Review material for Geology 4460 Fall 2017

Here is an outline of the important topics from the early part of the course:

- a) The structure and formation of the solar system,
- b) The condensation model used to explain the compositional patterns,
- c) Tests of that model using meteorites and asteroids
- d) Overview of accretion and differentiation as evidenced by asteroids, meteorites, and the moon.
- e) The geology of the moon
- f) Atmospheres

The following outline list the major "topics" and "questions" we covered, but I haven't tried to list here the "answers" to those questions. Look at "The Solar System" by Wood, and the on-line PowerPoint presentations for that.

Overall structure of the solar system

- Patterns in location/motion of the planets
  - Names and order of planets
  - Regularly increasing spacing, with general idea of relative distances (Earth = 1AU)
  - Location all near a single plane
  - All revolve (and most rotate) counterclockwise as seen from the N side
  - Kepler's laws of planetary motion
  - How resonance with Jupiter prevented accretion at the asteroid belt location
- Patterns in composition
  - Inner terrestrial vs. outer Jovian planets
  - Compositional trends within terrestrial and Jovian planets
  - Small bodies (comets, asteroids, meteorites, small moons) as "fossil" record of early composition
- Patterns in activity
  - Large worlds active longer, small worlds cool faster -- and reasons

- Solar nebula model plus condensation model as explanation of above patterns
  - Evidence of similar nebulae around forming stars
  - How solar nebula model explains above patterns in location/motion
    - (counterclockwise motion, common plane, regular spacing)
  - Role of angular momentum and its loss in structure of solar nebula
    - Why material collapses to form a disk
    - Why material can't immediately spiral into the proto-sun
    - Role of jets in removing angular momentum
    - Role of strong stellar wind in eventually clearing gas
  - More details regarding the condensation model
    - Expected temperature structure in the nebula
    - General pattern in condensation as nebula cools
      - Initial high temperature appearance of Ca, Al, Ti oxides
      - Lower T appearance of Mg rich silicates, Ca rich plagioclase, and metallic Fe
      - Still lower T appearance of more Fe rich silicates, Na rich plagioclase, then FeS and Fe_3O_4
      - Still lower T appearance of OH bearing silicates plus sulfates, carbonates, and carbonaceous compounds
      - Still lower T appearances of ices: H_2O then NH_3 and CH_4
    - The general temperature range of the sequence:
      - First major condensates occur at approximately ~1700K.
      - Most non-OH silicate condensed by ~600K
      - OH silicates and low T compounds condense near ~300K)
      - Ices (first H_2O then NH_3 and CH_4) start to condense near ~150K
    - Relationship between the condensation sequence and Bowen Reaction Series
    - Simple model: Subsequent gas loss but solid material preservation fixes final composition of each region
  - Tests of the condensation model using general composition of planets
    - Role of ice (then gravitational collapse) in formation of Jovian planets
    - How inner terrestrial planets shows higher T composition than outer
    - How outer solar system icy satellites and comets fit into pattern
    - Expected asteroid (and meteorite) composition based on model

Tests of the condensation model using meteorites

- Classification of meteorites into falls and finds.
- Importance of Antarctic meteorites
- Classification of meteorites into
  - undifferentiated (chondrites) and
  - differentiated (irons, stony-irons, achondrites)
- Origin of differentiated meteorites in differentiated asteroids
- More detailed classification of undifferentiated chondrites into
  - carbonaceous, ordinary and others.
- More detailed classification of the carbonaceous chondrites
  - General meaning of the CI, CM, CO, CV, CK classification.
    - (But don't worry about characteristics of each type)
  - General meaning of the petrologic classification 1,2,3,4,5,6
    - (But again don't worry about the characteristics of each type)
- How carbonaceous chondrites represent an "unequilibrated" mix of components from
  - different temperature states of the condensation model:
    - CAI's (Calcium-Aluminum rich inclusions)
    - Chondrules
    - Matrix of Phyllosilicates, FeO, Fe, FeS, C compounds
- How chondrules represent brief high temperature "melting events"
- How CAI's contain strange isotopic anomalies and how those anomalies indicate an
  - incompletely mixed early solar nebula
  - ^{26}Mg (from ^{26}Al) anomalies and the time scales they imply
  - ^{18}O vs. ^{17}O vs. ^{16}O anomalies
    - Understand the O isotope diagrams
    - and the different meaning of the slope 1/2 and slope 1 lines
- Use of radioactive age dating techniques
  - Understand the Rb/Sr isochron diagram
  - Understand in more qualitative terms the use of Uranium/Lead dating
  - Understand the implications of the papers we read for overall age of the solar system
    - and also the time range over which different components (CAI vs. chondrules) formed
- How the standard condensation model is too simple
  - The existence of incomplete mixing as evidenced by isotopic anomalies
  - The strange temperature events as evidenced by chondrules
  - The existence of a small component of pre-solar "interstellar" grains
  - Rims of different isotopic composition on CAI's (circulation in nebula)

Mineralogy

- Most common minerals
- Understanding of basic melting behavior (solid solution and immiscible)
  - Solidus, Liquidus curves, eutectic points, lever rule

Accretion and differentiation

- Craters as evidence of accretion.
  - How the number of preserved craters varies with planet size
  - The role of planetary cooling rates
- The relationship of asteroid C,S,M types to differentiation (and meteorite types)
  - The question of why some (especially inner belt) asteroids differentiated
- Mixing of different region planetoids as gas clears from the solar system
  - Ejection of comets from outer solar system into the Ort cloud
  - Problems with volatiles (H_2O, C) on the earth
    - Possible origin from scattered asteroids or comets
- The origin of the moon
  - Chemical composition of the moon
    - Similarity to composition of Earth's mantle
    - Lack of volatiles and large iron-core component
    - Complications in explaining this using condensation model
  - Unusual dynamics
    - Moon an unusually large moon
    - Earth-moon system has unusually high angular momentum
    - Difficulty in capturing moon from a solar orbit
  - Early giant collision and how it can explain above properties
- Role of gravitational energy, short and long-lived radioactive elements in differentiation

Detailed lunar geology

- The highland vs. mare differences
- The mare basins, the mare within them, and the difference in definition and age between them
- The evidence for volcanism
- General crater mechanics and morphology
  - The variation of morphology with size (simple bowls to multi-ring structures)
  - The use of crater morphology (eg. flat bottom craters, dark haloes, etc.) to obtain depth info.
  - The use of crater statistics to obtain ages -- including use of size-frequency diagrams to address issues such as saturation, and partial resurfacing.
- The use of superposition to obtain relative ages
- The lunar age system: Pre-Imbrian, Imbrian, Procellarian, Eratosthenian, Copernican in the original Shoemaker system, Pre-Nectarian, Nectarian, Early Imbrian, Late Imbrian, Eratosthenian, Copernican in the revised system.
- A general idea of the absolute ages for critical events (accretion, mare basins, maria, etc.).
- The lunar magma ocean, and how the anorthosite crust and the Europium anomaly are evidence of that event

- The relationship between lunar structure and the Bowen reaction series
  - The expected layering of anorthosite, KREEP, pyroxene and olivine layers
  - The Europium anomaly as evidence of the global magma ocean

- Variations in lunar composition with position
    - Review the mineralogy related to anorthosites, troctolites, norites
    - Spatial variations perhaps produced by different stripping of the upper crust (by Procellarum impacts or mode-one convection) or by a late companion moon impact.
    - The main lunar crustal terranes now defined:
        1) Feldspathic Highlands Terrane,
        2) Procellarum-KREEP Terrane,
        3) South Pole-Aitkin (Basin) Terrane
- Lunar stress patterns and possible evidence of cooling history.
- Recent work on the deep interior structure of the moon
    - Evidence for a liquid core (seismic and rotation/orbital)

Magma oceans on other planets

- The role of volatiles in creating blanketing atmospheres
- Different crystallization and floatation sequences given different pressures and volatile contents
- Similarities or differences in the resulting "initial" planetary states, such as primordial crusts

The Nice model for orbit evolution

- The role of resonances in changing orbits
- Migration of the giant planets due to interactions with planetesimals
- Possible cause of the Late Heavy Bombardment
- Possible role in controlling outer planet orbits
- Possible role in scattering outer planetesimals (Kuiper belt, etc.)
- Possible role in clearing asteroid belt, delivering water to earth

Planetary Atmospheres

- Hydrostatic equilibrium, exponential pressure structure, and "scale heights"
- Temperature structure
    - Adiabatic lapse rates and convective stability and energy transport
    - Role of water in producing a "wet adiabat"
    - Radiative transport of energy
    - How the above two determine the division between the troposphere and stratosphere
    - Equilibrium temperatures (balance of solar input and radiated energy)
    - Greenhouse effects

Planetary Atmospheres

- Composition of atmospheres
    - Primary (preserved), Secondary (outgassed) and late arriving volatiles
    - Escape of atmospheres
        - Thermal (Jeans escape) and effects of temperature and atomic weight
        - More general understanding of other escape mechanisms such as
            - Hydrodynamic escape (H dragging other components)
            - Photochemical escape
            - Impact ejection
        - Solar wind stripping
    - Diagnostic measurements such as isotopic ratios

- Circulation of atmospheres
    - Hadley cells
    - Wind patterns such as trade winds
    - Coriolis force
        - Circulation around high and low pressure areas
    - Role of Coriolis force in "jet streams"