Sedimentary Rocks

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We've heard about igneous rocks. Formed by cooling & crystallization of melts. If you sample a random part of Earth's interior, odds are pretty good you'll get an igneous rock. What about Earth's surface? [Q: What do you hit if you dig in your yard? Soil, which is made largely of rock fragments.] Usually you'll hit sediment, and those can be transformed back into rock.

Today: Fate of rocks at the surface, and the processes they record along the way (we'll talk later, in the lectures on plate tectonics, about how they get to the surface)

Let's start with a story about some enigmatic features in a ~500 Ma rock outcrop in Wisconsin (PPT), from a paper by Whitey Hagadorn et al. (Geology, 2002). Like all good stories, it is a tragedy.

> *"The following scenario for medusoid stranding, decay, and burial is hypothesized. Jellyfish were blown or swam into a shallow embayment. The tide ebbed and escape behaviors were initiated … During mass strandings, most jellyfish settle on the surface with their subumbrella down, and they commonly pump their bells in an attempt to escape from stranding … This escape behavior often compounds their fate, because they pump much of their stomach and internal cavities full of sand, thus exacerbating their fate through extreme sand loading. … The only structure often preserved within the umbrellar center is a convex sediment mound formed either through pulsing of the dying jellyfish or decomposition of the sediment-laden gastrovascular cavity."*

Tragic indeed. But this is a great example of the rich information stored in sedimentary rocks.

We could also use the grain size and ripple wavelength of the sandstone to infer water depth and wave energy. In fact, my group has been doing experiments to try to interpret ripple patterns preserved in sedimentary rocks [PPT: Myrow photo of outcrop with defects, and time lapse of experiment].

Let's make a table of the different stages that different kinds of sedimentary rocks pass through. This will help you interpret the samples you examine in the lab.

<table>
<tr><td colspan="2">Source Rock</td><td></td></tr>
<tr><th>(Silici)clastic sedimentary rocks</th><th>Chemical/Biological sed rocks</th><td></td></tr>
<tr><td>Physical processes
• Mechanical weathering – fragmentation of bedrock
• Erosion – detachment from surface in source area
• Transport – moved away from source area by fluid (water, wind, ice) or gravity
• Fining – breakdown into smaller particles during transport</td><td>Chemical processes
• Chemical weathering
  o Dissolution – usually in H_2O
  o Alteration – to different minerals by chemical reactions
• Transport – in solution</td><td>Breakdown</td></tr>
<tr><td>Deposition
• Mechanical – due to drop in transport energy</td><td>Precipitation
• Inorganic due to saturation
  o addition of solute
  o loss of solvent by evap
  o change in solubility
• Biotically mediated (e.g. shells of silica or carbonate)</td><td rowspan="2">Sedimentation</td></tr>
<tr><td colspan="2">Burial*
• In a depression or basin (ocean, lake, valley)
• In a place where Earth's surface is sinking (Gulf of Mexico)
• More sediment deposited on top</td></tr>
<tr><td colspan="2">Diagenesis (alteration of rock) → Lithification (transformation into rock)
• Pressure, heat, different fluids lead to…
• Compaction
• Dewatering
• Chem reactions
• Addition of minerals, including cementation</td><td>Lithification</td></tr>
<tr><td colspan="2">Sedimentary Rocks</td><td></td></tr>
</table>

*Note the preservation bias. In general, sed rocks record what is happening in basins, which often contain bodies of water. The soil you dig up in your suburban back yard in western MA will probably not form a sedimentary rock in that location, because it is eroding rather than being deposited & buried.

Different kinds of sed rocks result from

- Different source material (rock)
- Different pathways through the process we just sketched out

Knowing the names & categories that have been devised to describe sed rocks is valuable, and your textbook chapter will help with that. [PPT: textbook tables on clastic, bio/chem]

Equally important is knowing how a rock records different parts of this pathway, especially:

1. Which transport agent(s)? How strong? If water, how much, and what kind of flow?
2. Tectonic/geographic settings of source & sink. “Active” margin like the Pacific rim, or “passive” like eastern N. America? Steep river exiting mountains, large river floodplain, beach, or sea floor?
3. Climate. Glacial? Tropical? Desert?
4. Biological activity. Production, deposition, alteration of sediments.

How can we look at a sed rock and deduce these things? Rest of lecture:

- Indicators of these four factors in clastic and chem/bio sed rocks
- Prominent recent examples of geologists applying these ideas

	Clastic	Chemical/Biological

1. Type & strength of transport agent	• Grain size – prop to transport energy. Boulder/gravel/sand/silt/clay – 256/2/0.05/0.005 mm
	• Grain shape – transport distance. Larger grains round more easily
	• Grain sorting – change in transport energy in space (river profile) or time (e.g. fining up) [PPT]
	• Bedforms (shape of sed surface due to transport processes) [hand samples, recall ripple example]
	  ○ Symmetry → bi/uni directional flow
	  ○ Amplitude → flow energy, wind vs. water (eolian dunes make thick X-beds) [PPT]
	  ○ Orientation → transport direction
		• Reworking of chem./bio sed rocks, can apply clastic methods
		• Diagenetic textures, e.g. ooids

2. Tectonic & geographic setting of source & sink	• Mineralogy – source rock type varies with tec setting • Quartz content – mafic minerals, feldspar break down faster, so distal sediments more qtz-rich • Grain size – proxy for topographic slope and tec activity • Indirect, via transport agent & energy (steep coastal river vs. large delta)	• Species composition • Presence of clastic component → higher energy, near shore • Rock type – limestone (carbonate) made of foraminifera [PPT], chert (silica) made of diatoms, radiolarian [PPT] → CCD
3. Climate	• Chem weathering of grains • Sequence of deposits → climate change • Coarser grains → colder • Indirect, via transport medium (e.g., glacier vs. wind vs. river)	• Redox state – BIFs • Presence of evaporite • Species composition • Chemical composition – climate proxies (lecture later in course)
4. Biological activity	• Bioturbation • Clasts made of biogenic material • Sed structures, esp fossils	• Species composition • Mineralogy (microbial role in dolomitization?) • Sed structures – reefs, stromatolites, fossils in general

<u>Case Studies</u>

1. Snowball Earth

- An idea that goes back to mid-20th century
- Present them with diamictite/tillite with dolostone stratigraphically above, say deposited in marine sediment, and BIF found in deeper water. What kind of environment and climate?
- Then say paleomag inclinations indicate deposition near equator, in Neoproterozoic (~600-800Ma). Glaciers at the equator?
- The story (popularized by J. Kirschvink @ Caltech & P. Hoffman/D. Schrag @ Harvard):
  - Global glaciation → ice @ equator ("snowball Earth")
  - Ice-rafted debris deposits glacial sed in ocean [PPT]
  - Ocean sealed off from atmosphere → oceans become anoxic
  - CO_2 from volcanoes causes strong greenhouse → melts ice
  - Sudden input of CO_2 into ocean causes deposition of "cap carbonate", which alters from limestone to dolostone [PPT]
  - Oceans become oxic → dissolved Fe is oxidized and precipitates out as BIFs (magnetite, Fe_3O_4, or hematite, Fe_2O_3, interbedded with shale or chert) [PPT]
  - Extreme wind & waves due to crazy weather and sea level rise from melting ice → giant wave ripples [PPT]
- This is inferred to have happened not just once, but a few times

This is a controversial story, and there is debate about these interpretations of sed rocks. Global glaciations! Do you buy it? What are some potential problems with this hypothesis?

2. Evidence for water at Meridiani Planum, Mars, from the Opportunity Rover

- Was Mars ever wet?
- Opportunity sent to Meridiani Planum because spectra collected from orbit showed evidence of hematite (Fe_2O_3), often found in aqueous environment
- Evidence from sed rocks exposed in wall of Endurance Crater [PPT]:
  - Clastic sed rocks
    - Derived from wx of basalt
    - Cross-stratification – wind or water? Probably wind, given size. [PPT]
    - "Festoon" cross-lamination with sinuous crests interpreted to be diagnostic of transport in water [Dave Rubin animation]
  - Chem sed rocks
    - Jarosite and other hydrous sulfate salts suggest formation in water-rich environment
  - Diagenetic features
    - Hematite concretions – "blueberries" [PPT]
    - "Vugs" – voids left by mineral dissolution, matrix intact [PPT]

These interpretations, too, are not without controversy. What do you think: was Mars wet?

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