INTRODUCTION TO STRATIGRAPHIC ANALYSIS AND LITHOLOGIC CORRELATION

I. Rock Unit Classification

A. Lithostratigraphy: The study and organization of strata on the basis of physical lithologic characteristics

1. Rock type, color, mineral composition, grain size, overall texture

B. **Lithostratigraphic Units**: rock units delineated on the basis of physical properties... i.e. rock unit organization

1. Bodies of sedimentary, volcanic, metasedimentary or metavolcanic rock distinguished on basis of lithologic characteristics
    - a. Conforms to law of superposition
    - b. Above units often layered or tabular in form
    - c. Mappable/distinguishable lithologic characteristics
    - d. Defined entirely on basis of physical lithologic character
    - e. Lithostraphic units inherently carry NO CONNOTATION of age or time

2. **"Stratotype" or "Type Section"**- locality and geographic occurrence of a lithostratigraphic rock unit used to define the distinguishable characteristics of the unit

C. **Nomenclature**

1. **Lithosome**- masses of rock of uniform character that have intertonguing relationships with adjacent masses of different lithology

    a. E.g. sandstone lithosome, shale lithosome, etc

    b. equivalent to "facies" concept

    c. "Intertonguing" implies complex 3-D boundary relationships between lithosomes: both laterally and vertically.

    d. Of variable shape
    (1) sheetlike, blankets, wedges, prisms

    e. Of variable size and dimension

2. **Formation**: fundamental lithologic stratigraphic unit

    a. lithologically distinctive rock unit that is at a mappable scale at the surface and/or traceable into the subsurface

    b. Formations may consist of one lithosome or multiple lithosomes (uniform or variable lithology)

    c. Commonly named on the basis of type sections and geographic locality where units are defined.

3. **Members**: subdivision of Formation, distinctive mappable facies within the formational unit

4. **Beds**: smallest formal lithostratigraphic unit, represents subdivision of formation

5. **Groups**: 2 or more formations of similar stratigraphic character

6. **Supergroups**: 2 or more groups

7. **Lithostratigraphic Hierarchy**
    - a. Supergroups
        - (1) Groups
            - (a) Formations
                - i) Members
                    - a) Beds

D. **Stratigraphic Contacts**

1. Concepts and Definitions

    a. **Contact**: boundary surfaces between different types of rock
    - (1) may be planar or irregular in character
    - (2) Vertical vs. Lateral contacts
        - (a) Lateral contacts = lateral facies change
    - (3) Contacts or separation points represent a change in process and interuption of depositional process

    b. **Conformity**: physically conformable contact between rocks with no physical evidence of a break in deposition

    c. **Hiatus**: a interval of geologic time represented by missing strata within a stratigraphic sequence of rock

    - (1) **Diastem**: minor depositional breaks involving short hiatuses in sedimentation with little or no erosion

    d. **Unconformity**: surface of erosion or nondeposition, representing a significant hiatus between younger and older strata.

    - (1) Implies significant erosion event or significant change in geologic process

2. Contacts Between Conformable Strata

    a. **Abrupt Contacts**: sharp, clearly definable boundaries between rock types or beds of rock

    - (1) Causes:
        - (a) primary sedimentation
        - (b) diagenetic alteration

    b. **Gradational Contacts**: gradual transition from one lithology to another
    - (1) reflects gradual change in depositional conditions with time

(2) "Progressive Gradual Contacts"- progressive transition of lithology
   (a) e.g. fining-upward sequences: sandstone to mudstone

(3) "Intercalated Contacts"- interbedded relationship with overall change in character
   (a) e.g. sandstone to thinly interbedded sandstone and shale to shale.

3. **Contacts and Unconformable Strata**

   a. **Angular Unconformity**: angular discordance of strata above and below unconformity

      (1) evidence: discordant stratal dip

   b. **Disconformity**: erosional contact between parallel strata above and below

      (1) evidence: erosional contacts, wavy contact surfaces, rip-up clasts, basal lag conglomerates

   c. **Paraconformity**: unconformable contact between parallel strata with no visible signs of physical break or erosion (difficult to detect)

      (1) Evidence: biostratigraphic

   d. **Nonconformity**: unconformable contact between younger sedimentary strata and older igneous or metamorphic crystalline rock

4. **Contacts between Laterally Adjacent Lithosomes**

   a. **Pinchout**- lateral thining of unit to point of extinction

   b. **Intertonguing**- lateral splitting of lithologic unit into "tongues" that in turn pinch out independently

   c. **Progressive lateral gradation**- gradual lateral transition

E. **Vertical Successions Of Strata**

1. Lithologic uniformity: uniform successions
2. Lithologic Heterogeneity: variable composition
3. Cyclic Successions
   a. Repetitions of strata and/or lithologies
      (1) Implies repetition of depositional process
         (a) climatically and tectonically controlled

      (2) "Cyclic" or "Rhythmic" sedimentation
         (a) e.g. varves/seasonal lake deposition
         (b) turbidites
         (c) coal cycles

F. **Depositional Sequences**

1. **Sequence Stratigraphy**: any grouping or succession of strata.

   a. Formal application: stratigraphic units bounded by major unconformities.

   b. stratigraphic unit of a conformable succession of genetically related strata and bounded at top and bottom by unconformities (or their correlative conformities)

   c. Sloss (1963) recognized 6 major "Cratonic Sequences" on the North American Craton. ("Supersequences" of Mitchum, Vail and others)

      (1) Sequence: large-scale rock unit, consisting of genetically associated formations bounded by cratonwide unconformities
         (a) Processes at scale of epeirogeny and/or eustasy on a continent-wide scale
            i) Sequences controlled by continent-wide transgressive or regressive events

I. **Geologic Time And The Rock Sequence**

A. **Geologic Time Units**: marriage of stratigraphic units to geologic time and history.
   1. Geologic time units are conceptual units rather than actual material or rock units.
      a. However, most geologic time units are based on material units.

B. Basis of Stratigraphic Time Units
   1. Stratotypes or rock units
      a. Isochronous Rock Units: the stratotypes or rock units upon which the geologic time units are based, have been formed during the same time span and are everywhere bounded by synchronous surfaces (i.e. all points have same age)

b. Geochronologic Units: a unit of time: divisions of time distinguished on the basis of rock record

c. Chronostratigraphic Units: a unit of rock: upon which time scale may be based

(1) Analogy: chronostratigraphic units represent sand flowing through hourglass during a certain period of time. Geochronologic units represent the interval of time during which the sand flows.

(2) Overview of Chronostratigraphic Units

(a) Lithostratigraphic Units (layered rocks)
(b) Lithodemic Units (instrusive/metamorphic xln rx)
(c) Magnetopolarity Units
(d) Biostratigraphic Units
(e) Pedostratigraphic Units: buried paleosols
(f) Allostratigraphic Units: mappable unconformity-bounded sequences (e.g. Sauk sequence of Sloss = Allostratigraphic Unit)

2. Rock-independent units

C. Isochronous Time Units

1. "Chronostratigraphic Units": a unit of rock: bodies of rock that serve as reference sections for all rocks formed during the same interval of time (aka "time-rock" units)

a. isochronous body of rock all formed at the same time

(1) defined by stratotype or type section

(1) Series: subdivision of system (corresponds to Epoch geochron. unit)

(a) Lower middle and upper used when referring to rock units (as opposed to time below)

(2) Stage: corresponds to short periods of geologic time (corresponds to age geochron. unit)

(3) Chronozone: smallest formal unit of chronostratigraphic time (corresponds to "chron" geochron. unit)

2. Geochronologic Units: divisions of time distinguished on the bases of the rock record = the interval of time for formation of the rock unit.

a. Eon, Era, Period, Epoch, Age, Chron in order of decreasing hierarchy of time.

(1) "Early middle and late" used when referring to time as this is time and not rock

3. Polarity-Chronostratigraphic and Polarity Geochronologic Units

a. Polarity-Chronostratigraphic Unit: a body of rock that exhibits the primary magnetic-polarity record imposed at the time of formation

(1) Polarity Chronozone: fundament rock unit of polarity

4. Polarity-Geochronologic Units: divisions of geologic time distinguished on the basis of the magnetopolarity rock record.

5. Geochronometric Units: a time unit independently derived of the rock record, arbitrary subdivisions of time with no real basis in the rock record.
a. Of use in subdividing the Precambrian (e.g. Archean-Proterozoic boundary arbitrarily chosen at 2500 Ma)
(1) Absolute time units
(a) Ma = Million Years = "Mega Ans"
(b) Ka = thousand years = "Kilo Ans"
(c) Ga = Billion Years ="Giga Ans"

D. **Diachronous Time Units**
1. Diachronic Unit- a stratigraphic unit that comprises the unequal spans of time represented by a specific stratigraphic unit
a. "Time Transgressive" Stratigraphic Units

b. A function of lateral facies distribution of stratigraphic unit, and lateral migration of facies patterns over time
(1) A given lithostratigraphic unit may form at various times at various geographic locations and transgress several time periods.

II. Conversion of the Chronostratigraphic Time to Geochronologic Time

1. Time scale originally divised to organize the occurrence and position of stratigraphic rock units (eonothems, systems, etc.)

2. To formulate a Geochronologic or "Time" Time Scale: must convert the rock record to time record, i.e. geologic time intervals are conceived as being the time equivalents of rock referent units already defined.

3. Calibration of the Relative Geologic Time Scale with "Absolute" geologic time
a. Biochronology: dating by fossils on the basis of well defined, short-lived synchronous biologic events
b. Radiochronology: Using radioactive decay rates, labortory experimentation, and rock mineralogy to examine the absolute age of the rock event.
(1) Based on radio isotope analysis of minerals within rock, and back-stripping from lab decay rates to determine age of rock unit.

I. CORRELATION OF STRATIGRAPHIC UNITS

A. Introduction

1. Correlation = demonstration of "equivalency" of stratigraphic units

2. Fundamental Objective of Stratigraphy: exploring practical and reliable methods of correlating stratigraphic units from one geographic area to another

   a. Entire Geologic Column = composite stratigraphic record in terms of rock units

      (1) Geologic Column = one large global correlation exercise

B. Correlation Defined

1. Traditional Philosophies

   a. Narrow definition: demonstration of "time" equivalency

      (1) i.e. two or more bodies of rock were deposited during the same period of time

      (2) In this case, correlation purely on the basis of lithologic similarity is not feasible

   b. Broader Based View: correlation allows that equivalency may be expressed in lithologic, paleontologic, or chronologic terms

      (1) i.e. two bodies of rock can be correlated as belonging to same lithostratigraphic or biostratigraphic unit, even though they are of different ages of formation

      (2) More widely accepted presently, broader based view widely used by petroleum companies in subsurface correlation of lithology (which is a controlling factor of petroleum occurrence)

2. NAM Stratigraphic Code and Types of Correlation

   a. Lithocorrelation: correlates units on basis of similar lithology and stratigraphic position

   b. Biocorrelation: similarity established on basis of fossil content and stratigraphic position

   c. Chronocorrelation: establishing equivalency in age and chronostratigraphic position

      (1) Established by any method that allows matching of strata by age equivalence

(2) Lithostratigraphic correlation on a local scale may show chronostratigraphic equivalence, but on a regional scale, lithostrat correlation may reveal time transgressive boundaries

3. "Matching" of strata: correspondance of serial data in a vertical section without regard to stratigraphic units

   a. e.g. simply matching lithofacies between two units in two different geographic areas may not lead to lithostratigraphic or chronostratigraphic equivalence

** Correlation must demonstrate geometric relationships between rocks, fossils or sequences of geologic data for interpretation and inclusion in facies models, paleontologic reconstructions or structural models**

Primary Objective:

(1) Establishment of equivalency of stratigraphic units between geographically separated parts of unit

4. Further Definitions
   a. Direct Correlation: correlation established physically and unequivocally
      (1) physical mapping and tracing of unit from one area to next

   b. Indirect Correlation: using indirect methods such as
      (1) geophysical well logs
      (2) polarity reversal data
      (3) fossil assemblages

II. **Methods Of Lithocorrelation**

A. Continuous Lateral Tracing of Lithostratigraphic Units (Direct Correlation)

1. requires good exposure
2. relatively simple structural conditions (e.g. faults)
3.

4. Techniques:
   a. walking out beds of rock from one location to next
   b. Physical tracing and mapping from air photos/maps

5. Inherent Problems:
   a. Complexity of Lateral Facies changes
   b. Limited areas of exposure
   c. Structural complexity (faults)

B. Lithologic Similarity and Stratigraphic Position
1. Similarity of lithologic successions
2. Marker beds or key beds

C. Correlation by Well Logs
  1. Drill holes
  2. Lithologic logging
  3. Geophysical Logging: wireline geophysics
    a. Gamma Ray
    b. Resisitivity/SP
    c. Caliper

III. Overview Of Analytical Techniques

A. Rock Outcrop Techniques
  1. Applicable to exposed sections of surface rock outcrops
    a. Road-cuts
    b. Mine-Pits
    c. Natural Hillslope Exposures

  2. The Measured Section
    a. Measuring Vertical Sections of Rock Exposures
      (1) Basic Tools: Jacob's Staff, rock hammer, brunton compass, notebook, altimeter, graphpaper

      (2) Measuring rock sections with detailed descriptions:

        (a) Using jacobs staff with detailed measurement of thicknesses of beds with description of physical properties
          i) I.d. of exposed and covered portions of section
          ii) Hand leveling and basic surveying techniques for determining vertical thicknesses

            a) Horizontal vs. inclined sections
            b) Trigonometric solutions for thicknesses

        (b) Basemap plotting locations of positions in sections and notable exposures
          i) Keying photos, samples, and notable relationships to survey locations on basemap
          ii) Air-photo/remote sensing techniques

        (c) Petrologic Descriptions
          i) Lithology, color, texture, mineralogic characteristics
          ii) Sample collection for thin section/petrographic analsis
          iii) Pebble compositions/unique mineralogy

        (d) Sedimentologic Descriptions

- i) Cross-bedding, paleocurrent indicators, sedimenary structures
- ii) Bedding contacts
  - a) abrupt, gradational, etc.
  - b) scoured
- iii) Unconformable vs. conformable contacts
- iv) Vertical grain-size changes/changes in facies
  - a) fining-upward sequences
  - b) coarsening-upward
  - c) fining and thining upward

(e) Structural Observations
- i) Strike and dip
- ii) joint orientations, faults
- iii) intrusive/volcanic contacts
- iv) folding/overturned beds

(f) Paleontologic Sampling and Analysis
- i) fossil i.d. and collection

(g) Magnetopolarity sampling

b. Selecting Sections

(1) good exposure

(2) largest vertical continuity possible

(3) Locating multiple sections over geographic area of same units
- (a) allowing for lateral facies analysis
- (b) i.d. laterally traceable lithosomes or marker horizons
  - i) Physically tracing and mapping correlative stratigraphic horizons
- (c) I.d. large-scale stratigraphic relationships through geologic mapping/regional mapping

c. Presentation of Field Data

(1) Tabulated written desriptions/tabular summary
- (a) narrative descriptions

(2) Columnar or Stratigraphic Sections
- (a) Graphical + descriptive
- (b) I.d. vertical cycles
- (c) displaying paleocurrent data
- (d) grain-size/facies analysis

(e) Stratigraphic Columns show generalized "layer cake" vertical stratigraphic relationships
    i) structural and topographic considerations removed

(3) Geologic Maps and Cross-sections
    (a) graphical display of structural and stratigraphic relationships
    (b) Cross-sections show absolute topographic, structural and stratigraphic relationships
    (c) Topographic basemap showing section locations, sample locations, photo locations, etc.

(4) Stratigraphic Cross-sections and correlation charts
    (a) Correlation of stratigraphic horizons between exposures or measured sections
        i) 2-d correlation charts
            a) correlating time, biozones, rock units
    (b) Fence-diagrams
        i) 3-d correlation charts

B. Subsurface Techniques

1. Much of our present knowledge of stratigraphy and near-surface stratigraphic sequences comes from subsurface drilling and exploration

    a. much stratigraphic work an outgrowth for exploration of oil and natural gas by petroleum companies

    b. oil company profits and the "national security" associated with petroleum have advanced the science of geology immeasurably

2. Overview of Drilling techniques
    a. Cable Tool Drilling
        (1) several thousand year old method first developed by Chinese for drilling water wells
        (2) Involves a "percussion" technique
            (a) raising a weighted drilling "chisel bit" and allowing it to free-fall and "jack-hammer" the rock,
                i) fracturing and grind the rock into chips

            (b) At systematic intervals the drill bit is pulled from drill hole and a bailer is used to extract the drill cuttings

                i) samples collected and labeled for depth, formation, and field geologic description

    b. Mud-rotary technique

(1) rotary torque is used to turn a hardened drill-bit which crushes and bores the rock
    (a) Hardened drill bit or core barrel attached to drill rods, which in turn are rotated by hydraulic processes

    (b) Drilling mud/clay is pumped under pressure through the drilling rods and bit, to cool the bit

        i) drill cuttings are carried with drilling mud back out of the hole
            a) drill mud has higher specific gravity than cuttings, cuttings float and are easily separated

        ii) cuttings are retrieved from mud via a sieve box, shaker table and water rinse, with mud re-circulated back through the bit

            a) lag time between bit grinding and mud circulation + hole caving result in partial admixtures of cuttings from multiple horizons

            b) drill cuttings form primary tool for lithological and stratigraphic analysis.

    (c) Cores are taken by hollow drill barrel, but is very expensive and used sparingly as needed

3. Analytical Techniques

a. Driller's and Geologists logs
    (1) Field/hand lithologic descriptions of stratigraphic horizons at the drill hole
        (a) derived from drill cuttings
        (b) somewhat interpretive in cases of cross-mixing of cuttings
        (c) i.d. first occurrences of lithologies and depths of occurrence
        (d) subtle eye and communication with driller as to recording depth and drilling conditions
            i) various lithologies display various resistance to drill advance

b. Sample analysis of drill cuttings and rock core
    (1) microscopic i.d. of drill cuttings
    (2) thin-sections from cores
    (3) i.d. of micro-fossils from drill cuttings
    (4) fracture analysis from core samples

4. Wireline Geophysical Analyses

- a. Involves lowering geophysical probe down completed drill-hole on electrical cable
  - (1) depth and geophysical data transmitted as electronic signals back to recording station (computer controlled data reduction)

- b. Electrical Surveys
  - (1) lowering electric log sonde down borehole
    - (a) an elongated electrode

  - (2) SP = spontaneous potential
    - (a) based on salinity of water-bearing subsurface formations
    - (b) measures small spontaneous voltage present at permeable rock horizons (water bearing)
    - (c) Based on salinity of formation waters
      - i) if formation salinity > drill mud coating borehole, then negative SP recorded
        - a) permeable saline water bearing beds e.g. sandstone and limestone

      - ii) If Fm salinity < drill mud, SP = positive
      - iii) If Fm salinity = drill mud SP = O

        - a) uniform values commonly associated with impermeable shale units (devoid of water)
  - (3) Resistivity
    - (a) measures electrical resistivity of rock
      - i) passing small current through sonde into rock and reading resistivity
      - ii) largely dependent on fluid content, porosity of rock
        - a) porous SS contains abundant salt water = low resistivity
        - b) impermeable shale and limestone low water content = high resistivity
- c. Radioactive Surveys
  - (1) Gamma Ray: measures natural radioactivity of rocks
    - (a) general high for shales, low for sandstones and limestones

  - (2) Neutron Activation: actively bombards strat with neutron particles and measures secondary response of rocks
    - (a) involves active radioactive source
    - (b) secondary response related to porosity of rocks

- d. Sonic Logs
  - (1) Sonic: source of sound waves
    - (a) transmitter with receiver on probe
  - (2) log measures transmission velocity through rocks

e. Caliper Logs

(1) electronic caliper that measures diameter of bore hole

(2) measures the resistance of rock to drilling

(a) limestone = resistant = smooth drill hole

(b) soft shale = non-resistant = caving of drill hole walls (larger diameter)

f. Drilling Time Logs

(1) log measure of depth and the rate of advance of drill bit

(a) provides insight into lithologic character in relation to resistance to drilling

(b) high porosity rocks (e.g. shales): low velocities

(c) low porosity rocks (dense limestone) high velocities