EMES 303

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January 2026

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1.1 Planet re-surfacing driven by tectonic, eustatic & climate cycles

- Continents get destroyed by erosion
- Resultant redistribution: Erosional landscape, depositional landscapes
- Three fluids which transport sediment: Wind, water, ice—transports most of our sediments

1.2 Fluid Flow: Laminar & Turbulent

- $R_e = \frac{UL}{\upsilon}$
- Laminar flow doesn't really exist in nature
- Turbulent flow: little tiny eddies that form
- All particles are taking different directions even though they are going in the net same direction
- Low R_e are laminar and high are turbulent

1.3 Hjulstrom Diagram

- Max velocity at which it will stay on the bed of the river for settling velocity curve
- Same for particles eroding

1.4 Particle Transport

1. Bedload: particles moving along the bottom; traction transport=creep,sliding,rolling; constant contact with the bed; Saltation transport—jumping

2. Suspended load transport: middle of the stream

3. Washload: really fine grain materials at the top of the stream, typically always at the top with minimal flow

1.4.1 Saltation

- Always grains to be transported quickly

- Hop length can be 100-1000's time the grain diameters

- Water it is less; typically hop height ¡ 10 hop distance ¡ 100

1.4.2 Suspension Load

- Hangs out right above that bed

- Turbulence near the bottom of the channel caused by rocks and not even surface creates the lift to the suspend sediment

- Time differential: bedload will take a longer amount of time then suspended load

- Muds and fine sands will be in suspension load

- gravels and coarse sands will be in saltation

- Coarse gravels will be creep

- Muds and very few fine sands will be in suspension in air

- Saltation for sands in air

- Creep for gravel in air

1.5 Driving Forces

Water & Ice:

- Primary force: gravity

Wind:

- Convection, pressure differences, sometimes gravity (katabatic)

1.6 Rockfalls

Rockfalls

- Sediments goes into free-fall, gravity acts on it; big talus slopes pile up on the bottom

Rock slides

- Motion along a shear plane, coherent block behavior is going downhill

Slumps

- Acting along a shear plane but rotation is involved; tend to be in modern soils; modern riverbanks; non-lithified rock, listric planes

1.7 Sediment-gravity flows | Turbidity, debris, grain flows

1.7.1 Derbis Flows

- Rocks have to already be broken for it to happen
- Most is sediment... 90% sediment 10% water for example
- Behaves cohesively; can carry huge things internally with them
- Has to have a trigger; extreme distances over low gradient slopes
- Thick, poorly sorted, lack internal layering in a given bed; chaotic in internal sorting; subarial typically; subaquial—more water making it more transported by the fluid
- Mud Slides are debris flow but dominated by mud size particles
- Volcanic regions with lots of ash are prone to mud slides

1.7.2 Turbidity current

- Driven by density differences
- Once sediemnt is suspended, flow continues due to gravity & inertia
- Becomes more dilute through time
- Flows can travel several thousands kms. even acorss low gradents less than 0.1 degrees. flow speeds can exceed 19 m/s and be sustained at 3-10 m/s on gradients of just 0.2 to 0.3 degrees
- Good organization-bouma sequences; characteric succesion that suggest that turbidity is dieing out over time

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2.1 Turbidity Currents

- Bouma Sequences: 5 characteristics horizons (A-base, B, C, D, E top)
- Erosional base
- Laminated sandstone on the top like sheets of paper
- On top of that there are ripples
- On top of that laminated siltstone and on top of that laminated mudrock
- More water = more stratigraphical organization
- With increasing fluid content and progressively less particle organization debris flows can transform in turbidity currents
- A landslide off a shelf may start as a debris flow but end up as a turbidity current

2.2 Bedding and bedding planes

- Really thin beds (< 1cm) this are lamina
- 1-3 cm very thin beds
- 3-10 thin bedss
- 10-30 medium bed
- 30-100 thick bed
- 100 $<$ very thick beds
- Sometimes it is difficult to tell where the beds begin and end—amalgamated sandstone
- Mudstone (dashed lines), base of sandstone channel will be erosional or other times it will be sitting above the mudstone are called sharp; the first is sharp & erosive
- Things that are gradually changing through time are gradational
- you can have a really thick bed that is laminated inside
- Weathering profile: where beds are—how resistant they are to weathering and erosion
- Walls the are steep are mostly held up by sandstones (like vertical walls)
- Less steeps slopes are mostly held up by mudstones

- Within a profile we pay attention to: bed thickness, lateral continuity, nature of the contacts between beds (sharp vs. gradational), and internal grading or structures
- Internal grading—coarse to fine inside the bed
- Normal grading is where older and coarser sediments are on the bottom of the bed
- Inverse grading is the opposite—debris flows

2.3 Bedforms

- Form on beds
- Natural self organizing agent
- Through time they self organize and end up with equidistant spacing
- Tend to get larger and more organized through time until a dynamic equilibrium—might change where they are the structure, spacing, height is fixed

2.3.1 Bedforms: ripples

- 0.5-3.0 cm
- Small and have a λ of 5-20 cm
- Stoss & lee side
- Sand grain will start it journey on stoss side and hop its way thorugh saltation and bedload transport to the top of the dune crest
- Stoss side is $10 - 15°$ of steepness
- Then they begin to pile up on to the top and suddenly they fail and avalanche down
- This keeps happening through time—why ripples migrate downflow
- Dunes work the same way
- Geometry of the lee side—steep towards the top and tangential towards the bottoms
- Can help us figure out which way is up

2.3.2 Lower Plane Beds

- Stuff that is left behind that is transported by bedload in a river
- Grains that are not moving very quickly, crude horizontal stratification
- Imbrication—-particles with long axis sticking on top of each other to show direction of flow—tilt in direction of flow
- In low flow velocities
- Imbrication is good to look at which way rivers flowed in the past

2.3.3 Dunes

- Height—more than a few cm to 10s of m
- λ — 10s of cm to 100s of m

2.3.4 Upper plane bed

- Taking sediment moving so quickly that it becomes a sheet
- High flow velocities form nice bevels, laminated surfaces
- Internal lamination, planar bedding
- Parting lineations—little eddies that form (tiny currents) taking individual sand grains that make tiny piles of grains
- Two little eddies that create stripes in the rocks—not very tall (tiger stripe appearance)—parallel to the flow direction

2.3.5 Antidunes

- Dune migrates the opposite way, upstream
- Rare and hard to diagnose

2.4 Two Kinds of Ripples

- Current (asymmetric) Ripples: formed by a current with a preferential flow direction: you can see the asymmetry moving toward the short side of the ripple
- Oscillation ripple (symmetric)—flows goes in and out, happens in tidal environments
- Side view is ripple cross-lamination
- Straight ripples mean flow velocity is lower creating tabular cross bedding

- sinuous the top of the dune is not straight creating trough cross bedding
- Over time you end up shaving off the tops and we get them stacked on top of each other—lee side is typically the only thing preserved in the rock record
- We get sets of cross strata and they will accumulate through time
- Tabular because the planes between the sets is a flat line
- In contract to trough cross bedding—makes a big U/smiley shape, convex up U shape dishes

2.5 Flaser Bedding

- Ripples with but mud + sand
- Heterolithic combination of the two
- Sand from flood tide being worked into little ripples and as the tide goes out it deposits a little layer of mud (from ebb tide)
- Depends on the amount of sand vs mud in the system: sand dominated is flaser, equal components is wavy, dominated by mud is lenticular
- Flame structures— sand is loading into the mud and get little triangular shape flames—deformation feature associated with loading wet sediment

2.6 Dish Structures

- De-watering structures—trying to migrate its way up through the sandstone that create these little smiley faces—monolithic typically

2.7 Ball and pillow structures

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2.8 Bounce Marks

- Some twig or rock that is just bouncing along the bottom almost form short parallel dashes

2.9 Groove Casts—continuous dragging

- long linear line that is being put in the bottom of the channel and sediment fills it in
- Usually seen on the bottom of the bed

2.10 flute Casts

- Bulbous end to them that gets speared out
- Bulbous end to the fan is the direction of flow
- Caused by stone sitting on channel bunch of sediment that is accumulating on it and a divit on the other side

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3.1 Cross Strata

- Scoop like shapes on the bottom—forms trough crossbeds
- Much lower flow velocities to create tabular crossbeds
- Tabular crossbeds and looked like foresets on top of each other
- Foresets dip in different directions in trough crossbeding it is forming troughs so it is either coming out towards you or away from you

3.2 Beds can be internally

1. Parallel beds/laminated—upper planes bed often leave behind laminations
2. Graded—sedimentation units characterized by distinct vertical gradations in grain size—flow velocities can lift the easiest ends up on top—normal and reverse
3. Massive—beds appear to be lacking internal structures. Rare. could be due to secondary processes, such as extensive bioturbation or liquification of sediments
4. Cross-bedded—migartion of ripples or dunes

3.3 Climbing ripples

- Forms when deposition takes place very rapidly during migration of current or wave ripples.
- Ripples climb on one another
- Point bars, flood plains, river deltas

3.4 Hummocky cross-stratification

- Marine realms—sometimes large lakes
- Characterizied by upward cross stratification over lain by concave down cross lamination
- Eye shape in the geological record
- Bottom part is swale and top is hummock
- Storm deposits, hollow up a little hole in the floor (swale) and drape it over with more sand (hummock)6

3.5 Convulated Bedidng

- Slump, ball in pillow, flames in the bedding
- Jumbles up, high pore pressure

3.6 Sole marks

- Groove casts- elongated nearly straight ridges
- bidriectional indicator
- Flute Casts- unidirection paleocurrent indicator

3.7 Raindrop Imprints

- Way up indicator

3.8 Mudcracks

- Polygon patterns concave shape way up indicators
- V shapes in between always taper downwards

3.9 Parting Lineations

- Bidirectional paleocurrent indicator

3.10 Rip up clasts

- Fine grain muds encased in sandstones
- Rivers moving downstream canabalizing mud that was deposited

3.11 Trace Fossils

- Evidence of life but not fossils of organic matter
- If you see big dinosaur prints you probably arent in the middle of the ocean during that time period
- Agael mats that are sticky with sediment of on top and it builds up agael mounds through time (stromatolites)—can be really small or big but are characterized by fine laminations
- Angle repose—to steep for sand to be doming up on the sides—tells us there is a biological, domal structures with internal laminations—oldest evidence of life on earth

3.12 Trace Fossils and Ichnofacies

- Assemblages of a specific depositional environment traced fossils (ichnofossils)
- Not fully lithified rock
- recurring assemblage of trace fossils indicative of specific enironmental conditions
- Skilithos: ichnofacies found in high energy shifting sands; dominated by vertical or U-shaped dwelling burrows, really shallow water
- Cruziana: found in lower-energy environment—offshore, offshore transition—happens on the bedding plane (cruises across the bedding plane), needs a calm place to not blow itself off the plane
- Zoophycos: enigmatic multi-tiered feeding burrow with large lobes radiating from a central shaft
- Nereites:

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4.1 Ternary diagrma

- Big triangle A, B, C
- Percentage graphs, middle is 33% all around
- Lithics: rock fragments
- Amount of matrix: big kinds of grain vs. little dominating matrix

4.2 Rock name- first thing to know

- Mudstone/shale- tiny stuff
- Sandstone-medium stuff
- Conglomerate/breccia-big stuff
- Wacke = matrix-rich sandstone

4.3 Shales and Mustones

- $>$ 50% siliciclastic grains less than 0.062mm
- Shales and mustone are abundant, about half of all sedimentary rocks
- Shales are laminated
- Mudstones are nonlaminated, non structured internally
- Laminations represent suspension load is deposited out when velocity is 0
- Have high organic compounds

4.4 Siliciclastic rocks

- Where they came from and what they have been through
- Composed of particles derived by the weathering breakdown of older rocks, plus any minerals that form in-situ
- Allogenic- transported to its present position from elsewhere
- Authigenic- formed in its present position

4.5 Crust Composition: Minerals

- Common silicate minerals
- Common non-silicate Minerals
- 3000 minerals but 10 account for 90% of the crust

4.6 Crust Composition: rock type

- 60% feldspart, 25% quartz
- Quartz is more resistance to weathering because it likes being close to the surface

4.7 Conglomerates and Breccias

- conglomerate- sed. rocks that contain a substantial fraction (at least 30%) gravel
- Beccias- the gravel fragments are verya mgualr
- Particle Composition: Monomict or Oligomict conglomertates—single clast type
- Polymict conglomerates: many kinds of clasts
- Classification- class supported: touch and form a supporting framework
- matrix-supported-supported in a mud/sand matrix

4.8 Cheat Sheet

- mudstones: if massive, mudstone. If lanminated, shale
- sandstones: include quartz arenite, arkose, lithic arenite. Could use wacke or matrix rich as a modifer
- Conglomerates (rounded) breccias (angular): monomictic/polymictic, clast supported/matrix supported, conglomerate/breccia
- Rock description: color, texture - including grain size, roundness, and sorting, cement and/or matrix materials, fossils and accessory minerals, sedimentary structures, porosity, post depositional diagenetic features

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5.1 Sediments

5.1.1 Headwaters

- boulders
- cobbles

5.1.2 Floodplain: Sediments

- Sand
- Mud

5.1.3 Coast: Sediments

- As velocity of the river goes to 0, velocity goes to 0
- Creates a delta
- Primarily composed of sand and mud

5.1.4 Continental shelf: Sediments

- carbonate buildups in these shallower waters

5.1.5 Continental slopes: Sediments

- Slope failure here
- creates turbidites of sand & mud

5.1.6 Abyssal Plain: Sediments

- Mud particles that have fallen from the surface

5.2 Chemical Processes

5.2.1 Headwaters

- Quartz, feldspar, micas

5.2.2 Floodplains

- Feldspar's and mica's mainly break down into clays
- Lots of quartz and lots of clays—lots of chemical weathering
- Ions—sodium, calcium, potassium

5.2.3 Coastal

- Clays and quartz

5.2.4 Continental Shelf

- Lots of ions too—go into the carbonates (Ca, mg incorporated into these rocks)

5.3 As you go deeper/more transport

- Grain Size: decreases
- Rounding: increases
- Sorting: increases
- Compositional maturities (Qtz): increases
- Textural maturities (sorting, rounding, matrix): increases

5.4 Once deposited, how do we go from sand to sandstone

Once deposited, they have holes (pore space)

- Porosity—how much empty space is there between grains)
- Permeability—how interconnected are the spaces

5.5 Lithification

- Sediment + compaction (via burial) + cement (calcite or silica)
- Sedimentary rock give sufficient time
- First compaction—squeezes out water
- Precipitation or addition of new minerals cement

5.6 Metamorphism

Most basins have geothermal gradients 20-30 C/k so about 8km. This is a metamorphic environment

6 Carbonate

- Most carbonate sediment is produced in the shallow and tropical marine environments within a few tens of meters from the water surface
- Physical, chemical, and biological sediments—you need to be in the photic zone so organisms can photosynthesis which is faciliated by warm shallow water
- Warm and shallow waters help keep carbonates from dissolving
- Clastics enter the marine setting because velocity goes to 0
- 90% of the time carbonates form in-situ (locked in place)—precipitating in place
- Need to get salt/ions out to the ocean—restricted to shallow marine environments
- Carbonic acids sprinkle down onto silicate minerals → hydrolysis creates carbonate rocks
- Or transported through rivers → settles and forms
- Grain size and energy have nothing to do with eachother in the carbonate realm

6.1 Vertical facies

- If we see changes in facies in vertical succession (sandstones into mudstones into shales): we can determine what sea level is doing
- More complicated in marine world because organisms want to go towards sunlights

6.2 Lithification differs

- Clastics remain unconsolidated until they are deply buried
- Carbonates often cemented on or just below seafloor during early burial
- Can build up really dramatic angles and slopes that you can't get in clastic rocks—Steno's laws don't always work here

6.3 Mineralogy differences btw clastics and carbonates

- Calcite $CaCO_3$ Stable at the surface
- Most shells are made out of Aragonite (same chemical formula) but different physical structure—favored in modern ocean—unstable on surface so transitions to calcite
- Dolomite $CaMg(CO_3)_2$: Not common today—very common replacement mineral—calcite becomes dolomite during diagenesis

6.4 Mg rich Sea

- In Calcite (shouldn't incorporate Mg), cation radius is similar in these two elements so high magnesium can replace calcite creating high-magnesium calcite

6.5 Identifiying

- Most carbonates either have matrix or cement between grains
- Pore space between allochems (grains) is either filled by a matrix fine-grained micrite (carbonate mud) or by cement of precipitated calcite/aragonite
- Microcrystalline calcite or micrite- carbonate mud or lime mud. texturally analogous to the mud in siliclastic sed rocks, but composed of fine grained calcite—dull, opaque, grew brown
- Sparry Calcite- Large crystals of clear to white calcite (0.02-0.1mm) that appear clear to translucent in plane light)

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- Micrite: carbonate mud, or lime mud. dull, opaque, grey-brown
- Sparry Calcite-Large crystals of clear to white calite (0.02-0.1mm) that appear clear to translucent in plane light (disco ball)
- Micrite looks almost like clastic mud just made of carbonates
- You can break down organics into this mud
- Another way is chemically precipitate calcium carbonate out of the sea water from microorganisms
- Lots of plankton in the ocean—whitings of plankton blooms precipitate out of calcium carbonate
- micrite = lower energy environment
- sparry calcite cement: mud is removed and replaced with spar cement because of higher energy environments
- primarily dealing with calcite, aragonite, and dolomite—unlike clastic rocks we have a huge compositional diversity in grains, known as allochem
- What are the allochems made of? How many grains are there vs cement/matrix?
- Allochems are largfewr than 0.25 mm within a carbonate rock—can be transported or occur in-situ
- Made mainly of fossils but there are 5 types

7.1 Allochem type

1. Skeletal fragments: bioclasts—marine invertebrates, algae, and protists—whole mirco/mega fossils, broken shell fragments—Depositional environments, age of rocks is why fossils are important
2. Coated grains: ooids (<2mm) & pisoids (> 2mm)—spherical grains with concentric layers of calcite/aragonite around a central nucleus (grain of sand/tiny shell)— formed in shallow, high energy environments, supersaturated calcium carbonate in the water—nice spherical concentric rings are formed by rolling around due to waves on bottom
3. Peloids: Rounded (but not usually round) sand-sized grain (<2 mm) composed of structureless micrite (carbonate mud)—formed in many different ways—lower energy environments (lagoons are common)
4. Aggregates (or grapestones): lower energy conditions—aggregates of grains (usually ooids) cemented by microbial activiy—mud/silt winnowed but sand grains stable enough to allow microbial colonization

5. Clasts: Two types—intraclasts (from area of deposition) and extraclasts (from older rocks)—analogous to rip up clasts in clastic rocks. Often indiate storm reworking of cemented strata (which happens early in carbonates)

7.2 How to Detmine—Folk Scheme

1. Mud or cement
2. What are the grains
3. Give it a name

7.3 Dunham Scheme—better classification

1. Does it have micrite or sparite
2. How many grains relative to the other stuff—less than 10% grains it is a mudstone (call it a micrite)—more than 10% grains it is a wackestone (allochems aren't touching each other floating in the matrix)
3. If the individual grains are touching and have micrite between them it is a packstone
4. If the grains are touching and they have sparite inbetween them it is a grainstone
5. Finally, if the skeletal fragments are growing in place and haven't moved (large piece of coral)—calcium carbonate pieces are bound together from life activity it is a boundstone

7.4 For this class:

- For example: Trilobite Wackstone, Ooilitic grainstone
- Default naming scheme

7.5 Chalk

- White, fine grained
- Made up of cocoliths and forams—little plankton critters (made of $CaCO_3$)
- Low energy environment—deeper marine systems

7.6 Coquina

- Loosely cemented fossil hash
- Not much mud or cement

7.7 Travertine

Hot water calcium carbonate—common in building materials—water cools down and calcium carbonate precipitates out

7.8 Tufa

Cold water, in lake systems

7.9 Speleothems

- Cabe carbonates
- Stalactites—celing
- Stalagmites- bottom