SEDIMENTARY ROCKS:
- cover about 66% of the continents and most of the ocean floor

Why?
- more stable in most situations than igneous and metamorphic rocks which formed under higher T and P than they are found in
- also most sed are recent – non deposition-erosion episodes vs. deposition

Why study?
Abundance – diversity, etc. types of environments
Stratigraphic record
- facies – correlation
- biostratigraphy
- historical geology (earth history)
Practical
Resources - metal
oil and gas
evaporates
sand and gravel
Waste storage salt
shale
carbonates
Engineering building stone
site investigation
Quebec bridge

Sedimentary Petrology
AIM – observe and deduce
a) what is there?
b) what is the source?
c) how did it form?
d) what does it tell us about the resource or earth’s history?

Background basis for Observations
a) What should be look for?
b) What does the future mean?

Where to look
1. Modern Sediments – key to past and present
2. Theoretical Models – facies and otherwise still models – garbage in and garbage out
3. Associations with related rocks (Facies et al.)

How to Study? Same as Igneous and Metamorphic

- hand specimens – outcrops
- microscopy – binocular, petrographic, SEM - TEM
- physical tests, eg. grain size analyses, clay mineral analyses x RD
- geochemical analyses

Fundamental Classification

There are 1000’s so these are examples.

a) In general sedimentary rocks are the result of weathering and weathering products therefore rocks break down in 2 major ways: i) mechanical and physical; ii) chemical (acid rain speeds it up) not as satisfactory because it does not look at formation but instead looks at destruction. Therefore another scheme (FOLK?).

b) Three component system

1. Terrigenous
   - derived from erosion outside depositional area
   - carried as solids (clastics) (Bowen’s and metamorphic minerals)

2. Allo chemical
   - chemical ppte – carried as solids

3. Orthochemical
   - chemical ppte within the depositional area, eg. Bahama Bank limestone ppte

(1) and (2) become fragmental
(2) and (3) become chemical

Great deal of variability and numerous classification

For example, alternatives – abundant – you should not be frightened of alternative schemes but should be able to understand and rapidly distinguish what they are based on.

Asides:

Major Types of Sedimentary Rocks

According to Blatt-Ehlers

- mudrocks 65%
- sandstones 20-25%
- carbonates 10-15%
- all others 5%
Therefore you can see where emphasis should be put but mudrocks (mudstone, shale, graywackes) poorly studied. Why? Stay tuned.

This diagram should be thought of as Relative Rock Resistance with Time.

**Components in Sedimentary Rocks**

a) grains – normally particles of sand size or larger minerals or rocks  
b) matrix – material between the grains – normally detrital material  
c) cement – chemical ppte – holds grains and/or matrix together – occurs between other particles, e.g. hydrothermal silica vs. anhydrite (Australia)  
d) holes or pore spaces – hydrogeo – oil – air – gas

**Properties of Sedimentary Rocks**

Especially in clastic rocks depends on a variety of characteristics associated with the above components.

Texture of the individual grains

- size
- shape
- surface textures
- arrangements

1. **SIZE**: mainly in clastic or terrigeneous rocks

   - numerous grain size scales

   - Wentworth Grade Scale (geometric scale) Krumbein $\phi$ units negative log to base 2 of grain size in mm

     **Advantages or result**: i) constant ratio between classes; ii) geometric scale therefore equal significance is attached to each size ratio, e.g. a 1 mm change in boulder size is insignificant but in fine sands makes a considerable difference

**General: other pts: Measurement**

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Size (Dominant)</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>conglomerate</td>
<td>granules – coarser</td>
<td>ruler</td>
</tr>
<tr>
<td>sandstone</td>
<td>sand size</td>
<td>screens</td>
</tr>
<tr>
<td>siltstone – mudstone</td>
<td>silt (coarse)</td>
<td>microscope</td>
</tr>
<tr>
<td>mudstone – shale</td>
<td>silt – clay</td>
<td>settling in $H_2O$</td>
</tr>
</tbody>
</table>

**Significance of size** (i.e. mean grain size)

Can we correlate to:

- correlate to depositional environment?  
- distance from source?
source $\rightarrow$ conglom $\rightarrow$ sand $\rightarrow$ mud

In general size depends on:

i) size of available material
ii) energy of transport/depositional environment
iii) chemical environment, i.e. pH, redox, temperature, pressure

2. **SORTING**

- uniformity of grain size or measure of grain size distribution
- use of histogram plots or cumulative frequency curves to plot up size classes

Sorting: is an important indicator of textural maturity.

Depends on:

- size range of material supplied to environment
- type of deposition
- well worked vs. dumped and buried
- current strength energy environment
- time

Grain Size and Sorting:

Another example – observe different size materials in beach environment and fluvial environment.

![Figure. Size vs. Sorting](image)

- makes for interesting curves distorted 2 cycle sine curve
- beach generally better sorted than fluvial

Reason for the shape of the figure

Nature produces three basic populations of detrital grains to rivers and beaches (Wentworth)

1. pebble population from massive rock breaking along joints and fractures – depends on spacing of fractures

2. sand – coarse silt – residual products from weathering of granular rocks – like granite-schist etc. initial size related to original size of quantity or feldspars

3. clays – reaction products of chemical decay, e.g. in soils

3. **SHAPE OF GRAIN** (Sphericity)

- numerous measurements – formula

In general: 

$$\frac{\text{surface area particle (volume)}}{\text{surface area or volume of a circumscribing circle}}$$
Explanation: volume relation → a true sphere has the least surface area for a given volume – this in turn affects resistance of particles during fluid flow.

\[
\frac{\sqrt[3]{V_p}}{\sqrt{V_{cs}}}
\]

\(V_p\) = volume of particle
\(V_{cs}\) = volume of circum circle

Other methods, e.g., \(\sqrt[3]{\frac{\text{long int. short dimension}}{\text{long}^3}}\)
In this section difficult – depends on orientation

4. **Roundness** – difference concept

\[R = \frac{\text{average radius of corners and edges}}{\text{radius of maximum inscribed circle}}\]

We assign a value such that:

- if edges are sharp – radius is small – roundness is low
- if average radius fits more within the circle then roundness approaches 1.0

Microscope ID and charts used

Figure 4:10: Compares Sphericity and Roundness. Note also Powers Roundness (A53)

Table 4-4: Examples of both in some materials. Note sphericity usually high; note ss vs. shale for roundness.

5. **Shape** – note handout

Compact, platy, laded, elongate, etc.

6. **Surface Features – Texture** (Roughness)

Very important clues in history of the grain: reflects a number of interrelated things

- varies with mineralogy
- if all grains equal can reflect variable abrasional history of the same numeral in different settings

  e.g. abraded – chipped or broken
  lobeate – cobbled
  corroded – chemically etched
  smooth or polished – no markings
  frosted – chemical?
Examples of Uses

- pebbles in Colorado River; i) chert and quartz sphericity 0.6 – 0.8; ii) limestone sphericity 0.4-0.7
- Tahiti beaches – basalt rocks

<table>
<thead>
<tr>
<th></th>
<th>beach pebbles</th>
<th>river pebbles</th>
</tr>
</thead>
<tbody>
<tr>
<td>roundness</td>
<td>0.52</td>
<td>0.38</td>
</tr>
<tr>
<td>form</td>
<td>oblate</td>
<td>compact</td>
</tr>
<tr>
<td>sphericity</td>
<td>0.60</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Effect of Transportation

- pebble size reduction
- sorting
- abrasion increases
- more round – sphericity
- polish

Mineral Composition of Sedimentary Rocks

See handout for general overview using Classification of Terrigenous vs. Chemical Controls

Terrigenous

- availability – source, e.g. green sand beach
- mechanical durability – transport
- chemical stability
  - is obvious from observation
  - dependent on habitat etc.
  - Goldich – opposite of Bower Series Stability Series

Result of long term weathering

quartz, zircon, tourmaline, chert (excellent)

\[ \downarrow \]

micas

\[ \downarrow \]

feldspars

\[ \downarrow \]

mafics (poor) complete weathering
PETROLOGY OF SANDSTONES

a) Mineralogical Classification - based on mineralogical maturing or weathering

For example, FOLK – numerous possibilities

Handout figure

| Q = quartz | general supermature |
| F = feldspar | granitic terraines |
| R = rock fragments | volcanic metamorphic source |

Other terms used:

Grains
- Orthoquartyite – 90% or more quartz
- arkose (feldspatheric) – 20-25% feldspars or more
- ?? (lithie) – rich in rock fragments

Add Gilbert 1954; widely used as well

Matrix

Distinguishes on basis of matrix between grains (applies especially if matrix is large proportion)
- appreciable mud (poorly sorted)
- clean (e.g. sand) (well sorted)

Combine these in many different combinations

b) Textural Classification – textural maturity

Concept: greater mechanical energy; greater abrasion and sorting – stages

1. Immature > 5% terriq clay material; sand poorly sorted, angular
2. Submature < 5% terriq clay; sand poorly sorted, not well rounded
3. Mature ~ 0% clay; sand well sorted, not well rounded
4. Supermature ~ 0% clay; sand well sorted, well rounded

E.g., see handout for idea of sorting (page 21)

The concept of textural maturity is key to physical nature of the depositional environment.

Handout (p. 23) shows areas
Note: Scale shows

- effectiveness in winnowing (energy)
- source
- effect on rounding, sorting, winnowing of energy of waves and currents
- textural inversions and causes of kinds*

Combine Textural and Mineralogical

Example is handout (p. 25)

*idea of environment, possible sources from petrological descriptions

PETROLOGY OF MUDROCKS

Shales
- over 60% of sediments
- shale is a field term for fissile rocks

Mudstone
- non fissile

Much less know than other sedimentary (why?)
a) particle size (SEM for study)
b) complex physical/chemical histories
c) numerous reasons not studied

- not oil reservoirs
- not groundwater aquifers, etc.

mudrocks – terrigeneous rocks > 50% silt/clay size

<table>
<thead>
<tr>
<th>Grain-size of mud fraction</th>
<th>Unconsold.</th>
<th>Indurated non fissile</th>
<th>Indurated fissile</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2/3 silt</td>
<td>silt</td>
<td>siltstone</td>
<td>silt-shale</td>
</tr>
<tr>
<td>silt ~ clay</td>
<td>mud</td>
<td>mudstone</td>
<td>mud shale</td>
</tr>
<tr>
<td>&gt; 2/3 clay</td>
<td>clay</td>
<td>claystone</td>
<td>clay shale</td>
</tr>
</tbody>
</table>

Note: Many studies centre on organic matter visually ID algae, spore, coal ??, petroleum → source beds?

Petrographically
- microscopic to submicroscopic
- a real pain to study

PETROLOGY OF CARBONATE ROCKS

Depending on classification carbonates are 10-15% maybe 25-35% of sedimentary rocks – depends on purity, etc., eg. carbonaceous shales, etc., shaley limestones.
Importance:

- oil and gas reservoirs – more recently may be source rocks as well depends on % organic C
- aggregate – cements CaOH etc.
- stratigraphy – modern carbonate study areas shed light on paleohistory

Study Techniques:

- etching – shows residual non-carbonate
- ?– acetate-etch thin sections
- insoluble residue – geochem studies
- thin sections
- cathodoluminescence

CLASSIFICATION OF LIMESTONES

Basic components (neglect sand, silt, clay grains)

1. Microcrystalline ooze → micrite
   (lime – mud → opaque finely crystalline)
   - grains are 1-4 μ diameter
   - made of calcite (CaCO₃)
   Origin - chemically ppted mud
     - disintegration of organisms made of CaCO₃
     - some terrigineous

2. Sparry calcite → sparite
   - clear calcareous material → cement
   - crystals > 10μ diameter – clear, coarse
   Origin - pore filling cement
     - recrystallization of micrite

3. Allochems - formed by chemical ppte with some transport
   - often coarser components

Types:

a) Intraclasts – fragments, weakly consolidated carbonate sediment – eroded from adjacent carbonates and reincorporated in new deposit
   Environment – bottom seds torn up; increased current – energy

b) Pellets – rounded aggregates of fine grained calcareous material (micro x ?? calcite)
   Well rounded, sorted 0.03 – 0.20 dia.; fecal pellets, no internal structure

c) Oolites – spherical – elliptical bodies have a radial or concentric form surrounding nucleus
   - roll around in current – accrete

d) Fossils – fossil fragments

e) The “Lump” composite of oolites and pellets
Types of Limestones

Type I

- limestones – sparry allochemical
- well sorted ??, ss type
- clay size removed – usually found where strong persistent currents exist
- relative amounts of allochem – spar controlled by packing limitations

Type II

- limestones – microcrystalline allochemical
- clayey, ss, congl.
- weak currents and/or rapid formation of ooye

Type III

- limestones – microcrystalline
- claystones
- also disturbed microcrystalline rocks
- bioturbation – sparry infilling
- intraclasts of ??

Type IV

- ?? rocks “Biolithite” growing in situ

Also classed by Allochems

For example, > 25% intraclasts → intraclastic limestone; < 25% intraclasts > 25% oolites → oolite Ls if fossils 3X greater than pellets → biogenic Ls opposite 1:3 → pellitic Ls others pellet sparite or pelsparite.

See Handouts:

1. Carbonates Limestones
2. Terrigenous Admixtures
   > 50% terriq. use (2)
   10-15% terriq. impure chemical rocks
   clayey biomicrite
   sandy dolomicrite

Handout: Carbonate Textural Spectrum

DOLOMITES → DIAGENESIS

Generally low T and P conditions
- post deposition – pre final ??
Chemical-Physical changes
- compaction
- recrystallization
- deformation
- ppte
- dissolution

\[ \text{CaCO}_3 + \text{Mg} \rightarrow \text{Ca Mg (CO}_3)_2 \]

Locations
- major fraction of many carbonate rocks
- commonly where interfaces occur, e.g. saline water/freshwater; air/water

Saline Waters

Beachrock – evaporation in intertidal zone water/air/sed interface
aragonite, calcite cements
fibrous or micritic

Hydrothermal

Primary?

Seawater saturated with respect to dolomite but ppte not observed

Dolomitization

- replaces calcite/aragonite
- early diagenesis favoured by high Mg/Ca ratio in fluid

\[ 2 \text{CaCO}_3 + \text{Mg}^{2+} \rightarrow \text{Ca Mg (CO}_3)_2 + \text{Ca}^{2+} \]
Mg/Ca 1:1 to 10:1

Sources

- high Mg/Ca brines
- high Mg/Ca surface waters saturated