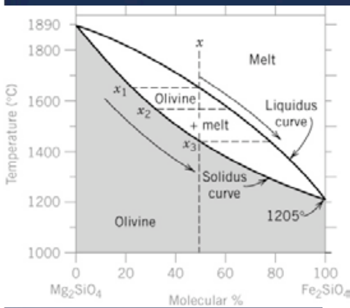
Minerals in Context: *Earth's Mantle*



Upper - transition zone - lower

- Silicates and oxides
- More complicated structures, chemistry
  - Solid solution, endmembers
  - Zoning
  - Phase transitions
    - Mantle convection
    - Earthquakes
    - Mineral behavior *f (T,P)*
- Deducing mineralogy on limited direct evidence

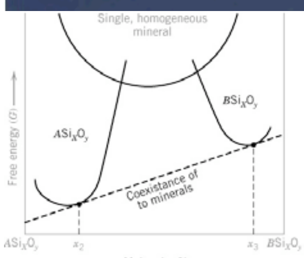
Minerals in Context: *Earth's Upper Mantle*



Olivine, 2 cm

Pala Intnl.

Figs. 23[rd] Man. Mineral Sci.



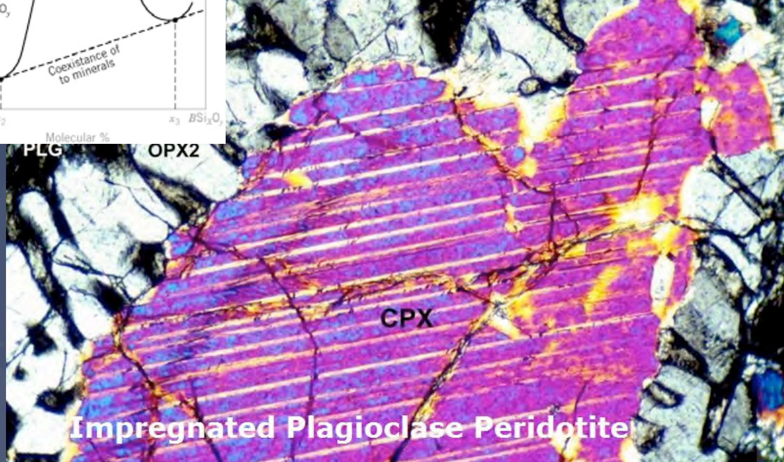


Photo: J. Lawford Anderson, USC

Silicates

- classes, formulae
- hybrid bonding

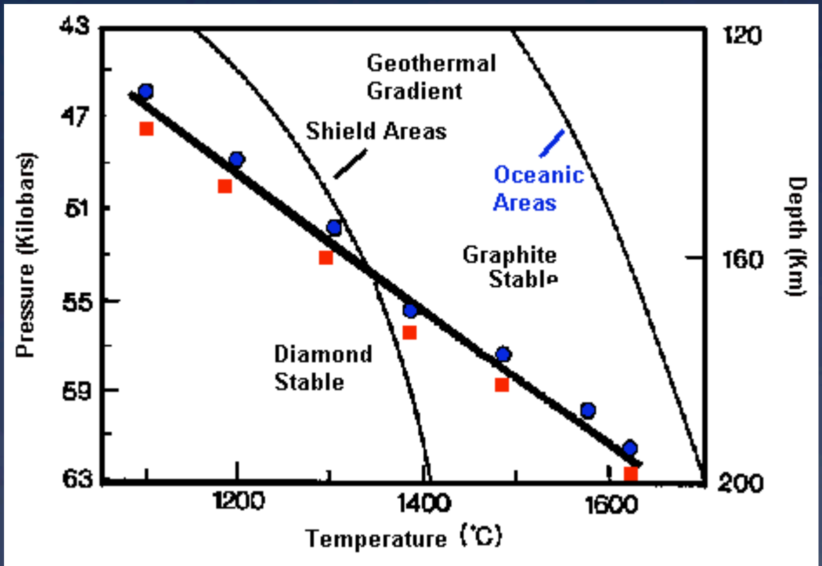
Olivine

- T – X diagrams, zoning
- cation ordering

Pyroxene

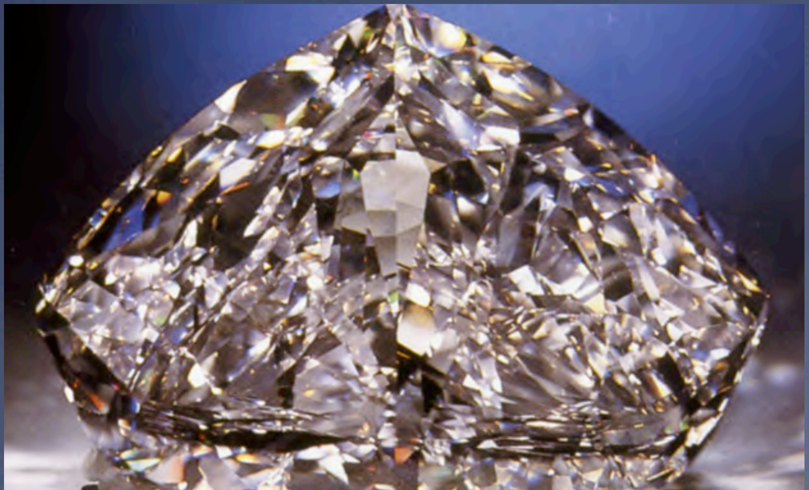
- exsolution, miscibility
- G – X diagrams

Minerals in Context: *Earth's Upper Mantle*



Diamonds

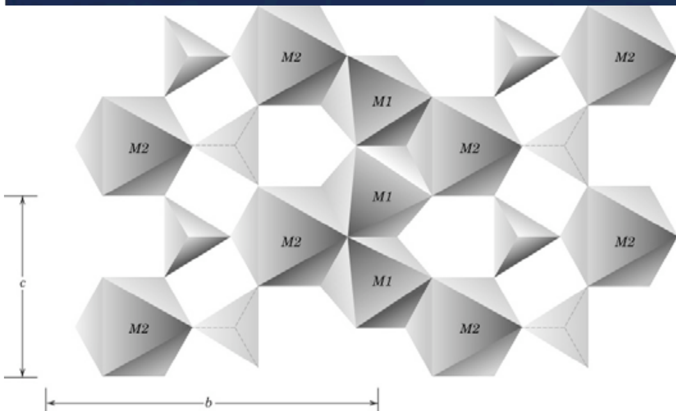
- polymorphs – phase diagrams
  - Metastability
- Miller indices
- formation
  - Isotopes
- surviving supersonic transport
- antiquity of diamonds
- important technological materials



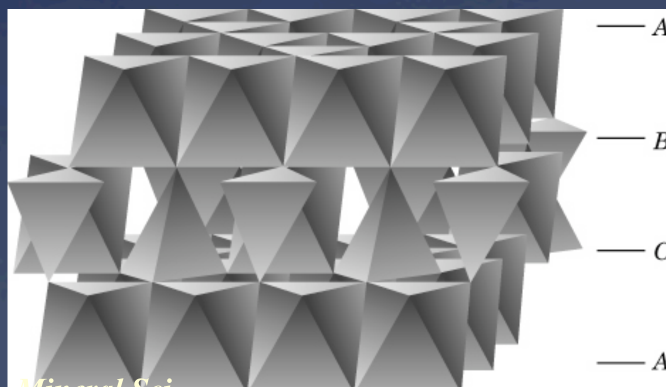
Centernary Diamond –

Premier Mine 599 ct, perfect color; cut to 273.85 ct, 247 facets, 39.9 x 50.50 x24.55 mm; *famousdiamonds.tripod.com*

Transition Zone, Lower Mantle, D"



Olivine



Spinel

Figs. 23rd Man. Mineral Sci

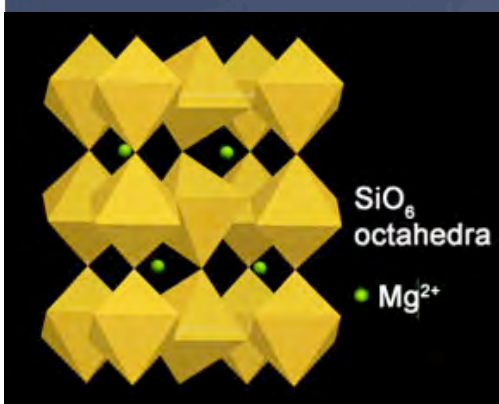
Polymorphic changes: ol, pyx

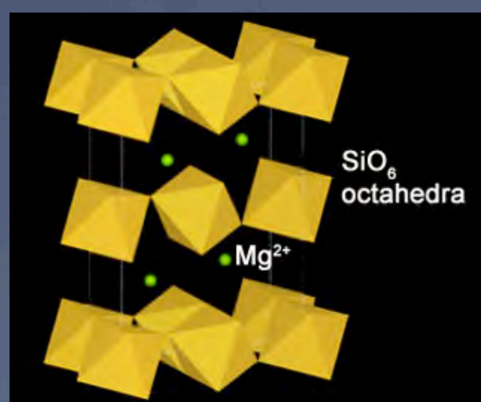
Oxides

- Structure types
- packing
  - *Perovskite*
- deep earthquakes

D" –

where experiments discovered minerals, mineral physics





Perovskite, Post-perovskite

Image source: www.iitaka.org/pp.html

Earth's Crust: Complexity and Diversity

Ettringite on Calcite. Rep. So.Africa. *Photo: ©Jeff Scovil*

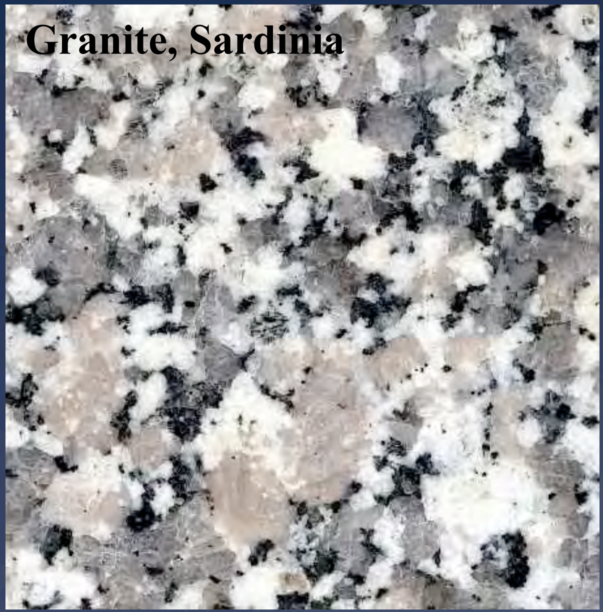
Near-surface (lower P-T) minerals

- Sulfides (S)
- Carbonates (CO_3), Sulfates (SO_4)
- Hydroxides (OH)
- Remaining Silicates (SiO_4), Oxides, Native Elements

Focus on geologic environment, occurrence

Environmental Indicators

Earth's Crust: Rocks and Technology



Schorl and beryl.
photo: ©Jeff Scovil

Silicates (SiO_4)

Quartz and Feldspar, Zeolites

- **Revisit polymorphic transitions**
- **Exsolution**
- **Technological uses, hydrocarbon cracking**

Phyllosilicates

- **wine filtering**

Non-quad inosilicates

- **Jadeite and nanomaterials**

Cyclosilicates, Nesosilicates

- **Environmental, PTXt indicators**
  - **Geochemical - B, Be, Li, F;**
  - **P – T - t: Al-silicates, zircon**

Earth's Crust: Minerals in our Lives

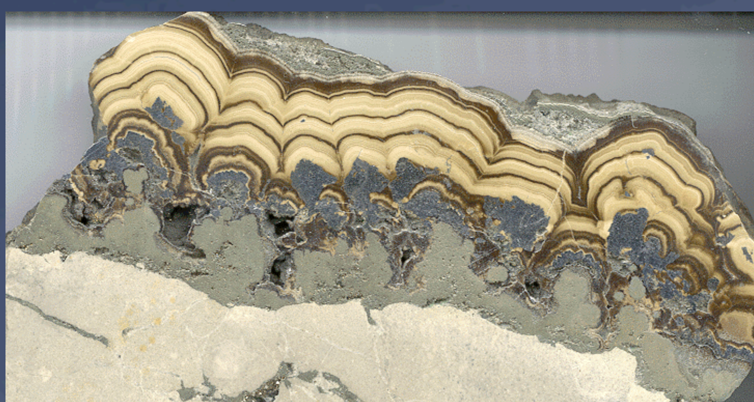
Black smoker at ridge. *Source: www.Udel.edu*

Environmental Mineralogy

Sulfides, Native Elements

Ore Deposits – Economic Geol

- **Formation**
- **Environmental impacts**



Slab of a Paleo-smoker: chert, galena, marcasite.
Czech Republic: *Photo: B. Dutrow*

Copper Mine, Butte, MT, USA

Minerals in Context: *From the Core to Crust*

Silver. Kongsberg, Norway. 12.7cm
Photo: Stuart and Donna Wilensky

Framework is Planet Earth.

Outcomes: **Basics and fundamentals of minerals, focus on internal structure and external manifestation- behavior, identification, what minerals record,**

Pros: **Framework of Earth's structure as context for minerals, linkages**

Cons: **Non-geology majors disinterested, structure vs. structure types, more than one environment**

Teaching MPG in Context
Petrologic Mineralogy: Rocks

Metamorphosed turbidite with staurolite, Coos Canyon, Maine, USA. ***Image: D. Henry***

Minerals as fingerprints to the Earth's evolution

Emphasis: **Advanced mineral chemistry and structures, thermodynamics, petrology**

Framework: **Rocks**

Use of minerals for geologic applications

Minerals in Context: *Rocks*

Tourmaline - with multiple compositional zones, useful for all three applications.
Image: Der Tourmaline: Steinerbooks.com

Syllabus for this course:
http://www.geol.lsu.edu/dutrow/petro_min

Three primary applications:

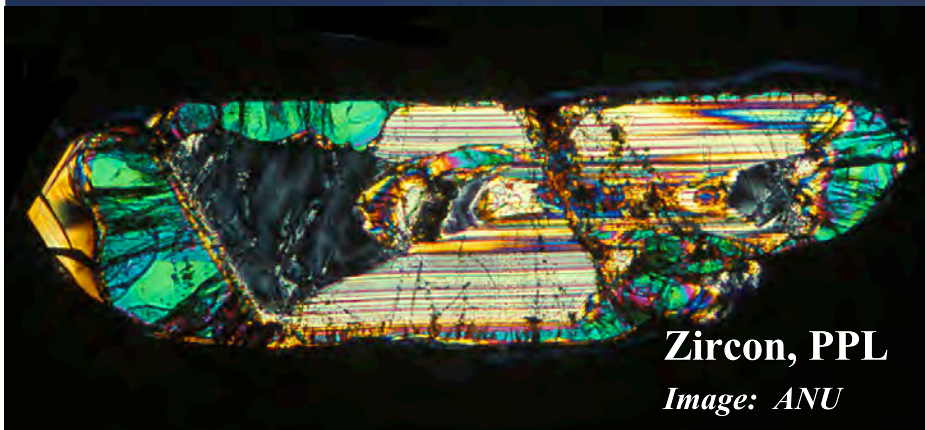
1. **Geochronology**
   - **Absolute time (not relative)**
   - **Thermochronology**

2. **Conditions of Formation**
   - **Pressure**
   - **Temperature**
   - **Fluid composition**
   - **Isotopes (traditional, non)**

3. **Provenance Indicators**
   - **Source region**
   - **Age**

Minerals Telling Time

Geochronology

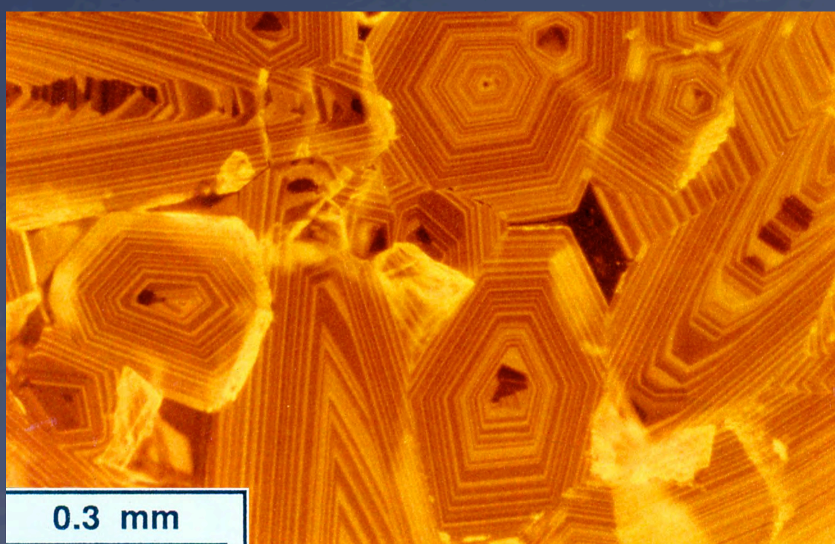


Zircon, PPL
Image: ANU

Imaging and Analysis Techniques

- In-situ vs. average
- Materials – *Cutting Edge* website

http://serc.carleton.edu/research_education/geochemsheets/

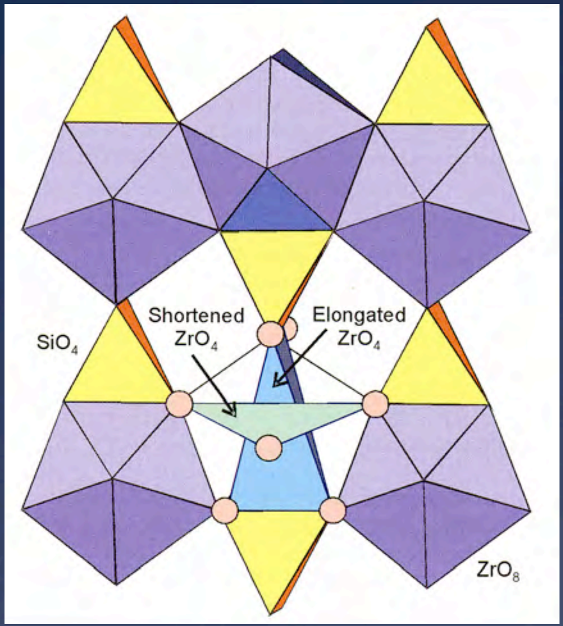


Cathodoluminescent image of oscillatory-zoned calcite, subsurface LA, USA. *Photo: D. Henry*

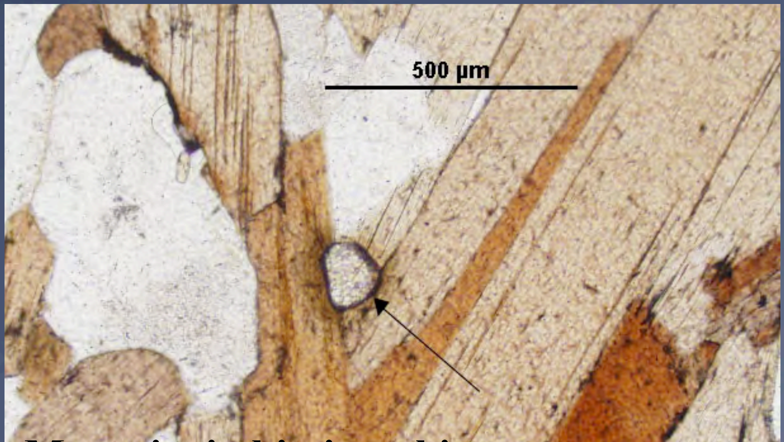
Overview of Age-Dating Techniques and Equations

- *e.g.*, U/Pb, Lu/Hf, Sm/Nd, Ar/Ar

Minerals Telling Time



Zircon structure
Image: Finch & Hanchar, 2003, Elements



Monazite in biotite schist.
Photo: www.smith.edu

Revisit mineral structures, chemistry in detail

- Why some minerals are better recorders than others?
- What do they have in common?
- Why is there no U in staurolite?

Minerals for Geochronology

- Zircon
- Titanite
- Monazite
- Garnet

Minerals in Context: *Rocks*

Thermochronology

- Feldspar
- Muscovite
- Amphiboles
- Apatite

- Importance of:
  - chemical zoning
  - solid solution, nomenclature
  - T - bonding environment and strength

Minerals Telling the Rock's P-T-X

Melting ice [H_2O (ice) = H_2O (water)] is endothermic and relates to the bonding E. This reaction cools our drinks.

Geothermobarometry

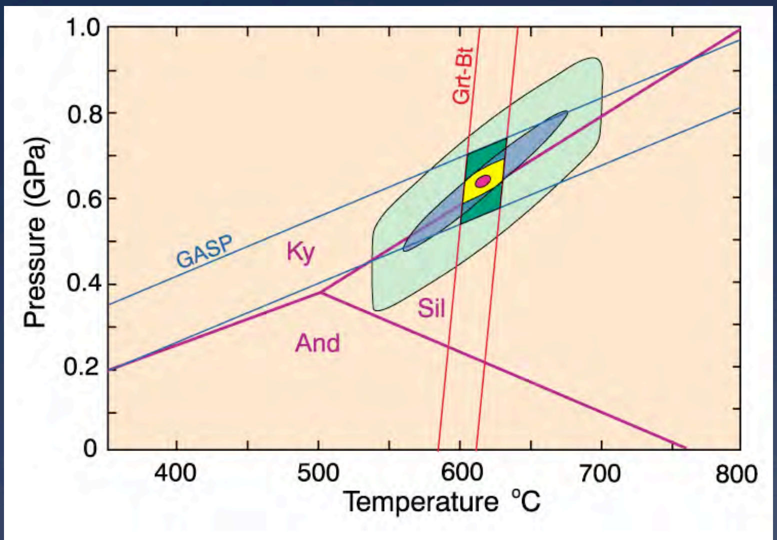
Overview of Thermodynamics

- laws
- Chemical equilibrium
- Textural equilibrium
- good thermometer vs. good barometer

Activity Models

- Why mineral chemistry and solid solution are important to know!

Minerals Telling P-T-X



P-T diagram with garnet-biotite geothermometer and the GASP geobarometer of a pelitic schist from southern Chile. From Spear (1993) MSA Monograph 1.

Grt-bt-sil schist, NW Maine. PPL FoV~3mm. Photo: B.Dutrow

Geothermobarometry

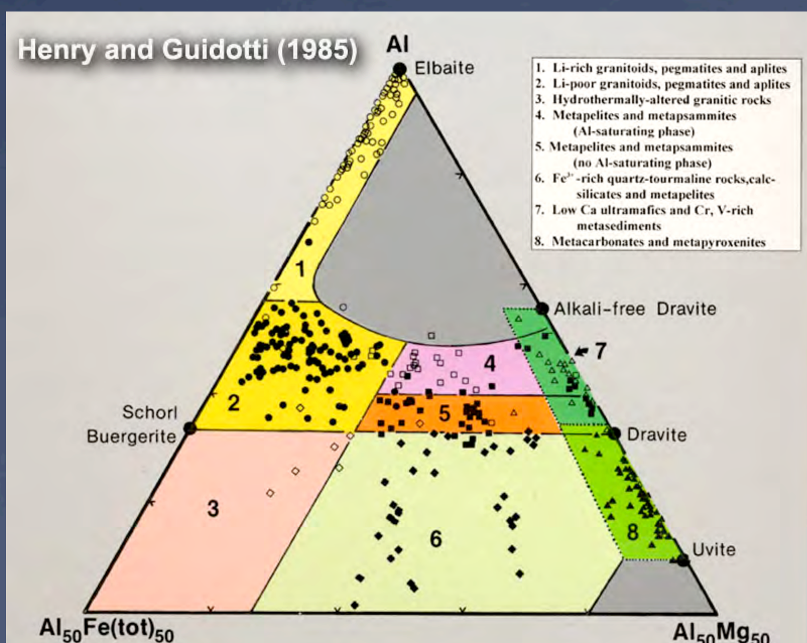
Mineral Equilibria

- **Exchange**

  e.g., Fe-Mg garnet-biotite
- **Discontinuous**

  e.g. hornblende-plagioclase, GASP
- **Single-mineral thermobarometers**
  - Ti in biotite, quartz
  - Al or Ti in hornblende
  - Zr in rutile
- **Problem sets**

Minerals Telling the Source: *Provenance*



Original QFL plots

Mineral chemistry as a clue to source region

- detrital zircon
- tourmaline
- amphiboles, pyroxene
- volcanic clasts

P-T of source region

Embedded Research Project

Semester-long project integrated into the fabric of course

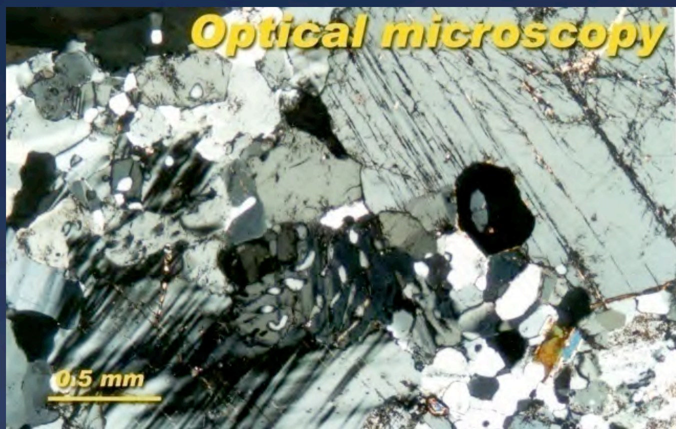
- Introduction to the culture of research (mundane to advanced)
- Research experience

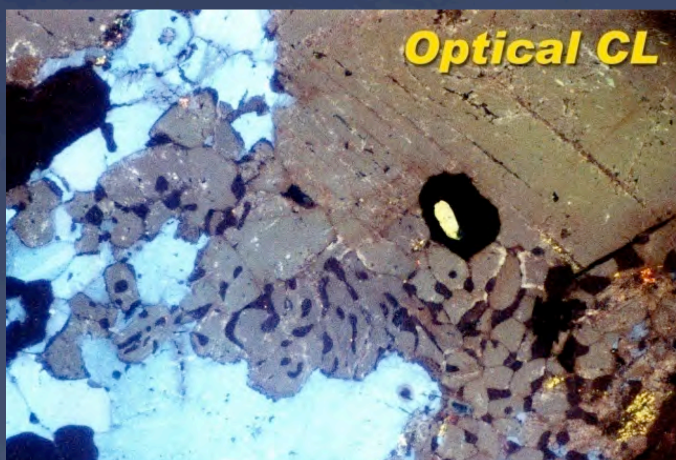
  processing rock sample, petrographic and analytical data acquisition, calculation of stoichiometry, P-T, and petrologic interpretation
- Venue to developing scientific communication skills

  written report and oral presentation

Step 1: Petrography; Photo: D. Henry

Active Learning – Using Minerals





Photos: D. Henry

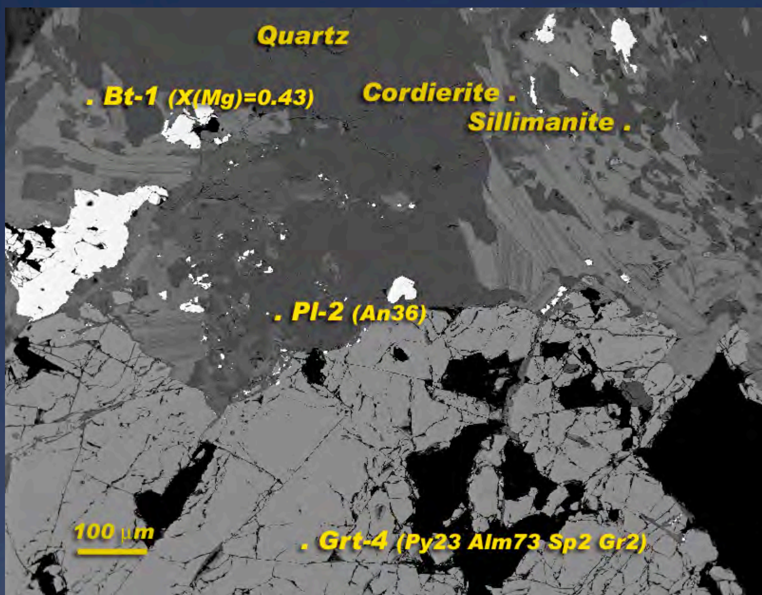
Simple tools

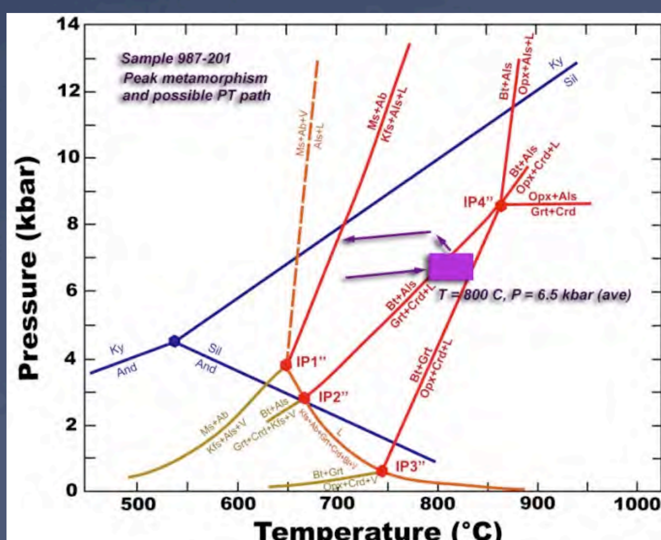
- **Optical microscopy**
- **Optical CL**

Advanced tools

- **SEM imaging - BSE**
- **EDS (mineral ID), electron microprobe spot analyses and data handling**

Example: *Analytical Data and Interpretation*



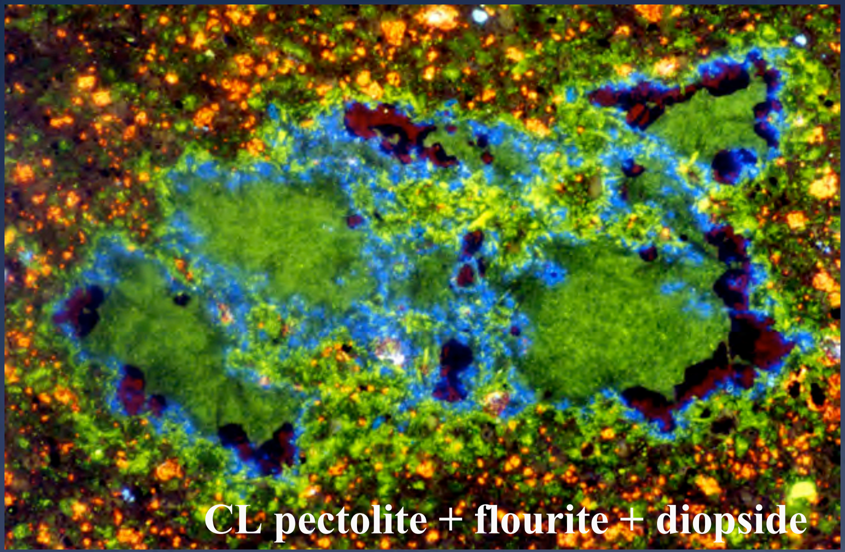


Peraluminous migmatite

- Quantitative spot analyses
- Mineral normalization schemes
- Application of TWQ - peak metamorphic conditions
- Consistency with biotite dehydration melting scenario
- Possible retrograde path

Slide courtesy of D. Henry

Petrologic Mineralogy – Context is Rocks



Field work, Sawtooth Mtns, ID. B.Dutrow

Outcomes

- **Understanding the utility of minerals to <u>solve geologic and tectonic problems</u>**
- **Detailed knowledge of mineral chemistry and structure as they relate to problem-solving**
- **Introduction to "doing science" by undertaking a research project**
  - **It isn't all glamorous!**

Pros: **immediate application**

Con: **Project is time consuming**

Teaching MPG in Context:
Earth Materials and the Environment

Riebeckite (crocidolite) **Kuruman, Northern Cape Province, South Africa.** ***Photo: Theodore Gray***

The Sleipner A platform (left) and Sleipner T platform (right). Since 1996, Statoil has separated about 1m t/y of CO_2 from the gas produced from Sleipner ©Statoil

Minerals (PG) as problems and solutions to Society!

http://www.geol.lsu.edu/dutrow/env

Earth & Environment: Minerals in our Lives!

Framework is societally relevant issues:

- Health effects of minerals
- Global warming solutions
- Minerals and mining for "green" energy

Zn-containing items used daily with sphalerite and zincite, commonly mined for supply. *Photo: B. Dutrow*

Earth & Environment
Minerals in Our Lives!

Actinolite asbestos French Creek, Chester County, Pennsylvania, USA. *Photo: Theodore Gray*

Additional Focus, emphasis:

1. Critical thinking
   - Assessing rather than assuming danger
     - ”Reporting Environmental Science” in *But is it True? A Citizen’s Guide to Environmental Issues, A. Widavsky, 1995. Harvard Univ. Press*
   - Pros and cons
2. Evaluating the system in its entirety
3. Need for geoscience in public policy

Minerals in our Lives – The “Asbestos” Issue

Ill effects of asbestos devastates families decades later

By BEN DOBBIN
Associated Press writer

IRONDEQUOIT, N.Y. — Dave Creighton didn't venture outside his air-conditioned home for six humid weeks last summer.

In the fall, no longer able to resist the lure of the outdoors, the stocky 56-year-old dressed up in blaze orange, borrowed a small tractor and trundled through the woods behind his hunting buddies. But he found himself gasping for air and soon quit from exhaustion.

Creighton thinks his lungs were irreparably damaged in the mid-1960s, during his early years as a mechanic stripping turbines at Rochester Gas & Electric Corp. He never felt any ill-effects at the time. Thirty years sailed by before he noticed a shortness of breath.

The culprit is asbestos, the onetime miracle insulation fiber that now kills as many as 10,000 people a year in the United States.

Since his diagnosis in 1996 with asbestosis, a scarring of the lungs that leaves victims prey to cancer and heart failure, Creighton's lung capacity has been steadily declining. It is now just 60 percent of what it should be.

Sitting at his kitchen table in this Rochester suburb with his wife, Nancy, he lists the good things he can't do anymore: Fish, camp, tramp up and down hills, haul wood for a chainsaw-artist friend, help neighbors out with "bull work."

"I don't do any of that any more," he said, lower lip quivering, eyes opening wide to hold back the tears. "It's been something I would never wish on my worst enemy."

In 1972, the federal government banned the use of asbestos in workplaces, chiefly shipyards, chemical and power plants, construction sites and other industrial locations where it had been valued for its insulation and fireproofing powers since the turn of the 20th century.

But 20 to 40 years can pass before the inhaled needlelike fibers manifest themselves in harmful ways — from relatively mild lung impairment to a string of deadly cancers.

"There is this sort of time-bomb effect," said Dr. William Beckett, a University of Rochester professor of environmental medicine. "Many people who have worked with asbestos are very concerned about it and get frequent checkups."

A 1982 study by Mount Sinai School of Medicine predicted 365,000 asbestos-related deaths by 2030, and those findings are largely holding up, said lead researcher Dr. William Nicholson, a professor emeritus of community medicine at the New York City school.

Associated Press photo

Dave Creighton, 56, believes his lungs were irreparably damaged when he worked as a mechanic stripping asbestos off turbines at Rochester Gas & Electric. He now rarely leaves his home in the Rochester, N.Y., suburb of Irondequoit. The inhaler on the table in front of him is a constant companion.

Some 27 million American workers were exposed to asbestos between 1940 and 1980, Nicholson found. Deaths from asbestos-linked cancers peaked at 9,000 to 10,000 a year through 2000 and will slowly fall but remain substantial for three more decades, he said.

"It may very well go the way of polio," said lawyer Dennis Herron, who helped Creighton obtain Social Security disability compensation, worker's compensation and out-of-court payments from assorted companies that made, sold or distributed asbestos.

In this manufacturing region of nearly a million people on Lake Ontario's southern shore, lawyers handle "a solid 100 asbestos cases a year," said Herron's former partner, Joe Rinere. In the latest settlement in January, 17 retired Rochester Gas & Electric workers were paid $2 million. Three are already dead of cancer.

Above all other product-liability cases, asbestos lawsuits clog dockets in state and federal courts. About 200,000 claims are pending, and as many as a million have been filed so far, said Beth Caputo of Mealey Publications which tracks litigation in the nation's courts.

Asbestos makers have already forked out tens of billions of dollars in damages, and dozens of companies have been bankrupted. The erratic scale of payouts, however, is quickening a debate in Congress over how courts should handle the torrent of claims.

Tony Giancursio, 67, a plumber who apparently was exposed while training as a pipe fitter at Eastman Kodak Co.'s film manufacturing plant in the 1950s, had a lung removed soon after his diagnosis in 1996 with mesothelioma, a rare cancer of the chest and abdomen that killed him in less than nine months.

An athletic, 200-pound ex-Marine with eight children, Giancursio could no longer eat solids and became tormented by the smell of food. His stomach ballooned as he wasted away.

"He was in such pain," said his wife of 44 years, Grace. "Every night, he was afraid to go to sleep. He'd want each one of the kids to stay over. To see a big, healthy man like he was end up being an absolute skeleton, it was a horrible nightmare."

Aside from worrying about lung cancer, Creighton fears his breathing will get shallower until he is tethered to an oxygen machine.

After a two-year stint as a Navy machinist, Creighton joined his hometown utility in 1964. Working on a turbine repair crew, he often had to remove huge chunks of brittle asbestos insulation with a claw hammer.

"There were days I can remember turning back and looking at that machine and it was one big cloud, nothing but asbestos," he said. "We wore no protective uniforms or masks."

Many of his former colleagues died before reaching retirement. Creighton's disability keeps him from the everyday tinkering around the house he once enjoyed so much.

"He was a very physical person. He could open anything — I don't care how tight it was," his wife said with a laugh, prompting Creighton to lift up his arm to display the flabbiness of his muscles.

Sometimes, the reminders cut deeply. At a zoo a few years back, his toddler grandson "put his arms up for me to pick him up and carry him," he recalled. "I couldn't carry him that far. You don't think that didn't hurt?"

One thing that keeps him going, he said, is the prospect of touring the country in their unused motor home once his wife retires with a pension in 2002 from her job as a high school math teacher.

"I've still got things to keep me living," Creighton said firmly. "It's not the quality that I'd like, but you go on."

LSU student newspaper

“Asbestos”

- Students have awareness
  - introduced in Mineralogy
  - importance of mineral properties
- Perceived as an important health issue (ads on TV)
- Provides entry to US public policy, need for science
- Engaging subject for *collaborative, critical-thinking projects*

Minerals in our Lives – The "Asbestos" Issue

Serpentine, var. chrysotile. Bad Harzburg, Germany. 3.6 cm wide. ***Photo: (c) Rainer Bode, Haltern***

Riebeckite (crocidolite)

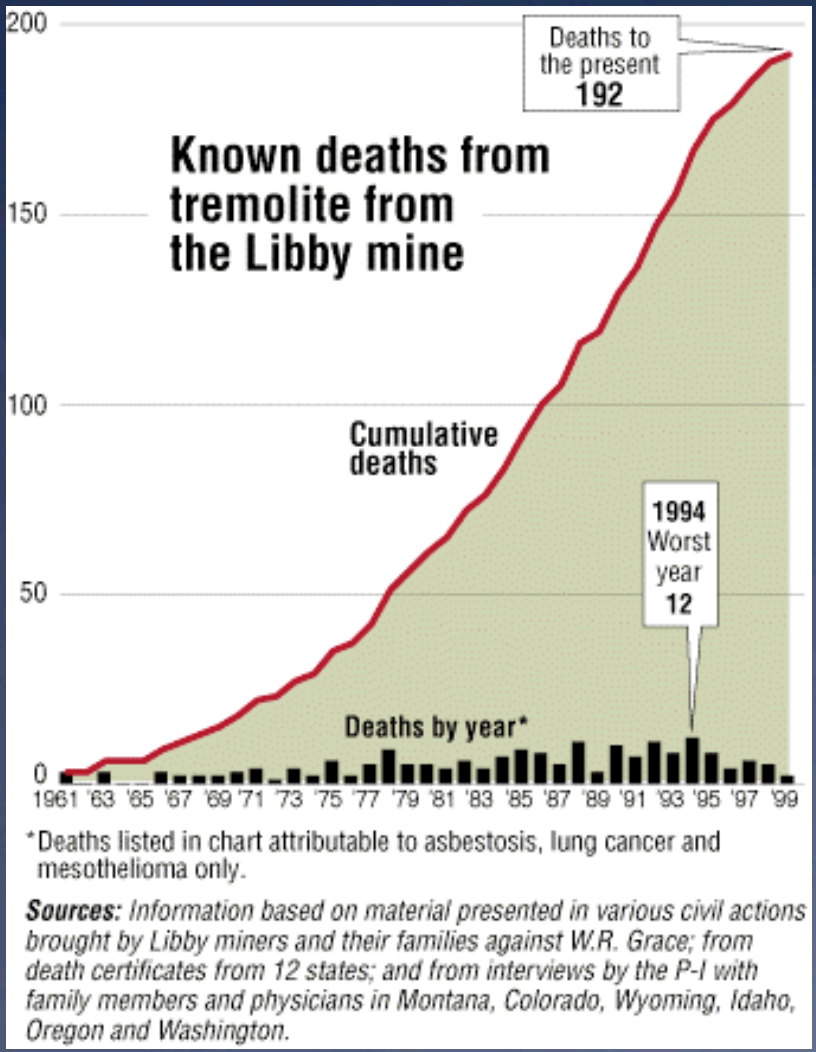
Photo: Theodore Gray

Mineralogic aspects:

- Review of phyllo- ino- silicates (compare/contrast)
  - Definition of 'asbestos' Chemistry – solid solution
  - Structure
  - Physical, surface properties
  - Mineral defects

- *Would differing physical properties have same biological response?*

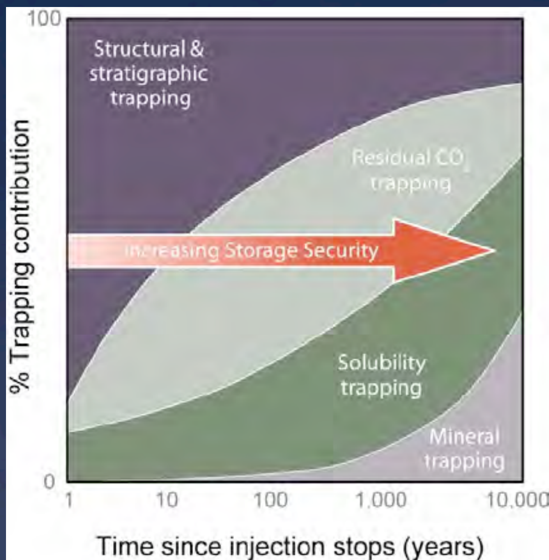
Critical Thinking via The Libby Project

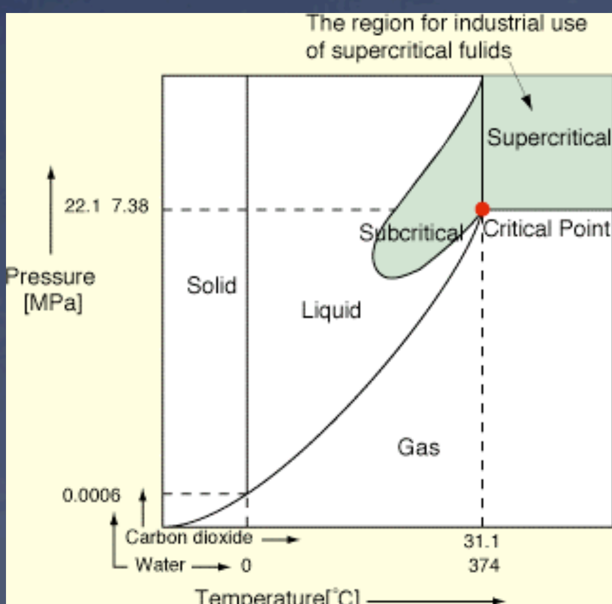


- Libby, Montana case
  - Winchite in vermiculite
    - Effects of solid solution on mineral nomenclature and regulation
- Collaborative Case Study (21)
  - ***Pro*** – makes the case that health effects are caused by "asbestos" with justification
  - ***Con*** – makes the case that there is insufficient evidence to unambiguously relate mine working
  - ***Jury*** – asks and analyzes information presented to decide the most compelling case

Students decide presentation content and style (all participated)

Climate and CO_2 Sequestration





Mineralogic, geologic aspects:

- sequestration and trapping
- mineral surfaces and reactions
- phase diagrams for CO_2
  - 3-phase fields
  - Critical endpoint
  - Supercritical fluids
  - Fluid properties, E.O.S.
- Mineral stability and fluids: geochemistry

Teaching MPG in Context:
"Green Energy" Is there such a thing?


Glass,
srs.dl.ac.uk/

- Critical thinking reinforced through considering and analyzing different energy options
- *Pros/cons* of the entire system

- **Nuclear**
  - No CO_2 but HL hazardous waste, large fresh water use, proliferation, cost, safety, U mines
    - Pre-Chernobyl and Three Mile Island generation "China Syndrome" (movie), Fukushima
  - Mineral solutions for waste immobilization, low T env.

"Green Energy" – Renewable: Solar, Wind


Tunisia - Image: geni.org

- No CO_2 but visual pollution and large footprint
- Need for metals, mining, separation
- Solar photovoltaics use
  - *amorphous silicon (Si)*
  - *gallium arsenide (GaAs)*
  - *cadmium telluride (CdTe)*
  - *copper indium diselenide (CuInSe)*

Solar power array.
Image: solarpowerninja.com

Minerals in Context: *"Green Energy: Wind"*

Wind energy requires high-strength, light-weight magnets using rare earth elements:

Nd

Sm

Gd

Dy

Pr

Power of visual communication

Image: www.aaesystems.ca

"Green Energy and REEs"

RARE EARTHS	ATOMIC NO.	COMMERICAL USE
Scandium	21	Stadium lights
Yttrium	39	Lasers
Lanthanum	57	Electric car batteries
Cerium	58	Lens polishes
Praseodymium	59	Searchlights, aircraft parts
Neodymium	60	High-strength magnets
Promethium	61	Portable X-ray units
Samarium	62	Glass
Europium	63	Compact fluorescent bulbs
Gadolinium	64	Neutron radiography
Terbium	65	High-strength magnets
Dysprosium	66	High-strength magnets
Holmium	67	Glass tint
Erbium	68	Metal alloys
Thulium	69	Lasers
Ytterbium	70	Stainless steel
Lutetium	71	None

Many of the Green Energy technologies (including hybrid cars) require considerable quantities of REEs.

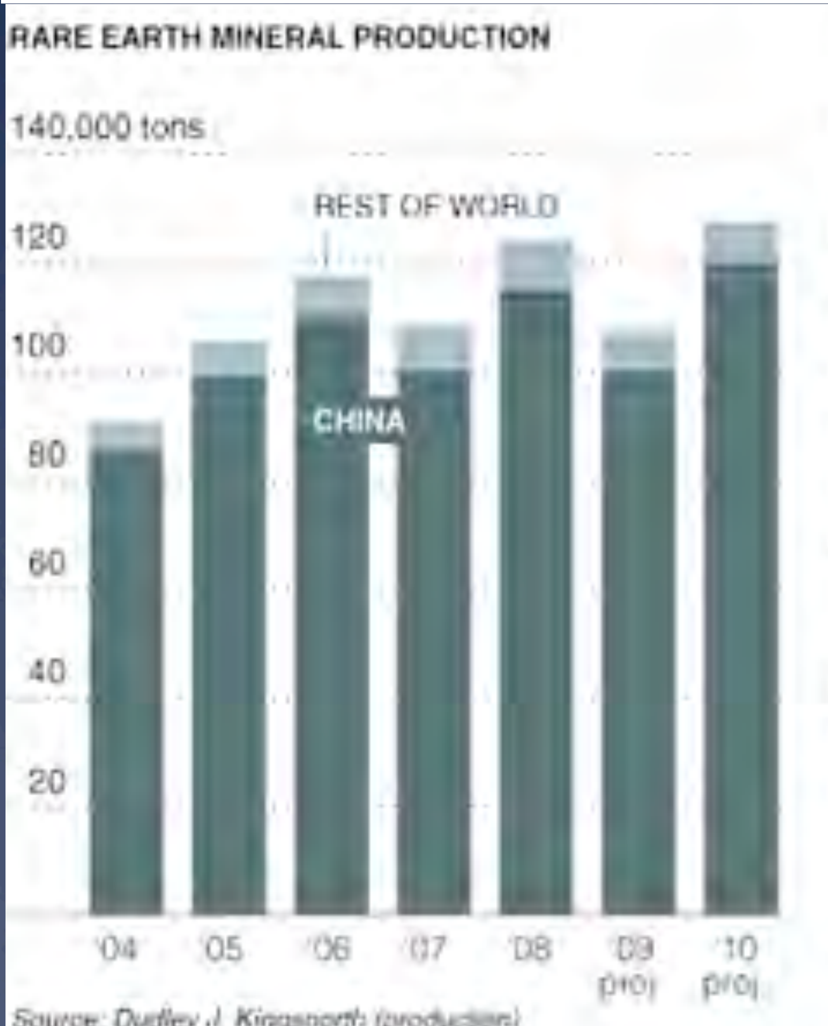
Each year every American requires 40,000 lb of new material (as of 1989).

Can our planet sustain this?

"Green Energy" and REEs

Rare Mineral Wealth

China accounts for the vast majority of the world's REEs that are used in a wide array of products.

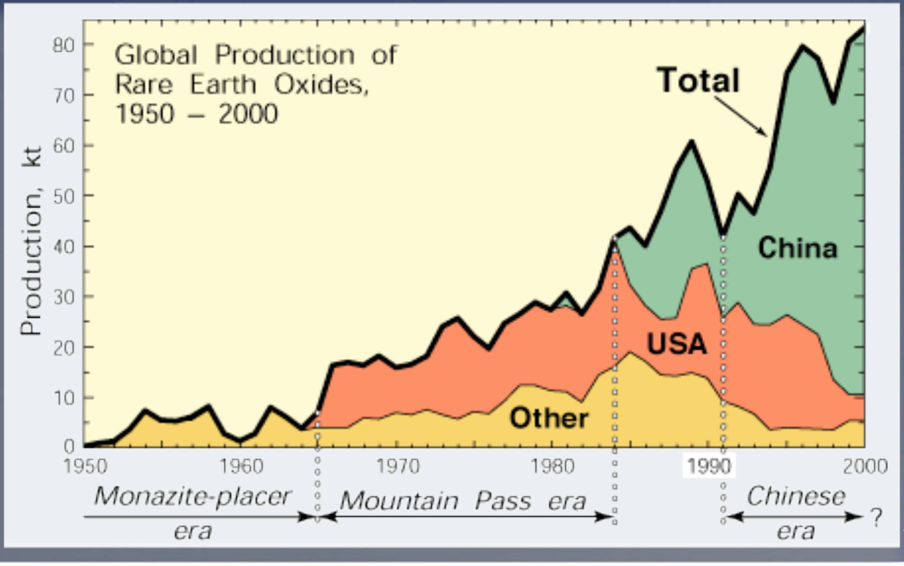


Need for REE is entry for *mining practices, environmental laws,* and a discussion of how *"green" is green energy.*

- **This incorporates the processes required for "green energy," and**
- **evaluating the system, from rock to processed material, as a whole.**

"Green Energy" and REEs

Mining for copper and cobalt, Katanga, Congo. © Per-Anders Pettersson



www.usgs.gov

Critical Thinking:

- compare mining practices and environmental regulations in different places in the world
- the locations of reserves
  - geochemistry
- lower vs. higher cost; what are you willing to pay?
- reuse, recycle

Research Project – The System Approach

Three Gorges Dam, China. 600' long. 18.2 Gwatts electricity. ***Image: NASA Earth Observatory; right: mtholoyoke.edu/~vanti20m***

Advantages and disadvantages of the entire system are required.

- No single side

e.g., Three Gorges Dam, China

- Supplies hydropower (3% electricity), reduced flooding; displaced 1 million people, destroyed environment, etc.

Teaching MPG in Context:
Earth Materials and the Environment

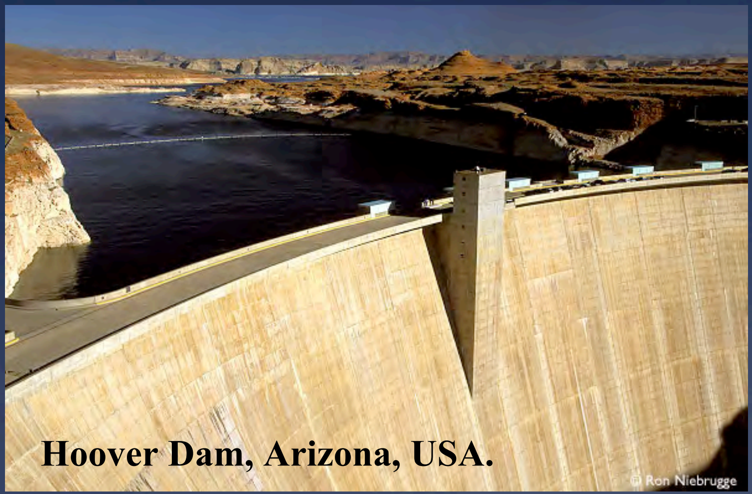
Mine at Butte, Montana, USA. ***Photo: B. Dutrow***

Danish Wind farm in North Sea. ***Image: www.fnfacts.com***

Outcomes

- Students link MPG to problems and solutions that are societally important
- Connect their study to "real life", critical thinking
- Internalize the need for understanding science in everyday decision-making
- Life-long learners

Teaching MPG in Context:
Earth Materials and the Environment



Hoover Dam, Arizona, USA.

Titanium Mountain Bike. ***Image: Marlin Bikes***

Student Comments from 2010:

- "She taught us to think like a scientist"
- "I feel more apt to look into how reliable articles are that outline scientific issues"
- "This was by far my favorite geology class"…you got us to take a closer look at 'greener' energy and critically think about science"
- "This was one of the best classes I've ever taken. I find it very important to apply what we've learned in other classes to 'real world' examples and we've done that."

Teaching MPG in Context

April 2007, v.3 n.2

- **There is no single method nor course, modify approach to highlight your interests.**
  - ***Faculty must teach to their strengths***
- **Students have different learning styles**
  - **Auditory**
  - **Visual**
  - **Kinesthetic**

Resources for Teaching MGP

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Syllabi for courses described:

Mineralogy – Planet Earth

- ***www.geol.lsu.edu/dutrow/mingy***

Earth Materials – Society

- ***www.geol.lsu.edu/dutrow/env***

Petro. Mineral. – Earth's study

- ***www.geol.lsu.edu/dutrow/pet_min***

On the Cutting Edge website for Teaching Mineralogy, Petrology, Geochemistry, etc.

http://serc.carleton.edu/NAGTWorkshops/index.html

Vast array of teaching materials; labs, problem sets and solutions

Acknowledgments

Discussions with Frank Hawthorne, Darrell Henry, Dave Mogk, MSU; organizers and participants of the 1996 Teaching Mineralogy Workshop, 2003 Teaching Petrology, 2011 MGP community

Melting ice, Sawtooth Mtns, ID. ***Photo: B. Dutrow***