Basic Principles of Stratigraphy and Depositional Systems

I. INTRODUCTION

A. Stratigraphy: the study of the geologic rock record in the context of geologic time.

1. Geologic Rock Record: analogous to a tape recording in which some historical events are preserved and recorded, others have been erased, and still others were not taped at all

a. Referred to as "Stratigraphic Record": originally involved the study of "layered" sedimentary rocks and the fossil record.

(1) Advances in sensing techniques (radiometric dating, seismic analysis, paleomagnetism) have expanded the study of stratigraphy and rock record to the realm of igneous and metamorphic rock sequences

2. Geologic Time: abstract concept of continuous linear time from earth's origins to present day (portions of which are preserved in the rock record, and portions of which are not)

a. Time record vs. Rock Record

3. The study of Stratigraphy represents an attempt to correlate the relative sequence of observations from the rock record, with that of historical/linear time.

B. Historical Geology: Use of the stratigraphic record to derive historical time record and physical/biological evolution of the earth.

1. I.e. examining the rock record to deduce the natural history of the time record.

C. Sedimentology: study of the processes and products of the near-surface environment of the earth

1. Sedimentology outgrowth of stratigraphy, historical geology

a. Stratigraphy originally based on layered sedimentary rocks and the fossils contained within.

b. Sediments accumulate as horizontal layers of particles under the force of gravity, "layer cake" approach to geology and interpretation of the rock record.

I. HISTORICAL PERSPECTIVES: SCIENTIFIC EVOLUTION OF STRATIGRAPHY

A. Greek Period

1. (500-425 BC): Halicarnassus studies earthquakes and ground motion

2. (276-195 BC) Eratosthenes studied the earth from a geometric perspective and estimated its diameter within 20%

B. Roman Empire

1. Pliny the Elder (23-79 AD) worked extensively on examining earth's processes and natural landforms

a. Wrote <u>Natural History</u> encyclopedia which was used for over 1500 years

b. Personally investigated the eruption of Mt. Vesuvius in 79 AD, during the ruin of Pompeii (killed by sulfuric gases)

(1) Pliny the Younger: described the event and the character of a Plinian Eruption

C. Renaissance

1. Copernicus (1473-1543): astronomer and physicist that studied the earth: bucked Catholic Church doctrine and argued for a sun-centered universe ("Copernican View of Universe")

a. Galileo (1564-1642): proponent of the Copernican view (persecuted for his beliefs)

b. Kepler (1571-1630) proponent of Copernican View

2. Niels Stenson (1638-1686) Danish physician brought to Florence Italy to study fossil sharks teeth ("glossopterae"-tonguestones)

a. Known as Nicolas Steno in Italy

b. Identified fossil "glossopterae" contained in limestone as sharks teeth

(1) Wrote <u>Dissertation of a Solid Naturally Contained within a Solid</u>, 1667

(2) Derived three fundamental laws of stratigraphy

(a) Defined strata: defined as layered deposits of lithified sediments

(b) Law of original horizonatality: no matter what the current bedding orientation, sedimentary strata were deposited as horizontal beds under the influence of gravity. Steeply inclined strata have therefore suffered structural disturbance.

(c) Law of lateral continuity: sedimentary strata were generally deposited in more or less continuous blankets or sheets (may have since be subjected to erosion and cross-cutting)

(d) Law of Superposition: sedimentary strata are such that deposition occurs in chronological succession with the oldest bed on the bottom and the youngest at top.

(3) Steno also implied that the fossil sharks teeth were from ancient species of organisms that were no longer in existence (implying uniformitarian view), however organisms of similar function had existed in the past.

(4) Steno accused of heresy by the Catholic Church, and ended his studies of geology and geologic history after one year, but laid the groundwork for modern geological principles.

3. Archbishop Ussher in 1658 provided first primitive attempt at dating the earth based on the Bible and Genesis

a. October 23, 4004 BC

D. Industrial Age (1700's to present)

1. Abraham Werner (1750-1817): led the concept of the "Neptunists": in which most rocks were view as chemical precipitates from seawater

a. "Primitive Rocks": crystalline rocks devoid of fossils (granite, slate, basalt, marble, schist) formed from precipitation from the "original sea" (oldest of all rocks)

b. "Stratified Rocks" (next oldest): limestone, sandstone, conglomerate, coal, chalk- interpreted as chemical precipitates and as reworked chunks of primitive rocks.

c. "Volcanic rocks": formed from burning of limestone and coal

d. "Washed Deposits": modern alluvium deposited from shrinking "original sea" (youngest of rocks)

(1) Global "Flood Based" theory of the earth was somewhat consistent with biblical interpretation, and was favored by the church

(2) Neptunists first implied the concept of time and ordering of geologic materials in the record

2. James Hutton (1726-1797)- Father of Modern Geology, scottish geologist from Edinburgh.

a. Law of Uniformitarianism: geological processes operating today, are similar to those that have operated in the past

(1) Present is the key to the past, the observable processes operating today are the key to interpreting the geologic record

b. Hutton examined the stratigraphic record and derived several basic theories

(1) Law of Inclusions: looked at volcanic basalt sills in Scotland, and noted blocks of the surround sedimentary rocks enclosed in the basalt and noticed the surrounding sediments baked by basalt

(a) the magma of basalt must have been intrusive, injected into the sedimentary rock after it had formed.

(b) Baking contacts implied that the basalt magma was hot at the time of intrusion

(c) Supported by another locality where granite had inclusions of schist: implied granite and magma is hot at the time of intrusion (in opposition to Werner and the Neptunists

3. John Playfair (1748-1819)- helped Hutton publish his results, drew a distinction between the "Neptunists" and the "Plutonists" with

regards to the origin of volcanic rocks

a. James Hutton Theory of the Earth with Proofs and Illustrations: published in 1795, forms the basis for modern geological interpretation, process oriented view of geology

(1) Emphasized Huttons unconformity at Siccar Point, Scotland (tilted sed rocks overlain by horizontal sed rocks):

(a) the unconformity implies that erosion of the rock record results missing segments of large portions of the time record.

(b) Slow rates of modern processes, implied that enormous amounts of geologic time are required to account for the relationships observed in the rock record.

4. Charles Lyell (1797-1875): spokesman and proponent of Huttons view, promulgated geology into modern paradigms

a. Wrote "Principles of Geology"

b. Expanded on the notion of Uniformitarianism implied by Hutton

5. William Smith (1769-1839): canal builder/excavation engineer in England

a. made observations of rock strata during excavations/canal cuts

b. soon recognized a pattern of strata using Steno's three principles

c. observed that various layers of strata contained unique fossil assemblages, unique to that above and that below

(1) Based on fossil types, Smith could begin predicting the types of rock layers to be encountered during excavation.

(2) Law of Faunal Succession: based on principle of superposition, recognized evolution of species in the fossil record.

6. Charles Darwin (1809-1882)- used William Smiths Faunal Succession observations to prove the theory of organic evolution

II. DEVELOPMENT OF THE GEOLOGIC COLUMN (TIME AND ROCK RECORD)

A. Early work

1. Giovanni Arduino (1713-1795), Johann Lehmann (1719-1767) and George Fuchsel (1722-1773)

a. Developed a three-part "geological column"

(1) Primitive Mountains (crystalline rocks with no fossils)
(2) Secondary Mountains (fossiliferous limestone and shale)
(3) Tertiary Mountains (unconsolidated clay, sand and mud of low hills)

(4) Volcanic Rocks

2. Werner/Neptunists: developed the five-part subdivision of the crust with implications for time and rock sequencing

3. William Smith: late 1800's worked out the stratigraphic column for Great Britain

B. Later Work

1. Modern geologic column based on early work utilizing the principles of superposition and faunal succession (physical and biostratigraphic correlation)

2. Paleozoic (Era) Portion of Column: derived by geologists working in England and Wales (Periods and Systems)

a. Cambrian: Adam Sedgwick in 1835, named after ancient Wales reference of Cambria, based on lithologic character, no characteristic fossils originally described until later

b. Ordovician: Charles Lapworth in 1879, named ancient celtic tribe, identified as sequence of rocks in Wales and England that occurred between two unconformities within the Cambro-Silurian Sequence of Sedgwick and Murcheson

c. Silurian: Roderick Murchison in 1835, named for Silures an ancient tribe of Welsh borderland (had bitter arguement and competitive match with Sedgwick over describing boundaries).

d. Devonian: William Lonsdale, 1837, after the county of Devon, England, defined by the Marine facies of the "Old Red Sandstone".

e. Carboniferous: named for coal-bearing rocks of England by W. Conybeare and William Phillips

f. Pennsylvanian and Mississippian: two-fold division of the Carboniferous in North America; Pennsylvanian by H. D. Rogers in 1858, and Miss. by Alexander Winchell in 1870.

g. Permian: defined by Murchison in 1841, based on rocks exposed near Perm, Russia

3. Mesozoic (Era)

a. Triassic: Fredrich A. von Alberti in 1834, named for a 3-division sequence of rocks (red sandstones and shales) in Germany

b. Jurassic: named for the Jura Mountains of Switzerland by von Humboldt in 1799

c. Cretaceous: named for chalk beds of norther France (cliffs of Dover across channel) by d'Omalius d'Halloy in 1882.

4. Cenozoic

a. Tertiary: first used by Charles Lyell in 1833, in reference to earlier usage by Arduino in 1700's

b. Quaternary: 1829 Paul Desnoyers

c. ** most of modern subdivision of Cenozoic is based on fossil types and radiometric dating

5. Precambrian: very slow process of unraveling Precambrian events and stratigraphy

a. Precambrian rocks contain few fossils and are largely comprised of igneous and metamorphic crystalline rocks

(1) Difficult to correlate without sophisticated geochemical techniques (chemistry and radiometric dating)

b. Precambrian stratigraphy took off slowly with advent of radiometric dating techniques by Boltwood in 1905 and Holmes in 1911

c. More recently, paleomagnetism and radiometric dating have been employed to decipher Precambrian history.

III. IMPORTANCE OF STRATIGRAPHY AS A TOOL FOR THE GEOLOGIST

A. Regulatory/Permitting Practice: Environmental Impact Statements

1. Necessary to document the geological conditions of a given site in relation to the permitting process

a. includes an account of structure, stratigraphy, age and composition of the underlying rock types and unconsolidated material

B. Engineering/Design Purposes

1. Regional Stratigraphic Columns and Correlation provide a framework from which to communicate rock types of a given area. The composition and structural nature of rock-soil-sediment units is very critical for engineering design

a. e.g. Landfill liner systems
b. Groundwater monitoring systems/remediation
c. Mining and Petroleum Extraction

C. Hydrogeology/Groundwater Studies (Environmental Problems)

1. Necessary to understand the stratigraphy and composition of rock types/soil/sediment of a given region to properly interpret and model the groundwater regime of that area

a. e.g. shale/sandstone relationships: confined vs. unconfined aquifers
b. Essential element of Numerical and Analytical Groundwater Modeling Analyses

D. Academic Studies/Resource Documentation

1. Understanding and documenting the stratigraphy of a given area is an essential element of documenting the geology of an area:

a. Interpreting earth history,

b. Developing paleogeographic maps
c. Tectonic/structural reconstructions

IV. **SUBDISCIPLINES OF STRATIGRAPHY**

A. Lithostratigraphy: correlation and organization of rock strata based on physical lithologic properties.

B. Biostratigraphy: correlation and organization of rock strata based on fossil content

C. Chronostratigraphy: Age dating of stratigraphic rock units in the context a absolute geologic time

D. Magnetostratigraphy: correlation and organization of rock strata on the basis of magnetic properties of sedimentary and igneous rock sequences

1. Remnant Magnetism Preserved in the rock at the time of formation.

E. Seismic Stratigraphy: correlation and organization of rock strata on the basis of seismic character.

F. Quantitative Dynamic Stratigraphy: numerical and quantitative examination of tectonic, climatic, chemical and physical sediment processes and modeling the extent to which these processes affect stratigraphic and basin fill patterns.

V. BASIC STRATIGRAPHIC LAWS, PRINCIPLES AND PHENOMENA

A. Steno's Laws of Stratigraphy (see above)

1. Law of Superposition: older below, younger above

2. Law of Original Horizontality: under influence of gravity, sediment and sedimentary strata will be deposited as horizontal beds

3. Law of Original Continuity: beds of sedimentary rock were at one time lateral continuous (with the exception of pinch-out or basin margins), and if applicable, have since been cross-cut by erosion (hence beds of rock can be identified on opposite sides of a valley)

B. Uniformitarianism vs. Catastrophism

1. Uniformitarianism View: Present is the key to the past, processes operating today have operated the same in the past

a. Promulgated by Hutton in 1700's and Lyell in 1800's

b. Very slow, incremental geologic processes have occurred over immense amounts of time, to result in large scale changes of the earth

(1) took the view that violent events (earthquakes, eruptions etc) were minor blips on the screen of time, and of little overall significance

c. First formulated in direct opposition to Creationist/church doctrine

2. Catastrophist View: large-scale catastrophic processes are responsible for most of the changes and evolution of the earth (floods, quakes, eruptions, storms)

a. Short bursts of violent (high energy) processes, followed by slow process cycles

b. Although originally proposed in the spirit of scientific thought, catastrophism was embraced by the church and biblical fundamentalists in terms of Noah's flood, fire and brimstone, etc.

3. Modern Resurgence of Catastrophism among Stratigraphers

a. More recently, sedimentologists and stratigraphers have recognized the importance of catastrophic events in shaping the rock record

(1) the volcanic eruption
(2) hurricane/storm deposits
(3) 100 year fluvial flood deposits

b. The "normal" day to day conditions of fluid flow, sediment transport, etc., may be quite negligible relative to the overall record of events preserved in the rock record.

c. "Catastrophic Uniformitarianism": combination of slow incremental process-response, punctuated by catastrophic events, repetitively in a cyclical pattern throughout earth history.

C. William Smith

1. Law of Faunal Succession: in a succession of strata containing fossils, the fossils found in the lowest beds are the oldest (take off of Steno's Superposition)

2. Principle of Fossil Correlation: assemblages of fossils found in a given rock layer or unit are of like age; therefore strata containing like fossils are of similar age

    a. Index Fossils: a given fossil species that is particularly useful for correlation of strata, it is unique in its stratigraphic occurrence, of limited vertical distribution and geographically widespread.

D. Geologic Time and the Geologic Record

1. Gaps in the Rock Record:

    a. Its clear that in any given stratigraphic section for a given geographic region, only a certain portion of the stratigraphic rock record is present. In the record that is present, many lengths of time may be unrecorded, missing or unaccounted for.

    b. Causes of Gaps in the Record (Hiatus)

        (1) Non-deposition: i.e. geologic processes did not result in a sedimentary or igneous product

            (a) Sedimentation processes are episodic: a function of energy in sedimentary system and sediment available for transport/deposition.

            (b) There may be long or short periods in which net sediment accumulation or aggradation = 0.

                i) E.g. and 1 foot sandstone bed may represent a single flood event in a fluvial system. The bedding planes that bound the sandstone bed above and below represent a break in the sediment accumulation process.

            (c) Diastem: a small-scale gap or break in the sedimentary-stratigraphic record

(2) Post-depositional Erosion: the geologic process did result in a sedimentary or igneous product, however this product was later stripped by weathering/erosion.

(a) Causes of Post-depositional Erosion

i) Broad "epeirogenic" upwarping of continental areas with subsequent weathering, erosion and stripping of sedimentary rock cover as land area is elevated relative to erosional base level

ii) Active Tectonic Erosion and Alteration

a) Tectonic Uplift, Erosion
b) Subduction--- return to mantle
c) Metamorphism

iii) Erosion in conjunction with sedimentary processes

a) Eustatic Fall of Sea Level: exposes coastal sediments, subject to subsequent erosion

b) Channel cutting and erosion by fluvial systems

c) Ocean current/wave base erosion

(3) The sedimentary and tectonic process is such that much of the time record is missing from the stratigraphic rock record.

(a) Much of absolute geologic time may be unaccounted for in the rock record

i) Completeness of rock record controlled by nature of sedimentary/igneous processes and erosion cycle processes

2. Unconformable and conformable sequences

a. Conformable sedimentary sequences: parallel beds of rock lying above and below one another with no evidence of erosive or structural discontinuities

b. Unconformities: sequences of rock which show evidence for erosive or structural breaks in the record. Unconformities are defined by surfaces of erosion.

(1) Marked by erosive, cross-cutting contacts, basal gravel lags, rip-up clasts.

c. Classification of Unconformities

(1) Angular Unconformity: angular discordance of bedding between older and younger sequences of rock, discordance marked by surface of erosion

(a) imply period of deposition, horizontal sediment accumulation, lithification, structural deformation/tilting of rock beds, subaerial exposure/erosion, renewed deposition on top of erosion surface.

(2) Nonconformity: sedimentary strata overlying crystalline rocks (igneous and/or metamorphic), separated by erosion surface

(3) Disconformity: major stratigraphic breaks in the sedimentologic record (erosionally or nondepositionally), with no angular discordance of strata

(a) Parallel beds with observable surface of erosion separating sequences

(4) Paraconformity: similar to disconformity but with no observable erosive break in the sequence

(a) often identified by fossil record or other stratigraphic technique

(5) Lacuna: refers to missing stratigraphic/time interval within the unconformity

VI. SEDIMENTARY FACIES

A. Stratification = Layer of sediment deposited under sedimentary conditions (may include clastic and non-clastic deposits). Sediment deposits generally assume near horizontal layering as a result of settling under the force of gravity (perpendicular to earth's surface).

1. <u>Strata</u> = multiple layers of sediment (plural), vs. <u>stratum</u> single layer of sediment (singular).

2. <u>Beds</u>: Strata greater than 1 cm in thickness, tabular or lenticular layers of sedimentary rock that have characteristics that distinguish them from those above and below.

   a. Bedding Planes: surfaces of contact that separate beds, often representing a break in sedimentary process or a surface of non-deposition, chemical alteration, deformation or biological alteration

B. <u>Lateral Extent of Stratification</u> : primarily a function of depositional environment, e.g. discontinuous fluvial channel sandstones vs. laterally continuous, regressive beach complex sandstones.

C. <u>Sedimentary Environments</u>

1. Defined by the complex interaction of physical, chemical and biological conditions under which sediment accumulates.

   a. Sedimentary Environment Defined by series of geomorphic and sedimentary processes.

   b. Characteristics of a given sedimentary environment yield a specific product of sediment and/or sedimentary rock.

D. <u>Sedimentary Processes and Products</u>

1. "**Facies**": a body of sediment or sedimentary rock that display characteristic or distinctive textural, structural and compositional properties.

   a. Facies by definition: readily detectable and discernable characteristics (chemical, physical or biologic).

**A sedimentary facies is the <u>product</u> of the sedimentary environment and its processes

   b. "**Lithofacies**": "rock" facies characterized by petrologic characteristics such as: color, lithology, texture, and sedimentary structures.

   c. "**Biofacies**": paleontological characteristics of a sedimentary deposit, distinctive and indicative of a given depositional environment.

2. Process-Response Models

a. Base Assumption: a particular set of environmental conditions operating at a particular intensity will produce a sedimentary deposit with a unique set of properties characteristic to that environment.

b. "**Process and Response**": a linked set of reactions between environments and sedimentary facies.

PROCESS (CAUSE)----------------------------------RESPONSE (EFFECT)

PROCESS (CAUSE)	RESPONSE (EFFECT)
Physical Processes	Geometry of Deposit
wave and current activity	Blanket
gravity	Prism
sea level fluctuation	Shoestring/Ribbon
tectonic activity	Primary Sediment Properties
volcanism	Physical
	Bedding/Contacts
Climatic Fluctuation	Sed. Texture and Structure
Weathering/Sediment Supply	Color
Water Depth	Particle Composition
Geomorphology	Chemical Properties
	Elemental Composition
Chemical Process	Biological
Solution	Fossil Content
Precipitation	
Authigenesis	Secondary Sediment Properties
Cementation	Porosity and permeability
Water Chemistry	Electrical Properties (Resistivity)
	Radioactive Properties
Biological Processes	
Biochemical Precipitation	
Bioturbation	
Photosynthesis	

c. Modern-Process Sedimentology: concerned with direct observation of field and laboratory phenomena; identifying sedimentary processes and defining sedimentary deposits in modern environment

d. Sedimentology of Ancient Sequences: concerned with observation and characterization of the sedimentary product (rocks and unconsolidated deposits), and working "backwards" to create and paleo-environmental interpretation

(1) Environmental interpretation important for defining the nature and character of resources found in the sedimentary environment (e.g. oil, coal, natural gas)

E. <u>Facies Associations</u>

1. Problematic aspect of process-response: any given lithofacies may be found in a multitude of sedimentary environments

a. e.g. trough-crossbedded sandstone may be found in a nonmarine fluvial environment or in a marginal-marine/beach face environment

2. **Sedimentary Facies Analysis**: Examining the Inter-relationship between sedimentary facies, i.e. looking at the larger package to make paleo-environmental interpretations.

   a. **Facies Associations**: Identification of groups of facies that are genetically linked to a given environment of deposition.

      (1) E.g. trough cross-bedded sandstone overlying erosive contact, overlain by rooted mudstone and coal-----indicative of fluvial environment

   b. Stratigraphic Relationships and Walther's Law: Examining the vertical and lateral relationship among sedimentary facies

      (1) **Walther's Law Defined**: facies that pass into one another laterally may also occur in vertical sequences in similar order.

      (2) Due to prograding and retrograding sequences, facies sequences in vertical contact were at one time likewise in lateral contact.

         (a) e.g. Transgressive and Regressive marine sequences

      (3) Facies that are in vertical association must also have been in lateral association in space, however not all lateral facies may be preserved in a vertical sequence.

   c. **Facies Models**

      (1) Defined: Idealized facies sequences used to "fingerprint" a given sedimentary environment
      (2) Case studies used to formulate "predictive" models of depositional systems.

         (a) Based on Observation of Modern Sedimentary Environments and employ the "Law of Uniformitarianism" that present processes have operated in the past as in the present day.

         (b) By deductive reasoning, if a specific set of facies associations can be recognized as a product of modern, observable processes ....

then those same facies associations recognized in the ancient environment would dictate an interpretation of a similar environment of deposition.

F. Shoreline Transgression and Regression

a. Transgression: movement of shoreline in a landward direction

(1) due to a rise in sealevel or tectonic lowering of land elevation

(a) "eustatic" sealevel change = global raise or lowering of sealevel

b. Regression: movement of a shoreline in an oceanward direction

(1) due to a lowering of sealevel
(2) or great influx of sediment to a coastal area

c. Net results in sedimentation style

(1) Regression: progradation of "proximal" facies overtop of "distal" facies

(2) Transgression: retrogradation of "distal" facies over top of "proximal" facies

G. **Principal Environments of Deposition**

1. **Continental**: Sedimentary environments found in a terrestrial setting...

a. **Fluvial**: Associated with processes of aqueous fluid flow on land (i.e. stream and river settings)

(1) **Alluvial Fan**: characteristic environment found at the front of steep mountain slopes. Sediment laden streams exiting canyon mouth, depositing sediment in cone-shaped fan at front of mountain.

(2) **Braided Fluvial**: high/coarse sediment laden rivers, characterized by "braided" river flow between migrating mid-channel sediment bars (high gradient

conditions)

(3) **Meandering Fluvial**: fine-load rivers, migrating/winding across a relatively low-gradient floodplain.

(a) Channel deposition

(b) Overbank/floodplain deposition

b. **Desert (Aeolian)**: dry climates, general lack of vegetation + high amounts of weathered sediment = wind-dominated sediment transport (sand dune amalgamation)

c. **Lacustrine**: lake-related sedimentation, streams and rivers flowing into standing water (feeding lakes), dumping sediment along lake margins, fine quiet water sedimentation and/or organo-chemical deposition

d. **Glacial**: continental/alpine morainal and/or till depositional processes, high amounts of sediment rapidly deposited; outwash processes cross-over into "glacio-fluvial" realm.

2. **Marginal Marine**: essentially coastal plain sedimentation where terrestrial fluvial environments transition into the marine/ocean environment

a. **Deltaic**: environment characterized by fluvial system depositing sediment into standing body of oceanic (and/or lacustrine) water. Sediment accumulation in form of delta.

b. **Beach/Barrier Bar**: wave-dominated beach processes as rivers deliver sediment to coastal area; waves re-work sediment into beach deposits.

Barrier Bar: Offshore accumulation of sediment, wave dominated on lee side of island, slack-water dominated on landward side of island

c. **Estuarine/Lagoonal**: similar to lacustrine, only in marginal marine setting, water chemistry is saline, quiet water sedimentation with bio-critter processes abundant.

d. **Tidal Flat**: low-lying coastal areas heavily influenced by tidal rise/fall of water, tides rework sediment, bio-critter processes abundant.

3. **Open Marine**

a. **Neritic**- i.e. shallow ocean setting

(1) **Shelf**: encompasses sand-dominated siliciclastic shelf or carbonate-dominated shelf accumulations

(2) **Organic Reef**: biochemical build-up of carbonate structure comprised of living marine organisms, dominated by corals and algae + other critters

b. **Oceanic**: i.e. deeper ocean setting

(1) **Slope**: steep-gradient slope transitional to shallow-water shelf and deep ocean floor

(a) . Submarine canyons/submarine fan systems

(2) **Deep-ocean Floor**

(a) Submarine fan deposition
(b) Abyssal plain, quiet water mud accumulation
(c) Deep-water chemical sedimentation below CCD: i.e. silica oozes (chert formation).

CONSIDERATIONS: SEDIMENTARY ENVIRONMENTS AND SEQUENCES*

Reconstructing ancient depositional environments ("paleo-processes") from sedimentary facies associations...i.e. "forensic" geology:

H. **Physical Criteria**: analyzing the physical nature of the deposits

1. **Geometry of Sedimentary Deposits**: the three-dimensional shape of sedimentary bodies

a. Sheets/Blankets: relatively equidimensional deposits displaying a width-to-length ratio of ~1:1.

(1) Relatively uniform thickness, that may cover 1000's of square miles

(2) Associated with shelf, beach or eolian environments, implies lateral continuity of process.

b. Prisms/Wedges: bodies of sediment that are roughly equidimensional in plan view, however display a "wedge" shape in cross-sectional view

(1) E.g. alluvial fans, delta environments

c. Ribbons/Shoestrings: long, narrow elongate bodies with length:width ratios > 3:1

(1) E.g. Fluvial and/or delta distributary channel deposits

d. Belts: amalgamated ribbons, i.e. connected laterally

e. Basic tool for determining shape: drill logs, isopach maps, extensive 3-d outcrop

2. **Lithology (i.e. "Lithofacies")**: type of rock composition inherently defines the possible type of sedimentary environment

a. Limestones:

(1) imply warm shallow-marine shelves

b. Fine-grained, quartzose sandstone

(1) eolian dune deposits
(2) mature beach deposits

c. Evaporites

(1) high-evaporation climate, restricted water, high salinity

d. Conglomerates:

(1) fluvial/alluvial fan environment

e. Coal

(1) Fluvial/floodplain environment (swampy)

3. **Lateral and Vertical Facies Associations**

a. Walther's Law: vertical succession of lithofacies are also in lateral association

(1) Proximal to distal relationship

(a) e.g. seaward: beach sand to offshore mud to offshore limestone

i) Transgression: i.e. relative sea-level rise: offshore facies migrate landward; net result: coarser "proximal" facies will pass upward into finer "distal" facies

ii) Regression: i.e. relative sea-level drop: nearshore facies migrate oceanward; net result: finer "distal" facies will pass upward into coarser "proximal" facies

b. Fining- and Coarsening-Upward Sequences: examination of vertical trends in grain-size

(1) Fining-upward sequence implies high-energy process passing into lower-energy process

(a) e.g. meandering fluvial "point-bar" deposition

(2) Coarsening-upward sequence implies low-energy process passing into higher-energy process

(a) e.g. prograding delta-distributary deposits

c. Cyclic Facies Patterns: examining the vertical succession of lithofacies

(1) Cyclic facies patterns: repetitive sequences or facies associations

(a) implies repetition of process and cycling

i) climatically or tectonically controlled

4. **Sedimentary Structures**: examining sed. structures in context of environment of deposition

a. Structures, Bedforms and Transport Energy

(1) reconstructing fluid force according to Hjulstrom relationships

(2) Limits: sed. structures are often common to many environments, making them of limited value directly

(a) e.g. ripple-laminated sandstone may be found in either fluvial or eolian or beach environment

(b) must be used in combination with other environmental indicators

5. **Paleocurrent Patterns**: reconstructing paleocurrents from sed. structures/bedding characteristics

a. Unidirectional vs. Bidirectional

(1) Unidirectional indicators

(a) e.g. dipping cross-bed foresets
(b) flute casts

(2) Bidirectional indicators

(a) e.g. parting lineations
(b) brush,bounce and prod marks

b. Unimodal vs. Bimodal vs. Polymodal

(1) Unimodal paleocurrent directions

(a) e.g. fluvial transport

(2) Bimodal paleocurrent directions

(a) e.g. tidal flat

i) recording incoming and outgoing tide motion

c. Limits: variability of paleocurrent data

(1) must employ circular statistics to confidently analyze overall current directions

6. **Sedimentary Textures**: i.e. use of grain size as indicator of proximal to distal relationships

a. coarse------proximal (high energy); fine-------distal (low energy)

b. Drawback: grainsize also a function of sediment supply available

(1) e.g. what if only silt sized sediment was available for

transport: may find it associated with either a high energy or low energy depositional environment.

I. **Geochemical Criteria**: examining geochemical characteristics of sediments

1. **Paleotemperature Determinations**: makes use of elemental isotopes preserved in rock record to make interpretations concerning past climatic and oceanic conditions

    a. **Oxygen-Isotope Ratios**: extensively used to reconstruct paleotemperature of seawater

        (1) examine isotopic content of fossil shell material

            (a) determine proportion of O^{18} (heavy oxygen) to O^{16} (common oxygen)

            (b) Relationship: in constructing carbonate shells, critters can not differential between O^{18} or O^{16}, and hence will incorporate each at the proportion found in seawater at the time of biochemical precipitation

            (c) Geochemical consideration: at constant salinity: O^{18} concentration decreases with increasing temperature, and likewise will be at corresponding concentration of carbonate shell material.

                i) Drawback: shell material must be relatively fresh and unaltered by diagenetic recrystallization

                ii) O-isotope studies primarily used for modern to Pleistocene to late Tertiary marine deposits.

J. **Biologic Criteria**: using paleo-ecology to reconstruct sedimentary environments; based on observations from modern marine ecology and biology, extrapolating to fossil record.

1. Biocoenosis vs. Thanatocoenosis

    a. Biocoenosis: assemblage of living ecologic community of organisms

b. Thanatocoenosis: "death assemblage" of critters, may not be the same as the "life assemblage" owing the processes of transport of shell material following death.

2. Fossil Salinity Indicators: saline sensitive critters

3. Fossil Water Depth Indicators: bathymetric sensitive critters

4. Fossil Water Temperature Indicators: temperature sensitive critters

5. Critters and Turbidity: turbidity sensitive critters

6. Drawback: must be in critter-rich environment, not of much use in continental environments.