Introduction to Petroleum Geology

I. The Basic Overview
   a. Petroleum Geology – application of geology (study of Earth, materials and processes) to the exploration and production of oil and natural gas

      i. Geology = interdisciplinary science at the crossroads of Chemistry, Physics and Biology
      ii. Petroleum Exploration = focus on oil and gas, part of the hydrocarbon family of organic compounds

   b. Petroleum-Related Hydrocarbons (hydrogen-carbon based organic compounds)
      i. Three Physical States: solids, liquids, gases (in order of decreasing density)
      ii. Gases: Methane, ethane, propane, butane + others
      iii. Liquids: oil, crude oil, "crude" (texas tea)
         1. Refined to derive petroleum products such as gasoline, diesel fuel
      iv. Solids: coal, kerogen, gas hydrates (ices of gas)
         1. Visco-plastic solids: tar

   c. Petroleum occurrence: natural containment in subsurface reservoir rocks that promotes accumulation of fluids over geologic time.

      i. The petroleum environment exists in the realm of sediments, sedimentary rocks and sedimentary basins.

      ii. Petroleum Generation: carbon-based, organic-rich sediments with biogenic materials derived from plants and animals.
         1. Marine Biogenic Sediment Production
            a. Invertebrates, reefs, phytoplankton, zooplankton
            b. Biologically rich, high productivity ocean settings
            c. Shallow, well oxygenated, sunlit, warm waters

         2. Nonmarine Biogenic Sediment Production
            a. Plant rich environments
            b. Tropical/Subtropical Zones
            c. Lakes and Floodplains, deltas

         3. Sedimentary Basins: accumulations of sediments in subsiding basins, deltas, continental shelves, tectonic depressions
            a. Water saturated, reducing environments (oxygen deficient) result in preservation of organic materials.
            b. Burial of organic rich sediment / sedimentary strata results in increased geothermal heating and lithostatic pressure.
            c. Heat and pressure during burial, combined with biologic activity, chemically and physically transforms biogenic sediment into liquid oil and natural gas.
            d. Geologic time required for biologic lifecycles, biogenic sediment transport, sedimentary basin development, burial and thermal maturation (time scale on 10^5 to 10^6 years of time).

      iii. Petroleum Reservoirs: sediments and sedimentary rocks with relatively high porosity and permeability ("oil aquifers").
         1. Sandstone Reservoirs
         2. Carbonate/Limestone Reservoirs

iv. Impermeable Seals and Caprock
    1. Mudstone, Shale
    2. Tightly cemented sandstones, carbonates

v. Traps – containment of petroleum in subsurface: geometric arrangements of strata that result in juxtaposing permeable reservoir rocks subjacent to impermeable caprocks to prevent buoyant migration of oil and gas upward to the earth's surface.
    1. Structural Traps (faults, folds, uncomformities)
    2. Stratigraphic Traps (depositional facies, lateral and vertical interlayering).

d. Required Conditions for geologic accumulation of petroleum
    i. Organic rich source rock (biogenic sediments) to generate oil and/or gas over geologic time.
    ii. Source rock burial and geothermal heating to convert organic sediment to petroleum compounds
    iii. Reservoir rock with requisite porosity and permeability to store and transfer hydrocarbon fluids.
    iv. Impermeable seal or cap rock to prevent upward escape of buoyant petroleum compounds to the Earth's surface.
    v. Geometric arrangement of source, reservoir and seal rocks in such a way to trap petroleum in subsurface.
    vi. A temporal sequence / geologic history of trap formation and petroleum generation that favors subsurface accumulation of petroleum
    vii. Subsurface preservation of petroleum accumulation over geologic time until extraction and production

II. Hydrocarbon Composition and Occurrence
a. "Natural Gas" = a mixture of hydrocarbons ('organic) and other non-hydrocarbons (non-organic) that exist in a gaseous phase or in solution with crude oil in natural subsurface reservoirs

    i. Free vapor phase gas vs. dissolved gas
    ii. Dry gas vs. wet gas a function of water vapor content
        1. Dry gas = e.g. methane (CH_4)
        2. Wet gas = e.g. ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12})
    iii. Sweet vs. Sour Gas = function of hydrogen sulfide (H_2S) content (low vs. high, respectively)
    iv. Other naturally occurring Gases
        1. Inert Gases via radioactive decay
            a. Helium (He), Argon (Ar), Radon (Ra)
        2. Other Naturally Occurring Gases
            a. Nitrogen (N_2) Carbon Dioxide (CO_2), Hydrogen (H_2), Hydrogen Sulfide (H_2S), Water Vapor (H_2O)

b. "Crude Oil" = mixture of hydrocarbons that exist in a liquid phase in natural subsurface reservoirs and that remain liquid at atmospheric surface pressures

    i. Liquid phase mixtures of oil and water in subsurface common
        1. Light Oil vs. Heavy Oil: density less than or more than water, respectively

    ii. Range of Elemental Composition of Crude Oil by Weight Percent

Element	Minimum Wt. %	Maximum Wt. %
Carbon	82.2	87.1
Hydrogen	11.8	14.7
Sulfur	0.1	5.5
Oxygen	0.1	4.5
Nitrogen	0.1	1.5
Other	Trace	0.1

iii. Molecular Composition – complex variety of over 200 organic compounds due to the versatile nature of carbon bonding with 4 electrons in outermost valence shell

1. Hydrocarbon Compunds
    a. Paraffins
        i. General formula: C_nH_{2n+2}
            1. n < 5 gaseous at normal temp and pressure
            2. n ranging from 5-15 liquid at surface temp. and pressure
            3. n > 15 solid waxes and viscous liquids
    b. Napthenes
        i. General formula: C_nH_{2n}
        ii. Liquid at normal temperatures and pressures
        iii. Comprise ~40% of crude oil composition
    c. Aromatics (ring structure molecules)
        i. E.g. benzene C_6H_6
2. Mixed compounds
    a. Crude oil contains low percentages of oxygen, nitrogen, sulfer, trace metals
3. Average Organic Composition of Crude Oil

Molecular Type	Weight Percent
Paraffins	25
Napthenes	50
Aromatics	17
Asphaltics	8
	Total 100

4. Average Crude Oil Distillates in Order of Increasing Density and Boiling Point Temperature

Component	Volume Percent
Gasoline	27
Kerosene	13
Diesel Fuel	12
Heavy Gas Oil	10
Lubricating Oil	20
Residuum	18
	Total 100

III. Stages of Petroleum Exploration, Production and Processing
    a. Land acquisition / mineral rights
    b. Petroleum Exploration and Geologic Prospecting
        i. Surface Geology / Geologic Mapping
        ii. Remote Sensing
        iii. Subsurface Geology
            1. Geophysics/Geochemistry
            2. Drilling/Exploration
    c. Petroleum Production
        i. Production Wells / Petroleum Engineering
        ii. Conveyance, Extraction and Storage Systems
        iii. Transportation
    d. Refining
        i. Chemical Processing
        ii. Distillation
    e. Marketing/Sales

IV. Historical Overview of Petroleum Production and Exploration

    a. Early History
        i. Liquid oil and semi-solid asphalt derived from natural outcrops and seepages
            1. Hand excavation in pits, collection from seeps and drainage at Earth's surface
            2. E.g. La Brea Tar Pits of Southern California
        ii. 200-400 B.C. Greeks used petroleum compounds to water proof ships and for medicine
        iii. 1600-1800 A.D. Europeans used petroleum products for manufacturing, water proofing and fuel
            1. Pitch, oil, tar, brine water
            2. Refined and separated through boiling and heating
        iv. 1800's refineries developed for fuel products
            1. Paraffin wax
            2. Liquid paraffin (kerosene, coal oil)
            3. Replaced whale oil for lamps and lighting

b. Modern History
    i. 1859 First successful / commercial oil well drill
        1. Cable tool techniques
            a. Simple impact / chisel drilling
        4. Oil Creek, Pennsylvania (Titusville) “Colonel Drakes Well”
    ii. Early 1900’s
        1. Advances in drilling and exploration techniques
            a. Exploration of anticlines
            b. Stratigraphic occurrence, paleo shorelines, diagenesis
            c. Advanced drilling techniques
        2. Advances in petroleum refinement and processing
            a. Lighter density derivatives (light gases, petrol, gasoline, diesel fuel)
        3. 1920’s birth of the modern petroleum industry
            a. British Petroluem, Shell (Dutch)
            b. Esso (Exxon), Gulf Oil, Texaco, Mobil, Socal (Chevron)
            c. Middle East and South American petroleum exploration
                i. Arabian-American Oil Company (ARAMCO)

    iii. Mid-1900’s / 1960’s
        1. Organization of Petroleum Exporting Countries (OPEC)
            a. Iraq, Iran, Kuwait, Saudi Arabia, Venezuela + North African Countries added in
        2. Advances in exploration techniques
            a. Geophysics, geochemistry, remote sensing
                i. Gravity/magnetic surveys
                ii. Seismic reflection
            b. Advanced drilling technology, enhanced recovery (e.g. Hydraulic fracturing)
    iv. 2000’s
        1. 3-D Seismic, GIS/GPS technology, offshore-deep water drilling
        2. Enhanced recovery (“fracking”), thermal processing (oil shale)
        3. Major Oil Producers
            a. OPEC Countries, U.S., China, Russia, Brazil, Malaysia

V. Thematic Topics in Petroleum Geology (crossroads of chemistry, physics, geology)
    a. Physical and Chemical Properties of Petroleum
        i. Chemical Composition
        ii. Physical Properties
    b. The Subsurface Geologic Environment
        i. Geologic Materials
        ii. Fluids
        iii. Temperature and Pressure
    c. Generation and Migration of Petroleum
        i. Biogenic Production of Organic Matter
        ii. Preservation and Diagenesis of Organic Matter
        iii. Thermal Maturation
        iv. Petroleum Migration
    d. Reservoir Characterization
        i. Geologic Materials
        ii. Porosity
        iii. Permeability
        iv. Diagenesis
        v. Reservoir Examples
        vi. Reserve Estimates

e. Traps and Seals
    i. Structural Traps
    ii. Stratigraphic Traps
f. Methods of Exploration
    i. Drilling Techniques
    ii. Well Logging and Petrologic Analysis
    iii. Surface Geophysics
        1. Gravity
        2. Magnetic
        3. Seismic
    iv. Borehole Geophysics
    v. Remote Sensing
g. Production Methods
    i. Petroleum Engineering / Production Wells
    ii. Primary vs. Secondary Recovery
h. Sedimentary Basins and Petroleum Systems
    i. Basin Styles and Tectonic Setting
    ii. Petroleum Occurrence
i. Nonconventional Petroleum Resources
    i. Tar Sands
    ii. Oil Shale
    iii. Tight Oil
    iv. Coalbed Methane
    v. Shale Gas