Sedimentology and Stratigraphy **Lecture 1: Introduction to the course and basic clastic lithologies**	**Materials needed:** Large Post-it notes Grain size cards Laminating material Good examples of: • Sandstone • Shale • Breccia • Conglomerate

Goals of the lecture:

1. **Students should know my philosophy of the course and where we're headed.**
2. **Students should be able to make key observations on basic clastic rock types and first order interpretations from them.**

Estimated time	Outline
15 minutes	I. **Think-pair-share:** what *is* sedimentology/stratigraphy and what do you expect to learn in this class? Read through syllabus afterward.
20 minutes	II. How this course has been re-vamped A. My philosophy for changing the course B. Go over the course concept map: point it out and briefly summarize projects.
45 minutes **10 minutes**	III. Basic clastic lithologies A. Gallery walk activity (see below) B. Summarize in mini-lecture

Lecture notes

Activity(ies)

Exercise: Basic clastic lithologies

Goal: make key observations of sandstone, shale, breccia, conglomerate

Give them grain size cards for this exercise.

Do this as a gallery walk: each group will have 2-3 minutes each and must make as many observations as possible. Can modify other observations if necessary. Come back and summarize their initial poster.

Cycle around a second time and make an interpretation or a guess at some type of place on earth where this rock might form of each rock. Then summarize at end.

Basic Clastic Lithologies Galley Walk

	Observations	Interpretations
Station 1 Sandstone	• Sub-rounded grains, possibly fU or vfU • fL size • Light colored • Stratified (dark and light grain layers) • Dense • No rxn with acid • Crumbles off/soft	• Deposited far from source • More organic-rich environment during dep of dark layers • A current smoothed out the layers (too flat layers for a current?) • Compacted

Station 2 Breccia	• Large grain sizes (2-6 cm)
	• Angular grains
	• Quartz
	• Small sample:
	  ○ weathered
	  ○ Stratified clasts
	  ○ Clast supported Gray rock rounded with angular clasts
	• Pink sample:
	  ○ Angular with angular clasts
	  ○ Pores filled with cement
	  ○ No rxn with acid
	  ○ Clasts are dense
	  ○ Some pores in matrix
		• Deposited close to source
		• Source rock is sedimentary
		• One source rock
		• Fault breccia?
		• Clasts from depositional source that got broken down somehow and reformed
		• Original rock was fractured/ shattered and the matrix material moved through filling in the voids. Matrix [injection] may have been cause of fractures.

Station 3 Shale	• Size = vfL • Dark gray • Sparkly grains • Subangular to sub-rounded (this is for whole sample, not grains in the sample) • Smooth • Soft, breakable • Gritty when tasted; not that gritty • Brownish grey streak (not typically used for rx, only minerals) • No distinct cleavage • Conchoidal fractures • Turns clay-like on teeth • No rxn with acid • Fractures apart easily	• Slow moving depositional environment • Calm marine environment • Little oxygen (black)
Station 4 Conglomerate	• Large clasts, rounded • 4-5 cm clasts • elongated clasts • Grains in cement/matrix are mL size • Clasts have crystals in them • Conglomerate • No layers	• Traveled med distance from source • Turbulent/energetic environment (water) • Various rock sources (because of different clast types) • Slight imbrication suggest currents

	• Weathered • Well sorted; actually, very poorly sorted • FL matrix • No rxn with acid	

Lab 1: Basic sedimentary petrography Sedimentology and Stratigraphy	Materials needed: • **Set of five sandstone thin sections with variable compositions, sizes, etc.** • **Petrography observation sheets**

Goals of the lab:

By the end of this exercise you should be able to distinguish, in thin section, between framework grains, matrix, and cement. You should also be able to recognize a few different varieties of quartz and feldspar grains in thin section. Furthermore, you will begin to develop some of the observational skills that you'll require for further petrographic analysis of rocks.

Estimated time	Lab outline
5 min **10 min** **30 min** **20 min** **60 min** **15 min**	I. Put class into working pairs, one person with some petrographic scope experience, the other with less (or none). II. Give them each a thin section and 10 minutes for the experienced person to show the inexperienced person around a bit on the scope III. Hand out a petrographic description sheet and have them make observations of the thin section in their own words. A. They need to make as many observations as possible B. If they're stuck, make some suggestions about observations they can make. IV. Give them 20 minutes to prepare a presentation on their individual thin section. V. Each pair presents their thin section observations to the class. A. Require them to do a summary first, then get into details. B. Warn them that I may interrupt at any time to encourage discussion and to point out particularly important/relevant observations. VI. Take 10-15 minutes at end to summarize key points. VII. Assign chapter reading on this topic and a short write-up to accompany. VIII. Finally, give them each a Dierk's thin section and they have to describe it for their write-up of Jackfork lithologies; along with several hand specimens.

Lecture notes

I could give a lecture on sedimentary petrography and show you a number of significant features of sedimentary rocks in thin section. However, I'm not sure that this would be particularly effective if you hadn't already seen some of these features first and described them in your own words.

Part 1: In this exercise you and your partner will have some time to look over a thin section of a sedimentary rock and make as many observations about the thin section as possible. You should look at the thin section in plane and cross-polarized light, and it might not be a bad idea to hold the thin section up and look at the whole thing in the light of the room.

Things to look for:

1. Does the thin section have a distinctive overall color?
2. Can you distinguish grains from the surrounding material?
3. What shape are the grains?
4. How big are the grains? There is a micrometer on the sc
5. Describe the different grain types you see. Don't worry if you don't know what minerals they're made of; we will deal with this later. Just describe them using sketches and words.

At the end of the gallery walk

1. Should take notes
2. That these are most basic clastic lithologies
3. Know difference between grains/clasts and matrix
4. Understand something about cements versus matrix
5. Compositional observations
6. Textural observations

At the end of the petrographic lab

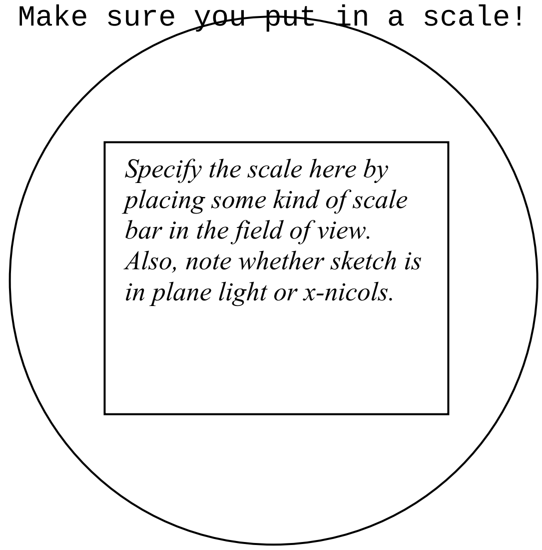
1. Matrix versus cement
2. Framework grains
3. Quartz, feldspar, lithics
4. Porosity
5. Mud matrix
6. Quartz overgrowths

Your name: ______________________________

Petrography worksheet

Sample ID:

Representative sketch of thin section
Make sure you put in a scale!



Overall appearance:

Describe, describe, describe: be detailed!!! Many of your descriptions of the overall appearance of the thin section were very brief, sometimes just a list of words ("uniform", "pink", "clear," etc.). Try to be more descriptive and use complete sentences. Pretend that you are describing the thin section to someone that can't see it and that they have to make a sketch of it from your description.

Compositional characteristics:

It would probably be more effective for you to divide this section up into a description of (a) framework grain composition; (b) matrix composition; and (c) cement composition. Again, a list of words probably won't do here. Be specific and do not be afraid to estimate percentages. For example, you might write:

Framework grain comp: ~70% quartz (monocrystalline); ~10% plagioclase (shows albite twinning); ~10% K-spar with tartan twinning; ~5% untwinned, altered feldspars (type unknown); ~5% other rock fragments (many look like the grain labeled "A" in the sketch above).

Matrix comp: comprises about 5% of the total thin section area. Looks like fine-grained, brown, granular masses, most likely a mix of clay and organic particles.

Cement: obscured by matrix, but may be quartz (some syntaxial overgrowths seen)

Textural characteristics:

Again, be specific. Give me actual sizes of grains here. You should try to estimate the average, min and max grain size.

You should consider using terms like "grain supported", "matrix supported", "poorly sorted", texturally mature, etc. Also, small, sub-sketches help considerably.

If there is a preferred orientation, tell me what has the orientation. Also, this orientation should show up in your sketch, above. The sketch that you make should show the textural characteristics you describe here.

Brief notes on using this worksheet

--Whenever you describe a thin section you should note the *scale* of objects. You will notice that there is a micrometer in your field of view on the petrographic microscope; taped to the side of each scope is a conversion chart for the scale of each micrometer unit (conversion to millimeters). Use it.
--Take care in your descriptions: Note whether you are you using any of the accessory plates. Is what you're describing visible in plane or cross-polarized light? What objective are you using?

Your name: ______________________________

-- "Overall appearance": hold the thin section up to the light (don't use the scope) and make observations. If you have the hand specimen that is the source of the thin section, make observations from it, too.
-- "Compositional characteristics": ask yourself "what is it made of?" Not just the entire thin section, but all of its component parts. If you don't know what it's made of, then describe it *really* well. You can use your description later when you meet up with an expert who can tell you what you're seeing!
-- "Textural characteristics": ask yourself "what shape is it? Do I see a preferred orientation or fabric? What sizes do I see?" Texture refers to the geometric properties of the thin section, not the composition.

Sedimentology and stratigraphy reading assignment #1

Consider what we have been doing in class up to this point: making observations of clastic sedimentary rocks in hand specimen and in thin section. Boggs, chapter 5, summarizes siliciclastic (*silici = silicate minerals, clastic = broken texture*) sedimentary rocks, their classification, major components, source terrain (provenance analysis), and alteration (diagenesis). Now that you have looked at the major siliciclastic lithologies, this chapter should serve as an effective review of what we've done so far, while adding some new information that we didn't cover. In particular, table 5.1 summarizes much of what talked about in class today.

> **Some foreshadowing:** on Thursday, you will be given the guidelines for the first course project, including some hand specimens and a thin section from the Jackfork Group (JFG). By Friday at 5:00 p.m., I expect that you will submit a write-up that describes the rocks of the Jackfork Group, using observations from the hand specimens, the thin section, and some information from a website that I have put together. I expect this write-up to make use of the material we have covered in class to date, but I *also* expect to see evidence that you have informed the write-up based on a reading of Boggs, ch. 5. For example, I didn't spend a huge amount of time on sandstone classification, but that doesn't mean that you shouldn't attempt to classify the JFG sandstones using the material on textural and compositional classification in the chapter.
>
> **Note:**
>
> - **What this means to you: the grade you receive on the write-up will be, in large part, determined by how effectively you integrate material from ch. 5 into your description of the JFG rock.**
> - **For clarification about grading, go back to the course syllabus and check out the grade rubric I will use to grade the write-up.**
> - **I do not want you to quote from the chapter or cite it as a reference. I want you to *use* the information in it to create a very thorough and complete description of the JFG rock units.**
> - **I would recommend reading the chapter before lab on Thursday, so that you can come to me with any questions you might have.**

Session 4: Bedding: lamina, lamina-set, bed, bedset	**Materials needed:** • **Powerpoint presentation of bedding** • **Boggs (ch. 4), pp. 88-96**

Goals of the session:

- **To be able to describe Jackfork Group bedding characteristics**
- **To be able to discuss possible interpretations of bedding contacts**

Estimated time	**Outline**
10 minutes	I. What is a 'bed'? A. Beds versus lamina B. Bedsets and truncation surfaces
10 minutes	II. Jackfork Group bedding style: using strat columns to depict A. Overview strat column B. Morris' strat column C. Outcrop photos and strat column from web site
15 minutes	1. Spend time describing in their own words: have them write
15 minutes	2. Go over descriptions: read some aloud
30 minutes	III. Discussion of contacts A. Conformable 1. abrupt: flat, wavy, irregular 2. gradational: progressive and intercalated B. Unconformable

Notes

- At this point, students should have solid knowledge of JFG lithologies. The issue now is: how do these lithologies stack up?
- They will need to know how to represent stratigraphy: strat columns
- They will need to know something about the difference between beds, bedsets, lamina, and lamina-sets
- They will need to know something about conformable contacts
- Do something with observation and interpretation of bedding styles.

Session: grain size
Sedimentology and Stratigraphy

Materials needed:

- **Sieve stack and shaker**
- **Mortar and pestle**
- **Clean paper sheets**
- **Weighing paper or boats**
- **Precision scales**
- **Sieve analysis form(s) & petrographic analysis forms**
- **600 ml beakers**
- **Sample bags**
- **Sharpee markers**

Goals of the session:

- **Students should be able to describe how to measure grain size using a simple sieve analysis (no pipette or hydrometer) and petrographically.**
- **Students should be able to describe how to statistically characterize the grain size of a sediment using both graphic and computational techniques**
-

Estimated time	Session outline
15 minutes	1. Discussion of measures of grain size
45 minutes	2. Go down to river and collect hand samples of the St. Peter vertically upward through the unit.
30 minutes	3. Come back, gently crush, and place samples in 600 ml beakers. Oven dry over lunch.
3 hours	4. Simultaneous: a. Each-one-teach-one sieving (each-pair-teach-pair) i. Show first pair how to do sieve analysis downstairs ii. That pair sieves its samples iii. That pair shows next pair how to sieve iv. Etc. v. Plot data as histogram and cumulative histogram vi. Use graphical techniques to estimate mean, median, mode, std dev. b. Petrographic measurement of long-axis grain lengths i. Outline method ii. Each person measures 30 grain lengths iii. Results go into one Excel spreadsheet iv. Calculate mean, median, mode, std dev. v. Plot data as histogram and cumulative histogram

Session notes	
Measures of central tendency • **The median** • **The mode** • **The mean** $$\bar{x} = \frac{\sum x}{n}$$	**Measures of variation or spread** • **The range: Max - Min** • **The variance and standard deviation** $$s^2 = \frac{\sum (x - \bar{x})^2}{n-1}$$ $$s = \sqrt{s^2}$$

Grain size homework: DUE THURSDAY, 9/18, BEGINNING OF CLASS

Read pages 59-74 in Boggs. The free, online text by Folk, pp. 29-40, is useful here too.

1. A very well-sorted sandstone has a mean grain size of 3.43ϕ. What grain size is this by the Wentworth scale?

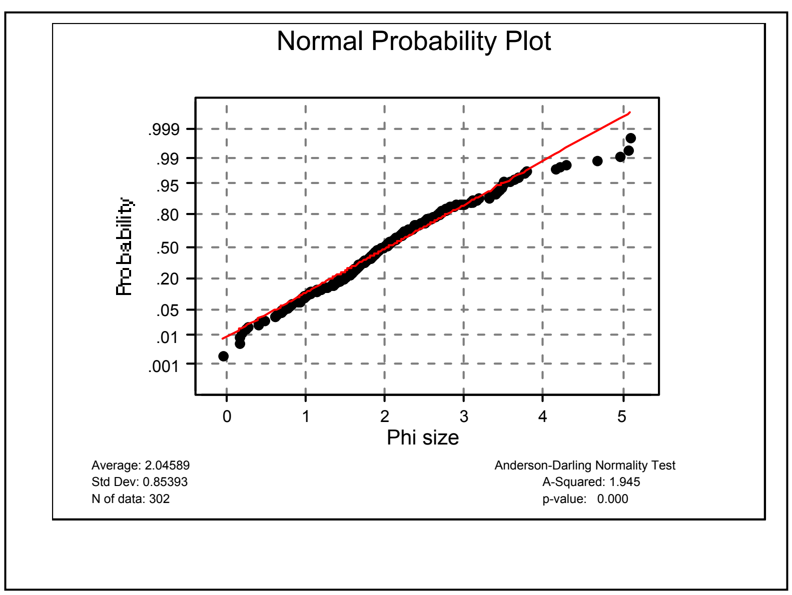
2. Fill in the blanks on the following table. **You must calculate the answers; do not read them graphically from a figure or table.**

Grain size (mm)	Grain size (microns)	Grain size (phi)
.025	25	5.3
	1823	
	392	
0.13		
		-4
1.7		
		1.21
282		
		0

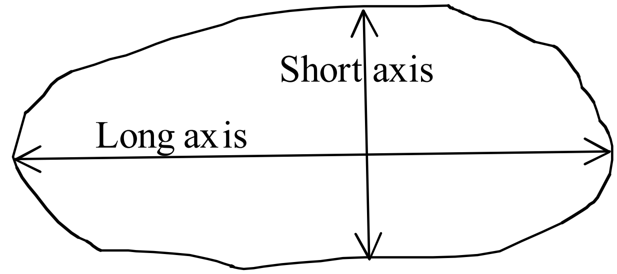
3. The plot on the right is a cumulative frequency plot (probability axis) of a sandstone sample like that shown on fig. 3.4 and 3.3d. Calculate the graphic mean and inclusive graphic standard deviation for this sample (based on Table 3.3).

Place your answers on the back and show your work!!

What term would you use to describe the sorting of this sample? (see page 69)



Petrographic measurement of grain size parameters



The long and short axes of a grain in thin section. In reality, the "short" axis is closer in length to the intermediate axis of a 3D grain.

For really hard rocks, you can't use a sieve technique to estimate parameters of the grain size distribution. You are faced with using another technique: the petrographic microscope and the stage micrometer. First, consider the shape of [most] sedimentary grains. They have a long, intermediate, and short axis. When you cut a thin section, you slice through the grain, so you only have two such axes to measure, a long axis and a short axis. It has been shown that the better axis to measure in thin section is the long axis: these measurements appear to be more reproducible between operators; maybe it's easier to see the long axis?

Second, it is important that you measure an unbiased sample. The way this is done professionally is to use a special attachment on the microscope stage that moves the thin section automatically across a grid pattern. You then measure the grain right beneath the cross hairs (or the one to the upper right, if the cross hairs don't land on a grain; or some such rule to remove bias). You will do this unprofessionally because I don't have 5 mechanical stages (I do have one).

What to do:

1. Look at the thin section, get it in focus, and make sure that you can read the micrometer. You should use the 10x objective and you should not change it while making measurements.
2. *Without looking down the scope*, nudge the thin section slightly about 3 mm or so.
3. Look down the scope and find the grain that intersects the crosshairs. If no grain intersects the cross hairs, pick the closest grain to the crosshairs in the upper-right quadrant of the field of view.
4. Measure the long axis length of this grain by using the micrometer. Record this value on the table below.
5. Repeat starting at #2, but nudge the thin section in a different direction. Try to make your nudges in directions that ultimately force you to look at the entire thin section.
6. Measure 30 grain lengths and convert these measurements to mm, then record these measurements on the group Excel spreadsheet (see me).

Measured length (micrometer units)	Measured length (mm)	Measured length (micrometer units)	Measured length (mm)	Measured length (micrometer units)	Measured length (mm)

Grain size plotting and statistics homework
Due: Tuesday (9/23) at the beginning of class.

For sieved data

1. Plot ϕ data as a histogram and as a cumulative histogram, both with percentage (probability) vertical axes.
2. Use graphical techniques to estimate the ϕ mean, ϕ median, and ϕ standard deviation.

For petrographically-derived data

After everyone collects their data, I will send the completed Excel file to you to complete the following:

1. Plot ϕ data as a histogram and as a cumulative histogram, both with percentage (probability) vertical axes.
3. Use Excel to calculate the ϕ mean, ϕ median, and ϕ standard deviation.

Have your plots and statistics ready to present to the class next Tuesday (9/23).

Session: The interpretation of grain size **Sedimentology and Stratigraphy**	**Materials needed:** • **Tape (to post graphs on wall)**

Goals of the session:

- **To develop a first-order understanding of the interpretation of grain size trends and grain size distribution trends**

Estimated time	Session outline

	1. *Graph du jour*.
	  a. Everyone posts their grain size data plots from previous exercise(s) and students look them over and critique them.
	  b. Derive the elements of a good data plot
	  c. How would we plot more than one sample from the same bed?
	2. Interpreting grain size data (read pp. 72-74 in Boggs)
	  a. Would like grain size to be a smoking gun for dep. environment, but it's not
	  b. Useful when applied carefully
	    i. Cohesive versus cohesionless fractions: presence/absence of clay
	    ii. Distribution versus tail-grading
	3. For Thursday: plot JFG grain size data
	  a. First, let's look over the database
	  b. As superimposed cumulative frequency curves
	  c. Mean and std dev next to strat column(s)
	  d. How does upper DeGray differ from lower DeGray?
	  e. How do mud-rich differ from mud-poor?

Session notes

- **Hand out homework assignment on DeGray grain size: using JackforkPetroDatabase from web site.**

Homework: Due at the beginning of class, Thursday, 9/25.

Using the Jackfork Group petrographic database (available from the course website: JFGPetroDataBase.xls), answer the following questions, using Excel graphs and text where appropriate.

Use the "Raw data example" worksheet tab at the bottom of the Excel worksheet for questions 1-3, as well as the strat column corresponding to the 8.8-11 m interval of my measured section.

1. How do the mean, median, and standard deviation (sorting) of grain size vary upward through the 8.8-11 m interval of the Lower DeGray spillway section?
2. How do the cumulative grain size distributions vary upward through this same interval?
3. Notice that the 8.8-11 m interval is an amalgamated bed, with sand-on-sand contacts within it. Are these contacts significant in terms of grain size? In other words, does grain size change substantially across these contacts?

For questions 4 and 5, use the "Summary petrographic database" worksheet tab on the Excel worksheet.

4. On average, is the Lower DeGray Spillway section coarser or finer-grained than the upper DeGray Spillway section? How does phi grain size differ between these two parts of the section? (Hint: sort on Upper or Lower Degray)
5. On average, are the mud-rich sandstones coarser or finer-grained than the mud-poor sandstones? How does phi grain size differ between these two general bed types? (Hint: sort on general bed type)

Session: Initial interpretation of the JFG at the DeGray spillway Sedimentology and Stratigraphy	**Materials needed:** • **Large Post-it notes** • **Pens and colored pencils**
Goals of the session: • **To begin the process of interpreting the JFG data available to the students.**	

Estimated time	**Session outline**
30 minutes **15 minutes** **15 minutes**	1. Using *all* of the JFG DeGray spillway data, observations, and write-ups that they've seen and collected to date, answer the following questions: a. What interpretations can you make that are supported by the data? b. How much can you actually say about the environment of deposition? c. Make a poster that outlines your interpretation(s) and the data that support it [them] i. This poster can be an outline, diagram, chart, text/prose, or some combination. Whatever works for you, but that conveys your ideas/interpretation(s) ii. Post the poster on the wall (maybe in the hallway) and we will all look them over and make comments using yellow stickies.
Session notes	

Session: Sediment gravity flow analysis Sedimentology and Stratigraphy	Materials needed: • Lock-exchange tank • Kaolinite • Mixing stick(s) • Salt • Bucket • Digital video camera with Firewire to mac • VideoPoint software

Goals of the session:

- **To analyze fluid flow and hypothesize about sedimentation from lock/surge type sediment-gravity flows**

Estimated time	Session outline
	1. Consider the JFG: a. episodic sedimentation b. always eventually fines upward to mud c. some sand beds fine upward d. mud in the matrix e. amalgamated beds f. a lot of massive beds g. marine fossils in the muds h. what do these things tell us? 2. Sediment-gravity flows a. What are they? b. Let's make some i. We will run two experiments of different composition ii. Make a prediction: which one will travel faster? iii. Make a prediction: how will velocity change at any given point in the flow? Near the lock, midway down, and near end of tank (ignore the reflected wave) iv. Make a prediction: how might sedimentation change at any given point in the flow? Near the lock, midway down, and near end of tank (ignore the reflected wave) c. What would happen to the flow as sediment concentration increased?

Session notes

- **Describe the experiment: what we'll do. Have students calculate:**
  - **Volume of lock exchange tank**
  - **Concentrations of the new fluids**
  - **Densities of the new fluid(s)**
  - **Hydrostatic pressure force at the beginning of the experiment**
- **Experiment 1: saline current with dye**
- **Experiment 2: cold water current with kaolinite clay (white)**
- **Experiment 3: cold water current with more kaolinite, dyed with food coloring?**
- **Use Videopoint to measure head velocities for each flow**

<table>
<tr><td colspan="2">Session: Grain size interpretation: detailed Sedimentology and Stratigraphy</td><td>Materials needed:
Overhead of JFG grain size trend, 8.8-11 m bed
Overhead of grain size distribution trend, same bed
Excel spreadsheet with plot of grain size dist trend (JFGPetroDatabase.xls)</td></tr>
<tr><td colspan="3">Goals of the session:
Understand difference between a bed and a sedimentation unit
Understand how to analyze grain size trends within a bed, as well as grain size distribution trends</td></tr>
<tr><td>Estimated time</td><td colspan="2">Session outline</td></tr>
<tr><td></td><td colspan="2">Bed versus sedimentation unit<ol type="a">
What does a typical bed look like
What does a typical sedimentation unit look like?
Vertical grain size variation in a bed: what does it mean?
Vertical variation in grain size distributions:<ol type="a">
Normal vs inverse grading
Tail vs distribution grading
Time to answer questions about project write up.</td></tr>
<tr><td colspan="3">Session notes</td></tr>
</table>