Sea Floor Sediments

Authors: Kristen St. John, James Madison University (stjohnke@jmu.edu); Mark Leckie, University of Massachusetts, Amherst; Megan Jones, North Hennepin Community College; and Kate Pound, St. Cloud State University.

Summary: This exercise set explores marine sediments using core photos and authentic datasets in an inquiry-based approach. Students' prior knowledge on sea floor sediments is explored in **Part 1**. In **Parts 2-3** students **observe and describe the physical characteristics of sediments cores** and **determine the composition** using smear slide data and a decision tree. In **Part 4** students **develop a map** showing the distribution of the primary marine sediment types of the Pacific and North Atlantic Oceans and **develop hypotheses** to explain the distribution of the sediment types shown on their map.

How Can I Use All or Parts of this Exercise in my Class?

(based on Project 2061 instructional materials design.)

	Part 1	**Part 2**	**Part 3**	**Part 4**
Title (of each part)	Sediment Predictions	Core Observations & Descriptions	Core Composition	Sea Floor Sediment Synthesis
How much class time will I need? (per part)	6 min.	30 min.	20 min.	50 min
What content will students be introduced to in this exercise?				
geographic awareness	X	X	X	X
marine sediments (distribution & controls on distribution)	X	X	X	X
What types of transportable skills will students practice in this exercise?				
make observations (describe what you see)		X	X	X
plot data - map, graph, pictorial form				X
form questions	X	X		
interpret graphs,		X	X	X

diagrams, photos, tables				
make hypotheses or predictions	X			X
synthesize/integrate & draw broad conclusions		X		X
work with diverse perspectives		X		X
written communication	X	X		X
making persuasive, well supported arguments		X		X
What general prerequisite knowledge & skills are required?	None	Basic geography; latitude & longitude	None	Basic geography; latitude & longitude
What Anchor Exercises (or Parts of Exercises) should be done prior to this to guide student interpretation & reasoning?	None	Part 1 & Intro to Cores Exercise	Parts 1-2	Parts 1-3
What other resources or materials do I need? (e.g., internet access to show on-line video; access to maps, colored pencils)	None	Core photos (can download see instructions in Part 2 #1)	None	Physiographic map of the oceans, colored pencils/pens and means of projecting a map (see suggestions in Part 4 #1)
What student misconception does this exercise address?	Sediments are the same across the ocean basin.			
What forms of data are used in this? (e.g., graphs, tables, photos, maps)	None – general knowledge	Table & photos	Table & photos	Map (& Table from Part 3)
What geographic locations are these datasets from?	General ocean	Pacific Ocean and North Atlantic Ocean		
How can I use this exercise to identify my students' prior knowledge (i.e., student misconceptions, commonly held beliefs)?	Part 1 of this exercise module is designed as an initial inquiry aimed at drawing out student beliefs and prior knowledge. In addition, Parts 2-4 often lead with tasks or questions that can further identify student prior knowledge.			

How can I encouraging students to reflect on what they have learned in this exercise? [Formative Assessment]	Each exercise part can be concluded by asking: *On note card (with or without name) to turn in, answer: What did you find most interesting/helpful in the exercise we did above? Does what we did model scientific practice? If so, how and if not, why not?*
How can I assess student learning after they complete all or part of the exercise? [Summative Assessment]	See suggestions in Summative Assessment section below.
Where can I go to for more information on the science in this exercise?	See the supplemental materials and reference sections below.

<u>Annotated Student Worksheets (i.e., the "Key"):</u> see following pages

Part 1. Sediment Predictions

1. What kinds of materials might you expect to find on the sea floor?

It is usefully to write these down for the group. For an introductory class expect answers such as dirt, sand, fish skeletons, clay, rocks, shells. It is useful to refer back to this in Part 3 when marine sediment composition is explored.

2. Do you expect any pattern to the distribution of these materials? Why or why not?

This question aims at getting students to think about what controls the accumulation of sediment on the sea floor. It is useful to keep a class list of responses to compare with later in Part 4.

Part 2. Core Observation & Description

In this exercise your teacher will assign you one or more cores from the **Table 2.1.** below and will prove you with a color photo of that core. Note that all of the cores in Table 2.1 are either core number 1, 2 or 3. This means that these cores are <u>at or close to the top</u> of the sediment sequence on the sea floor. Therefore the sediment in these cores represents modern or very recent environmental conditions at that location in the ocean.

Table 2.1. Sea Floor Cores

Core Identification: **Expedition-Site&Hole-Core&Type**	**Physiographic Location**	**Latitude / Longitude**	**Water Depth (m)**	**Reference**
Pacific Cores				
112-687A-2H	Peru continental shelf	-12.9/-77.0	316	Seuss et al., 1988
35-324-1	SE Pacific basin, North of Antarctica	-69/-98.8	4433	Hollister et al., 1976
28-269-1	Ross Sea, South of Australia, North of Antarctica	-61/7/+140.1	4282	Hayes et al., 1975
145-886B-2H	Chinook Trough, North Pacific abyssal plain	+44.7/-168.2	5743	Rea et al., 1993
145-882A-2H	Detroit Seamount NW Pacific	+50.36/-167.6	3243.8	Rea et al., 1993
145-881A-1	NW Pacific, East of the Sea of Okhotsk	+47.1/+161.5	5531.1	Rea et al., 1993
145-887C-2H	Patton-Murray Seamount, NE Pacific	+54.4/-148.5	3633.6	Rea et al., 1993
19-188-2	Bering Sea	+53.8/+178.7	2649	Creager et al., 1973
18-182-1	Alaskan continental slope	+57.9/-148.7	1419	Klum et al., 1973
33-318-2	Line Islands Ridge, south central Pacific	-14.8/-146.9	2641	Schlanger et al., 1976

8-75-1	Marquesas Fracture Zone, central Pacific abyssal plain	-12.5/-135.3	4181	Tracey et al., 1971
92-597-1	SE Pacific abyssal plain	-18.8/-129.8	4166	Leinen et al., 1986
178-1101A-2H	Antarctic Peninsula continental rise	-64.4/-70.3	3279.7	Barker et al., 1991
178-1096A-1H	Antarctic Peninsula continental rise	-67.57/-77	3152	Barker et al., 1991
178-1097A-3R	Antarctic Peninsula shelf	-66.4/-70.75	551.7	Barker et al., 1991
29-278-3	South of New Zealand	-56.6/+160.1	3675	Kennett et al., 1974
202-1236A-2H	Nazca Ridge, SE Pacific	-21.4/-81.44	1323.7	Mix et al., 2003
206-1256B-2H	Guatemala Basin	+6.7/-91.9	3634.7	Wilson et al., 2003
8-74-1	Clipperton Fracture Zone, central Pacific abyssal plain	+6.1/-136.1	4431	Tracey et al., 1971
136-842A-1H	South of Hawaii	+19.3/-159.1	4430.2	Dziewonski et al., 1992
198-1209A-2H	Shatsky Rise, NE Pacific	+32.7/+158.5	2387.2	Bralower et al., 2002
199-1215A-2H	NE of Hawaii, North Pacific abyssal plain	+26.0/-147.9	5395.6	Lyle et al., 2002
86-576-2	West of Midway Island, North Pacific abyssal plain	+32.4/+164.3	6217	Heath et al., 1985
195-1201B-2H	Philippine Sea	+19.3/+135.1	5710.2	Salisbury e al., 2002
130-807A-2H	Ontong Java Plateau, western equatorial Pacific	+3.6/+156.6	2803.8	Kroenke et al., 1991
181-1125A-2H	Chatham Rise, east pf New Zealand	-42.6/-178.2	1364.6	Carter et al., 1999
169-1037A-1H	Escanaba Trough, west of Oregon, N. California	+41/-127.5	3302.3	Fouquet et al., 1998

146-888B-2H	Cascadia margin, west of Vancouver, WA	+48.2/-126.7	2516.3	Westbrook et al., 1994
167-1010E-1H	West of Baja California	+30/-118.1	3464.7	Lyle et al., 1997
200-1224C-1H	North Pacific abyssal plain, South of the Murray fracture Zone,	+27.9/-142	4967.1	Stephen et al., 2003
127-795A-2H	Japan Sea	+44/+139	3300.2	Tamaki et al., 1990
28-274-2	North of Ross Ice Shelf, Antarctica	-69/+173.4	3305	Hayes et al., 1975
North Atlantic Cores				
37-333-2	Western flank of mid-Atlantic ridge	+36.8/-33.7	1666	Aumento et al., 1977
82-588-3	Western flank of mid-Atlantic ridge	+33.8/-37.3	3754	Bougault et al., 1995
172-1063A-2H	Northeast Bermuda Rise	+33.7/-57.6	4583.5	Keigwin et al., 1998
105-646A-2H	Labrador Sea, South of Greenland	+58.2/-48.4	3440.3	Srivastava et al., 1987
162-980A-2H	Rockall Bank, west of Ireland	+55.5/-14.7	2172.2	Jansen et al., 1996
152-919A-2H	SE Greenland, continental rise	+62.7/-37.5	2088.2	Larsen et al., 1994
174-1073-1H	New Jersey continental shelf	+39.2/-72.3	639.4	Austin et al., 1998
14-137-3H	Madeira abyssal plain	+25.9/-27.1	5361	Hayes et al., 1972

1. Find your core in Table 2.1. Note its location and water depth. Examine your core photo and make a list of observations and a list of questions about what you see:

*You will need to **print the photos** of the cores you want to use in this exercise. Refer to Table 1 and select all of these, or a subset to work with. If you choose a subset be sure to get examples of each of the sediment types and aim to get a broad geographic distribution. To download and print the color core photos go to: http://iodp.tamu.edu/janusweb/imaging/photo.shtml and entering the pertinent Leg-Site-Hole-Core information for the core of interest then clink on Submit Request. A link to the core photo requested usually pops up in a* *few seconds. These need to be printed on a color printer or viewed directly on a computer screen or projector.*

Anticipated Observations include: color variations and patterns, perhaps textures differences (e.g., large pebble mixed in mud), and may will notice cracks and/or missing intervals of the core.

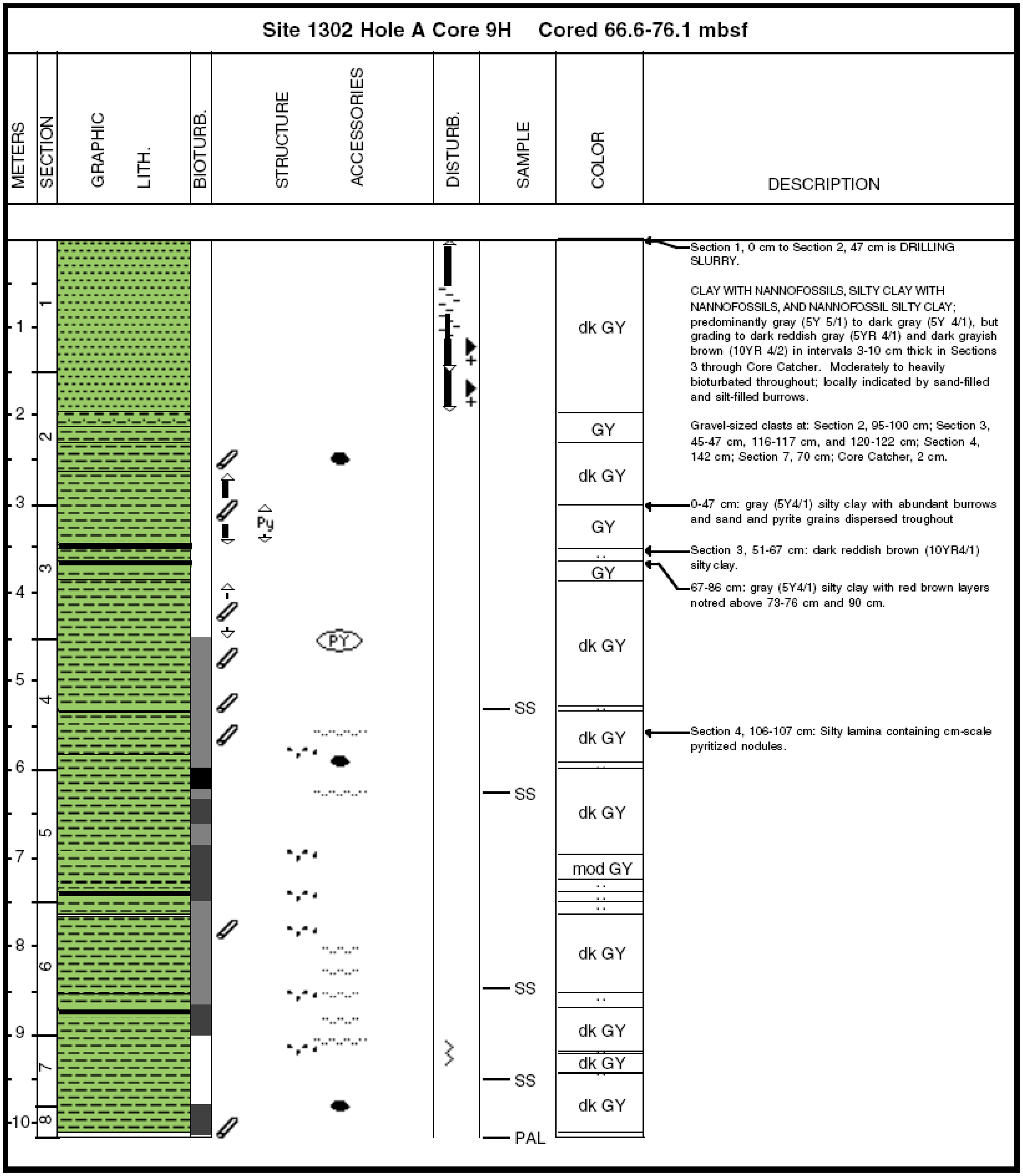
Anticipated Questions include:

- *What do the numbers and letters mean along the side of the core? Refer to the core identification nomenclature link in supplemental materials or to the Intro to Cores exercise.*
- *Why is this core so messed up (disturbed)? The drilling process itself can disturb the sediment in the cores.*
- *Why do the colors (or textures, etc) change? Students should be able to address this type of question as the exercise progresses.*
- *How old is this? Students should be able to address this type of question as the exercise progresses. (These are all recent sediments, Holocene or late Pleistocene).*
- *What is this made of? Students should be able to address this type of question as the exercise progresses.*
- *Where did this come from? Students should be able to address this type of question as the exercise progresses. See table 2.1.*

Note some of their questions may be of a practical nature and may be addressed right away, while others may be larger hypothesis-forming questions to compile and revisit later.

2. Design a way to **organize and record** your visual observations that could be used by all of the students in the class for all of the cores. This means you need to come up with categories (i.e., color) for your observations and also a means of recording them (i.e., all written, all sketch, some combination of the two?). Record your ideas below:

What you want to aim for here is something like the Visual Core Description (VCDs) sheets or a Barrel sheet that the scientists use when describing sediment cores. A VDC sheet usually is made for each section of core, whereas a Barrel sheet is the summary of all the VCDs for that core. An example of a completed Barrel Sheet is shown below. Notice that it has an area for a graphic representation (sketch) of the core as well as columns to make notes of particular characteristics along the side of the sketch – this way one can easily see at what depth in the core a special feature occurs. Symbols are used to represent different features. There is also an open space for written description. Notice that the written description includes the sediment type (e.g., Nannofossil silty clay, which is dominantly terrigenous *sediment with some calcareous microfossils too). In this activity students will have an opportunity to determine the sediment type by analyzing smear slide texture composition data and using a Decision Tree.*



3. Use the space below to describe your sediment core. Be sure to follow the template agreed upon by your class.

Encourage students to describe what they see. Depending on their background their description may or may not use sophisticated terminology. The level of description is up to you as the instructor.

To see the actually barrel sheets (the "key") for these specific cores, use the links provided in the reference section. *For newer core locations the visual core description sheets (or barrel sheets) will have a direct link. For older core locations, you will need to click on the Initial Reports link. Then for very old cores (e.g., DSDP cores) you will need to scroll through the pdf file until you see the core description pages which are usually near the end of the site chapter. In most cases the DSDP core description pages contain the smear slide composition data embedded in the page. For older ODP cores you will need to click on the Cores link to assess the VCDs and the Smear Slide link to access the smear slide composition tables.*

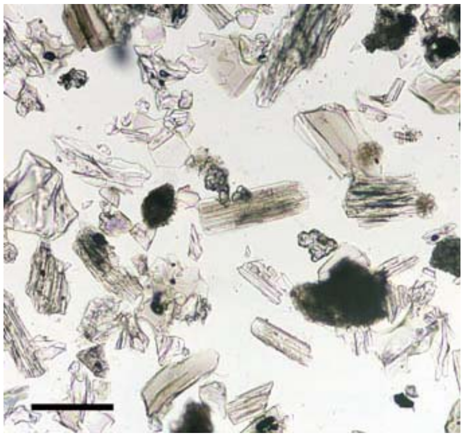
4. Using this activity as an example, explain the importance of a systematic, complete, and consistent method of recording scientific observations.

Shipboard sedimentologists are responsible for describing the geology of cores recovered from drilling into the sea floor. They provide the first complete description of the cores, so observation and classification are key aspects of what these scientists do. They describe the physical characteristics of the sediment seen on the split core as well as determine what type of sediment it is. This is important because the core description will be used (1) by scientists on the ship and at research institutions from around the world as a basis for sampling the core for detailed geologic study, and (2) for forming the first general conclusions about the environmental conditions and geologic history of that location on the sea floor. The shipboard sedimentologists have considerable responsibility to the scientific community at large for they are commonly the only scientists who have the opportunity to see all the cores from each of the sites drilled during an expedition. Thus, it is very important that they describe the geology in a manner that is both complete and consistent from expedition to expedition.[1]

Part 3. Core Composition

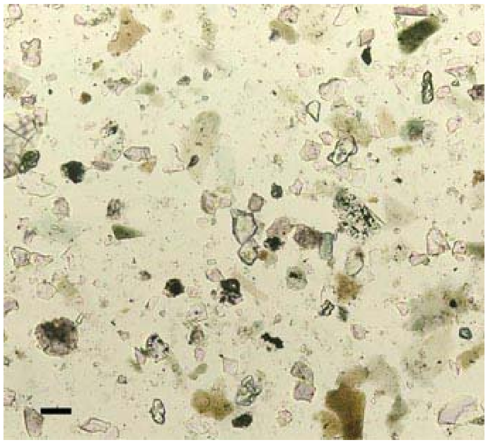
One core description category that typically *cannot* be determined from visual observations alone is **composition**. Composition can, however, be determined by examining a small (toothpick-tip sized) amount of sediment under a binocular microscope and matching the grains types observed to categories of known grain types. This method is called **smear slide analysis**[2]. Some of the main grain types found in marine sediment through smear slide analysis are **shown below** (all from http://www.noc.soton.ac.uk/gg/BOSCORF/curatorial/grain_id.html). These include minerals and mineral groups, volcanic glass, and microfossils.

Volcanic Glass, Minerals & Mineral Groups

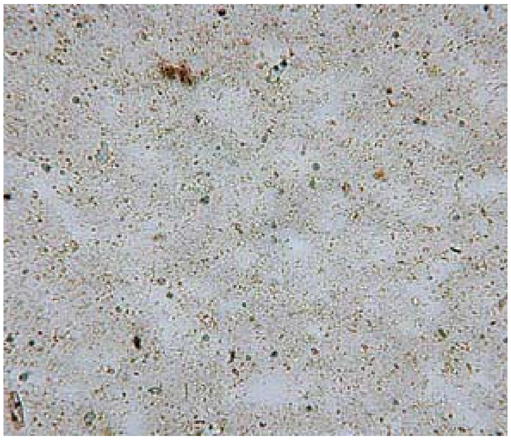


Volcanic glass. Bar scale= 0.05 mm

Feldspar mineral surrounded by volcanic glass. Bar scale= 0.05 mm

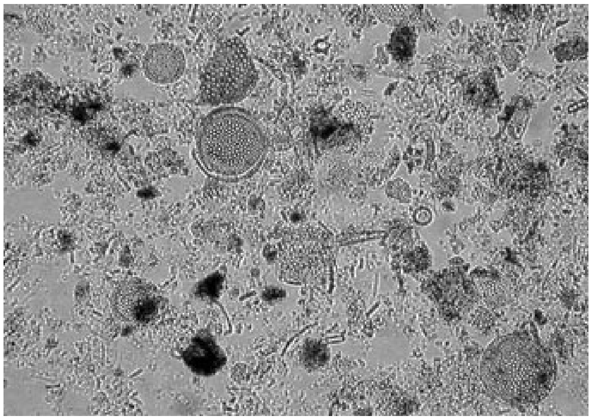


Silt-size minerals including green and brown biotite (mica) flakes.
Bar scale = 0.05 mm.

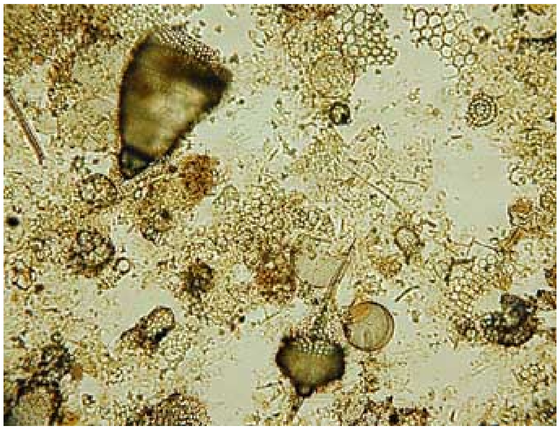


Clay minerals. Individual grains are under 4µm (0.004mm) in size.

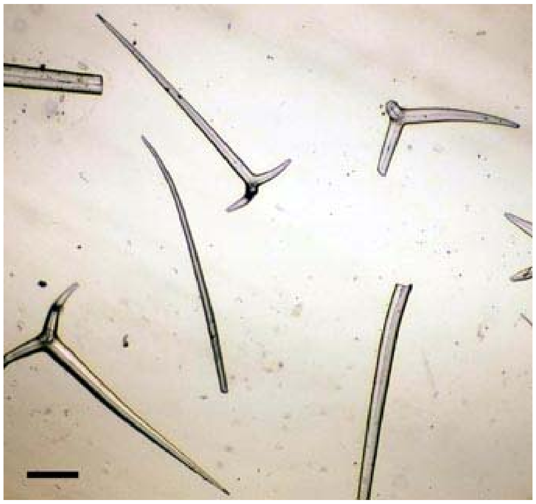
Siliceous (SiO_2) Microfossils



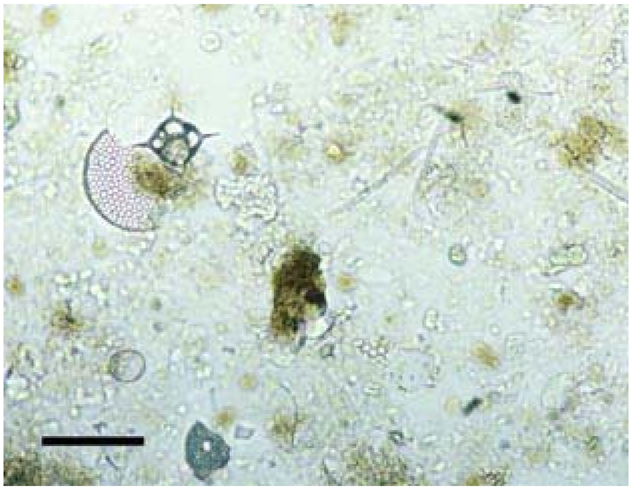
Diatoms (& clay). High power (x100) view.



Radiolarians with some diatoms (& clay). High power(x100)view

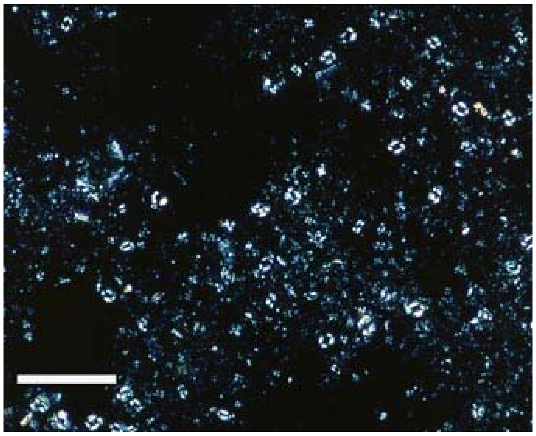


Sponge spicules. Scale bar = 0.05 mm

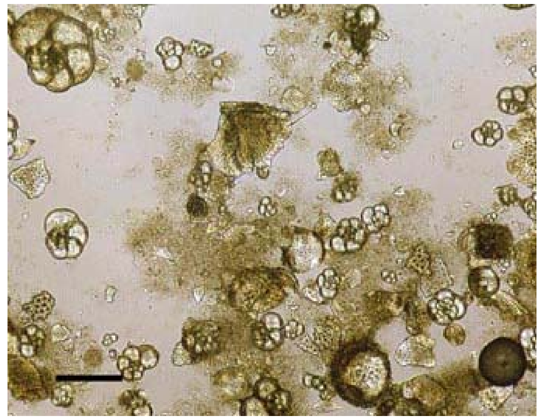


Silicoflagellate (top left) with diatom fragments, (& clay). Scale bar = 0.05 mm.

Calcareous ($CaCO_3$) Microfossils



Scatter of calcareous nannofossils (coccolith plates) seen in cross-polarized light. Note the black interference crosses shown by each plate. Scale bar = 0.05 mm.



Foraminifera (& clay). Scale bar = 0.05 mm.

Table 3.1. includes smear slide data for all of the cores in this exercise. This data includes estimated abundances of specific minerals & microfossils, as well as information on the texture (grain size) of the sediment in term of the relative percentages of sand, silt, and clay from specific places in the core. It s always a good idea to look at the core photo to see exactly where a smear slide sample was taken – samples may be taken of representative major sediment types, and other times samples may be taken from anomalous intervals. The composition and texture of the sediment will be the primary basis for determine the sediment type.

1. Use the Decision Tree (below) to determine the **type of sediment** in your core(s). Write the name of the sediment type in appropriate box in **Table 3.1.**. Add the sediment name to your Core Description (Part 2 #3).

For instructor reference, the names of the sediment types are provided in Table 3.1. *These names based on the choices from the Decision Tree. If you have access to a petrographic microscope you could expand this section of the exercise and request real smear slides for these cores to be sent to you from the Gulf Coast Repository: http://iodp.tamu.edu/curation/samples.html*

Decision Tree Notes:

- The decision tree aims to capture **end-member sediment types**:
  1. **calcareous ooze** (calcareous nannofossils and/or foraminifers)
  2. **siliceous ooze** (diatoms, radiolarians, sponge spicules, and/or silicoflagellates)
  3. **deep sea "red" clays** (may contain siliceous microfossils, fish teeth, Mn-Fe micronodules, and/or volcanic glass)
  4. **deep terrigenous sediment**
  5. **shallow terrigenous sediment**
  6. **glaciomarine sediment**
- In many settings the **sediment types can be mixed**, so it is possible to have a mix of microfossils and mineral grains. In this case the name could list the main components in order of abundance (most abundant listed last), for example a "siliceous clay", would be mostly clay minerals, but with a large proportion of siliceous microfossils. Be sure to note which component is most abundant and which component(s) are less abundant.
- If there is one **microfossil group that dominates** the composition, it is also appropriate to be more specific with the name, for example a siliceous ooze that is primarily composed of diatoms, could be more specifically termed a "diatom ooze".
- In any of the sediment types, but especially in biogenic oozes and deep sea ("red") clays, layers of **volcanic ash** may be distinguishable.

Decision Tree

For determining the dominant type of marine sediment based on smear slide data, visual core observations, and site characteristics.

Is the sediment >50% microfossils?

yes

It is a biogenic-rich sediment.

no

It is a non-biogenic sediment. Go to the next page.

Is it dominated by foraminifera and/or calcareous nanno fossils, OR is it dominated by diatoms, radiolarians, silicoflagellates, or sponge spicules?

forams, calcareous nannos

Sediment Type = **Calcareous Ooze**

diatoms, radiolarians, silicoflagellates, sponge spicules

Sediment Type = **Siliceous Ooze**

Non-Biogenic Sediment.

Is the texture and/or the mineral composition primarily clay (dust-size)?

yes

Is the drill site location in a deep basin or is it on (or near) a continental slope/rise?

Deep basin

Sediment Type = **Red Clay** (also known as Pelagic Clay, & Deep Sea Clay). Additional evidence is a red/brown sediment color, and sometimes black "spots" or nodules in the sediment, which are Mn & Fe mineral precipitants.

Continental slope/rise

Sediment type = **Deep Terrigenous Sediment**. Additional evidence may include fining-upwards sequences, sequences with sharp bases.

no

Go to next page.

Mixed grain size, primarily non-biogenic sediment.

Does the sediment contain isolated pebbles or gravel?

yes

Sediment Type =
Glaciomarine Sediment

no

Is this sediment on the continental shelf or the continental rise?

Continental shelf

Sediment type =
Shallow Terrigenous Sediment. (also known as Neritic Sediment, and Margin Sediment).
Some margin sediment may contain sea shells (mollusks), and tilted (cross)-bedding.

Continental rise

Sediment Type =
Deep Terrigenous Sediment
Additional evidence may include fining upward sequences with sharp bases.

Smear Slide Sample Identification	Texture (%)			Composition (%) Mineral Grains									Microfossils							Rock Frags./other				Sediment Names	Reference
Exp-Site&Hole-Core&Type-Section, Interval (cm)	Sand	Silt	Clay	Accessory Min.	Calcite/Dolomite	Clay Minerals	Fe Oxide	Feldspar	Other Minerals*	Mica	Quartz	Volcanic Glass	Calc. Nannos	Diatoms	Foraminifers	Radiolarians	Silicoflagellates	Sponge Spicules	Skeletal Debris	Carbonate Frags.	Organic matter	Nodules	Rock Fragments		
Pacific samples																									
112-687A-2H-1, 79	2	61	37	1	2	37		5			10		2	30	10								2	shelf terrigenous	Seuss et al., 1988
112-687A-2H-3, 69		80	20	2	1	19		23		2	35		5										10	shelf terrigenous (phosphare nodules)	
112-687A-2H-5, 61		45	55	10	2	17		5			13	1										37	5	shelf terrigenous	
112-687A-2H-6, 36		25	75	1		75					1	1		20										shelf terrigenous	
35-324-1-1, 120	none given					40					10			50										siliceous ooze	Hollister et al., 1976
35-324-1-2, 50	none given					85					10			5										red clay	
35-324-1-3, 100	none given					35	2				3			60										siliceous ooze	
35-324-1-6, 100	none given					97			1		2													red clay	
28-269-1-1, 134	none given				5	25					10			55		5								(clayey) siliceous ooze	Hayes et al., 1975
28-269-1-4, 37	none given					10					10		1	78			1							siliceous ooze	
145-881A-1H-1, 50	30	60	10								1	1		98										(clayey) siliceous ooze	Rea et al., 1993
145-881A-1H-2, 11	15	40	45			45			10					45										Mixed/glaciomarine (siliceous clay)	
145-881A-1H-2, 116	46	60						4			2	94												volcanic ash	
145-886B-2H-1, 39	2	10	88			81	2							4		3		10						red clay (with spicules)	Rea et al., 1993
145-886B-2H-5, 114	15	10	70			70	2	2			1			4		6		15						red clay (with spicules)	
145-886B-2H-6, 16	25	10	65			64	3							5		3		25						red clay (with spicules)	
145-882A-2H-2, 58	2	78	20			1						1	1	77				20						siliceous ooze	Rea et al., 1993
145-882A-2H-3, 34	2	85	13								1		1	78				20						siliceous ooze	
145-882A-2H-4, 80	20	75	5									1	2	96		1								siliceous ooze	
145-887C-2H-1, 75	10	82	8			7							1	72	4			10		6				siliceous ooze	Rea et al., 1993
145-887C-2H-3, 75	10	45	45			43					1			45	4	2				5				(clayey) siliceous ooze	
145-887C-2H-3, 85	3	92	5			5		2			1	92												volcanic ash	
19-188-2-1, 56	none given					25		5			5			65										(clayey) siliceous ooze	Creager et al., 1973
19-188-2-1, 120	none given					10		2			3			85										siliceous ooze	
19-188-2-2, 75	none given					10		5			5			80										siliceous ooze	
19-188-2-3, 75	none given					10		5			5			80										siliceous ooze	
18-182-1	no smear slide data																							deep terrigenous (clayey silt)	Klum et al., 1973
33-318-2-2, 67	none given						R						D		A				P	C				calcareous ooze	Schlanger et al., 1976
8-75-1-1, 100	none given					90			9						1									red clay	Tracey et al., 1971
8-75-1-3, 10	none given					10							90											calcareous ooze	
8-75-1-5, 10	none given					5							94		1									calcareous ooze	
92-597-1-1, 35	none given					85			13			2												red clay	
92-597-1-2, 110	none given					10			5				85											calcareous ooze	
178-1101A-2H-1, 80	1	60	39	1	3	50		8	1	2	15		4	5				2					14	deep terrigenous/glaciomarine	Barker et al., 1991
178-1101A-2H-2, 60	1	60	39	2	3	31		8	8	3	20			2	2			1					20	deep terrigenous/glaciomarine	
178-1101A-2H-2, 106	90	8	2		1	13		9		4	12			1	40			1					14	glaciomarine/(calcareous sand)	
178-1101A-2H-4, 61	1	75	24			5		12	20	4	18			2				1					30	deep terrigenous/glaciomarine	
178-1101A-2H-6, 61		70	30			8		12	13	4	18			10				6					20	deep terrigenous/glaciomarine	
178-1096A-1H-1, 0		30	70			60		5		5				30	1									deep terrigenous (siliceous silty clay)	Barker et al., 1991
178-1096A-1H-1, 130		20	80			80		5	6	5				1	1									deep terrigenous (silty clay)	
178-1096A-1H-4, 130		20	80			80		5	1	9				1	1									deep terrigenous (silty clay)	
178-1096A-1H-6, 30	1	25	74			74		10		15				1	1									deep terrigenous (silty clay)	
178-1097A-3R-1	all gravel																						100	glaciomarine/shelf terrigenous (diamict)	Barker et al., 1991
29-278-3-1, 127	none given					15							10	30	10	25		10						siliceous ooze	Kennett et al., 1974
29-278-3-CC, 0	none given					2			2				3	75		3		15						siliceous ooze	
202-1236A-2H,1, 75			100			14							57		25									calcareous ooze	Mix et al., 2003
202-1236A-2H, 92			100						R				57		29									calcareous ooze	
202-1236A-2H, 123			100						R				70		30									calcareous ooze	
206-1256B-2H-2, 113	20	16	64			100							89	9		1		1						mixed (calcareous silty clay w/ diatoms)	Wilson et al., 2003
8-74-1-1, 2	none given												55	10	35	10		<1						calcareous ooze	Tracey et al., 1971
8-74-1-5, 10	none given												5	10		75		10						siliceous ooze	
136-842A-1H-1, 27	10	50	40			40		17				23				2	1	1						red clay (silty clay with ash)	Dziewonski et al., 1992
136-842A-1H-4, 90		25	75	1		75		1				10				10		1						red clay (and deep terrigenous)	
136-842A-1H-6, 68	25	60	15	10		15		20	20			30				5								volcanic ash	
136-842A-1H-6, 130		52	48			18		1	1			1	30	6		30	10	2						(nannofossil radiolarian) ooze	
136-842A-1H-7, 20		22	78	1		78		7	2			5		2		3	1	1						red clay	
198-1209A-2H-1, 139	none given					21							70	2	5	2								calcareous ooze	Bralower et al., 2002
198-1209A-2H-5, 138	none given				1	13							80		5	1								calcareous ooze	
199-1215A-2H-1, 60			100			90			8	2														red clay	Lyle et al., 2002
199-1215A-2H-3, 100			100			90			9	1														red clay	
199-1215A-2H-CC, 0			100			90			10															red clay	
86-576-2-1, 7		5	95			85		1			4			1		3		1				5		red clay	Heath et al., 1985
86-576-2-2, 80	1	7	92			87		1			6					2						2		red clay	
86-576-2-4, 74	30	68	2			2		1			3	93										1		volcanic ash	
86-576-2-4, 110	1	1	98			94				1	1	1		1		2						1		red clay	

Smear Slide Sample Identification	Texture (%)			Composition (%)																				Sediment Names	Reference
				Mineral Grains									Microfossils							Rock Frags./other					
Exp-Site&Hole-Core&Type-Section, Inte	Sand	Silt	Clay	Accessory Min.	Calcite/Dolomite	Clay Minerals	Fe Oxide	Feldspar	Other Minerals*	Mica	Quartz	Volcanic Glass	Calc. Nannos	Diatoms	Foraminifers	Radiolarians	Silicoflagellates	Sponge Spicules	Skeletal Debris	Carbonate Frags.	Organic matter	Nodules	Rock Fragments		
Pacific samples																									
195-1201B-2H-1, 30		10	90			D		P	R		P	R												red clay	Salisbury e al., 2002
195-1201B-2H-5, 73		5	95			D		R	P		R													red clay	
195-1201B-2H-7, 85		10	90			D		P	P	R	P													red clay	
130-807A-2H-2, 74	10	60	30	2									75	2	20									calcareous ooze	Kroenke et al., 1991
181-1125A-2H-1, 49	25	30	45		P	R							D		P			R	P					calcareous ooze	Carter et al., 1999
169-1037A-1H-3, 80		C	A	R	R	A		R		R	C		R	R		R								deep terrigenous (silty clay; turbidites)	Fouquet et al., 1998
169-1037A-1H-5, 62	A	C	R		R			R	R	C	A			R				R						deep terrigenous (silty sand; turbidites)	
146-888B-2H-5, 99	70	25	5			5		10	33		5	25		2								15		deep terrigenous (silty sand with ash; turbidites)	Westbrook et al., 1994
146-888B-2H-6, 145		75	25			25		20	30			10	1	2							2	10		deep terrigenous (silty clay; turbidites)	
167-1010E-1H-3, 143	5	15	80			80		2	1			9											1	deep terrigenous (silty clay)	Lyle et al., 1997
167-1010E-1H-4, 110		10	90			80					2	10			3								5	deep terrigenous (silty clay)	
200-1224C-1H-1, 70		10	90			90										10								red clay	Stephen et al., 2003
200-1224C-1H-2, 2		5	95			95												5						red clay	
200-1224C-1H-3, 70		20	80			65										30		5						(siliceous) red clay	
200-1224C-1H-5, 1		25	75			50										45		5						(siliceous) red clay	
127-795A-2H-1, 84		10	90		2	60		5			10	15		2			1	1			1			deep terrigenous (clay)	Tamaki et al., 1990
127-795A-2H-2, 146		40	60			30						10		60										deep terrigenous (silty clay)	
127-795A-2H-3, 45		60	40			20		15			15	45		1										volcanic ash	
127-795A-2H-5, 81		40	60			60		10			20	10												deep terrigenous (silty clay)	
28-274-2-2,109	2	33	65		1	55		11	10		15			6				2						deep terrigenous (siliceous silty clay)/glaciomarine	Hayes et al., 1975
28-274-2-3, 86		25	75			60			1		1			35		1		2						deep terrigenous (siliceous silty clay)/glaciomarine	
28-274-2-6, 90		20	80		1	70		4	1		8			15				1						deep terrigenous (siliceous silty clay)/glaciomarine	
North Atlantic samples																									
37-333-2-1, 80	5	24	71										96		4									calcareous ooze	Aumento et al., 1977
82-558-3-3, 75	none given				2	9							87		2									calcareous ooze	Bougault et al., 1995
82-558-3-6, 75	none given				5	9							84		2									calcareous ooze	
172-1063A-2H-3, 62		40	60		R	D	T		T		A		C	R	T	T	T	R						(calcareous) red clay	Keigwin et al., 1998
172-1063A-2H-6, 66		25	75		R	D	T		T		C		A	C	T	T	T	C						(calcareous) red clay	Keigwin et al., 1998
105-646A-2H-1, 60	5	60	35		35	30					35													deep terrigenous (clayey silt)/glaciomarine	Srivastava et al., 1987
105-646A-2H-2, 87	5	85	10	5	5	10		10	5		65													deep terrigenous (clayey silt)/glaciomarine	
105-646A-2H-5, 33	10	55	35		15	25		5			35		3	10	2			5						deep terrigenous (siliceous clayey silt)	
162-980A-2H-1, 90	20	30	50	2		8				1	11		50	4	13	5		3						calcareous ooze	Jansen et al., 1996
162-980A-2H-3, 80	10	40	50			50			5	5	10		30											deep terrigenous (calcareous silty clay)	
162-980A-2H-6, 80	10	60	30	5		25		15	3	5	20		10		7			2					3	deep terrigenous (calcareous silty clay)	
152-919A-2H-1, 76	3	81	16			16		7	2		40	15				10		3					7	deep terrigenous/glaciomarine	Larsen et al., 1994
152-919A-2H-3, 18		85	15								2	69		4				10						volcanic ash	
152-919A-2H-4, 50		62	38			38		6	2		25	5	7	4				3					10	deep terrigenous/glaciomarine	
174-1073A-1H-1, 10	none given			2		23		14		2	20		20	4	5	5								shallow terrigenous	Austin et al., 1998
174-1073A-1H-1, 120	none given			2	1	39		12		4	20		8	1	8									shallow terrigenous	
14-137-3H-2, 90	none given					81	4		5	2		8												red clay	

*Other minerals includes opaques, phillipsite, phroxene, hornblende, and others
D= dominant, A= abundant, C= common, P = present, R= rare, T = trace

Part 4. Sea Floor Sediment Synthesis

1. Use the following color scheme to **plot** the sediment type of your core (from Part 3) on the class physiographic map of the sea floor. Through group effort, the class map should ultimately contain all of the exercise core locations in the Pacific (and North Atlantic Oceans) and their sediment types.

Blue = Calcareous Ooze
Yellow = Siliceous Ooze
Red = Red Clays
Purple = Deep Terrigenous Sediment
Pink = Shallow terrigenous Sediment
Green = Glaciomarine Sediment

You can use any physiographic map of the sea floor that has latitude and longitude coordinates along the edge. Hubbard Scientific sells a pad of 100 of these for $15. http://www.amep.com/standarddetail.asp?cid=1119

Suggested options for the class map:
(1) Use an ELMO (digital camera) projector to project the class physiographic map on to a screen. Students add their data to the map using colored pencils.
(2) Make a transparency of the physiographic map and use an overhead projector to project on a screen. Students add their data using colored transparency pens.
(3) Scan the physiographic map and print it on a large-scale plotter to map a poster size map. Students can use colored permanent markers to add there data to the class map.

2. Make a **list** of your observations on the distribution of each of the different sediment types. Consider factors such as distance from the continents, water depth, and latitude/longitude, among others.

Calcareous Oozes: Found on isolated highs (ridges, seamounts) in the deep ocean; not found along the continental margins.

Siliceous Oozes: Found in high latitudes and also at the equator; not found along continental margins; can be found in deeper water than calcareous oozes.

Red Clays: Found in the deep parts of the ocean basins (abyssal plains), away from continental margins.

Deep Terrigenous Sediments: Found along the base (continental rises, sediment drifts) of continental margins.

Shallow Terrigenous Sediments: Found very close to continents, on the continental shelf.

Glaciomarine Sediments: Found in high latitudes, can be found in shallow water near continents that have ice sheets and/or glaciers, but sometimes also in deep basins.

3. Based on your observations (#2), **develop hypotheses** for what controls the distribution of each of the sediment types in the ocean. By doing this you are attempting to *explain why* the different sediment types have the distribution shown on the class map.

Calcareous Oozes: need productivity in the overlying water column, need preservation of the calcium carbonate hard parts as this biogenic debris settles through the water column so the sea floor must be above the carbonate compensation depth (CCD), can't be diluted by terrigenous sediment input.

Siliceous Oozes: need productivity in the overlying water column – these do very well in upwelling zones where nutrients are brought to the surface waters, need preservation of the silica hard parts as this biogenic debris settles through the water column – shallow waters are undersaturated with respect to silica (but deep water is not), can't be diluted by terrigenous sediment input.

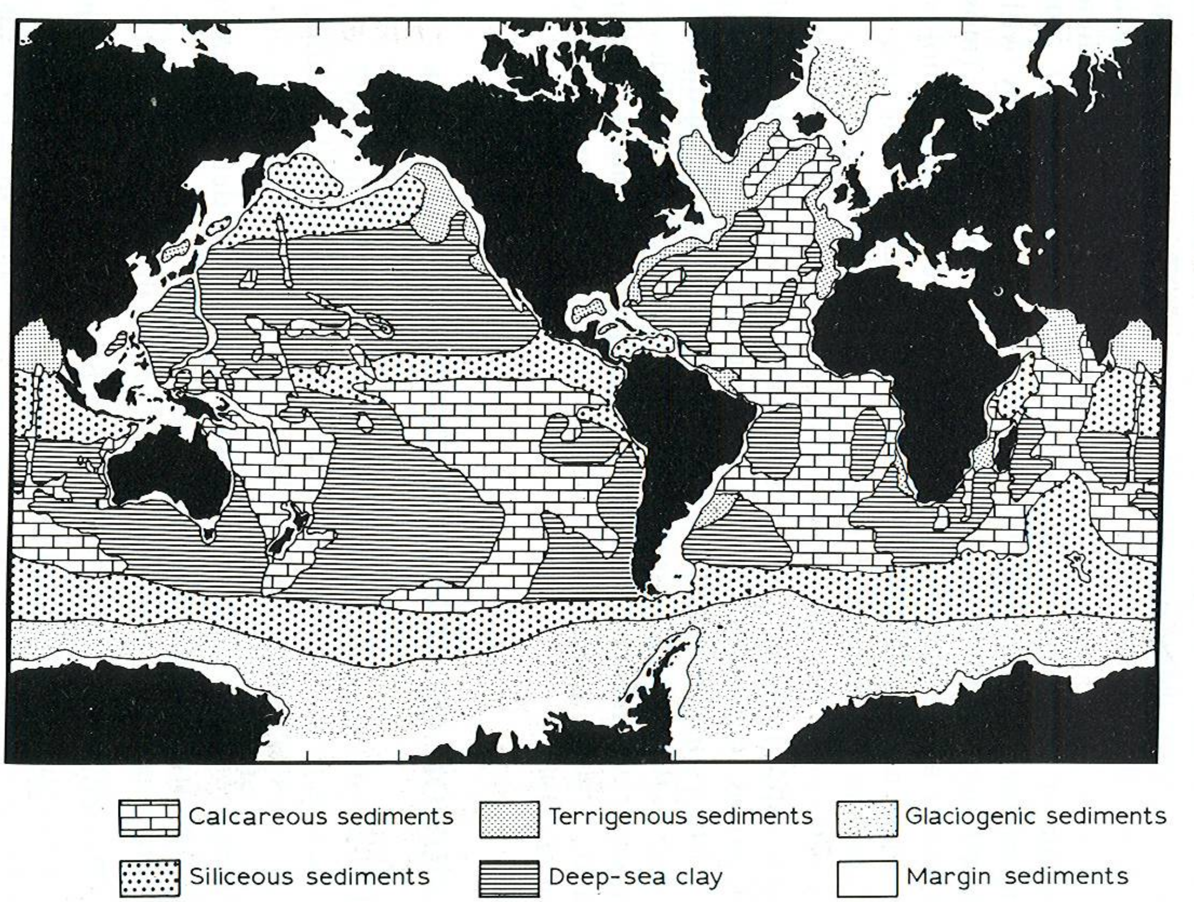
Red Clays: low sedimentation rates in the deep ocean far from land so that authigenic minerals precipitation can occur; down wind of "dust" supplying regions (e.g. deserts, loess fields), low biological productivity in overlying surface waters, and/or below the CCD.

Deep Terrigenous Sediments: High supply of weathering and erosion products from land which dilutes the input of other sediment types; being near a passive continental margin assures forming thick wedges of terrigenous sediment at the base of the continental slope, often associated with turbidity flows down submarine canyons. Active continental margins containing trenches will not have a continental rise of deep terrigenous sediment.

Shallow Terrigenous Sediments: High supply of weathering and erosion products from land which dilutes the input of other sediment types; transported to the continental shelf mainly by river system.

Glaciomarine Sediments: Depends on the transport of land-derived debris via floating ice (icebergs and sea ice). The expansion of glaciers and ice *sheets to sea level will result in glacial weathering and erosion products to be transported to sea, and released when the floating ice melts.*

4. Compare your class sediment distribution map to a published map of sea floor sediment types (e.g., see your text book, or see the map from Rothwell, 1989 distributed by your instructor). Are they generally similar? If not, where are the discrepancies? What might cause these discrepancies?



The map should look similar to the Pacific Ocean section of Rothwell's (1989) Sediment Type Distribution Map, shown above.

5. Compare the North Pacific and North Atlantic sediment distributions.

(a) In what basin are glaciomarine sediments more abundant? Why might this be the case?

These are more abundant in the North Atlantic because of ice-laden surface currents coming from the North which includes icebergs and sea ice from Greenland (only ice sheet in the Northern Hemisphere) and from the Arctic.

(b) Are calcareous-rich sediments in the North Atlantic found at the same depth, shallower depths, or deeper depths than in the North Pacific? Why might this be the case?

Calcareous oozes can be found at deeper depths in the North Atlantic. This is because the CCD is shallower in the Pacific than in the Atlantic. In the Pacific the waters are colder, older, and more acidic, which contributes to shallower CCD in the Pacific.

6. The map you constructed represents the modern distribution of sediment types in the Pacific Ocean. Do you think this map would also represent sediment type distribution in the geologic past and in the geologic future? What factors might vary (in the past and in the future) that could change the distribution of sediment types?

The map is not static for all time. Anything that affects the controls discussed in #10 above will result in a different sediment distribution pattern on the sea floor. As climate changes, ocean circulation changes, and as plate tectonics rearranges the seafloor and continents, the sediment accumulating on the sea floor will be influences by those changes.

<u>Summative Assessment:</u> There are several ways the instructor can assess student learning after completion of this exercise. For example:

(1)Students should be able to answer the following questions after completing this exercise:

The drill ship the *JOIDES Resolution* (Fig. 1) is used by the Integrated Ocean Drilling Program (IODP) to collect cores from the deep sea. Scientists study deep-sea cores to reveal clues to Earth history. Use the core photograph (Fig. 2) below to answer questions 1-4.

Figure 1. *JOIDES Resolution*.

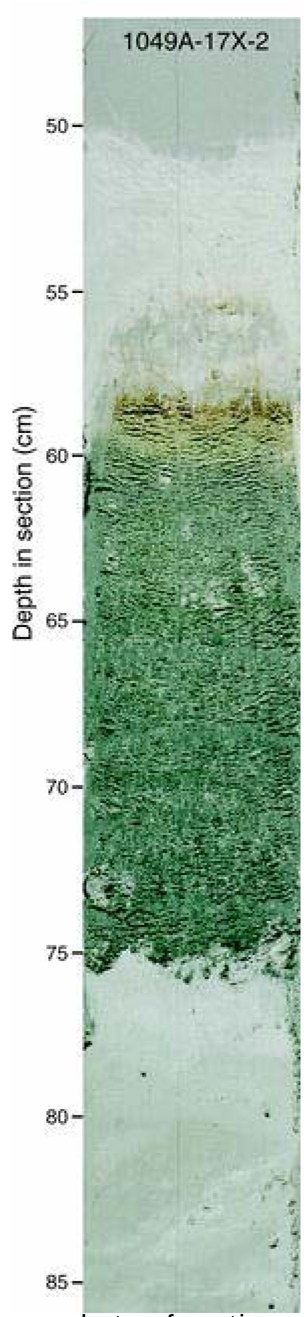


Figure 2. Close-up photo of section of split-core.

1. This core (Fig. 2) was recovered from drilling into the Atlantic Ocean seafloor east of Florida. Which of the following do you think are possible **sources of sediment** in this core?
    a. Remains of microscopic marine life
    b. Wind blown dust from land
    c. River transported sediment from land
    d. Material from outer space
    e. All of the above

2. Where do you think the **oldest sediments** are in this core section?
    a. At the top
    b. At the bottom
    c. At 75 cm depth
    d. At 58 cm depth

3. Which of the following is a reasonable hypothesis for what could have produced the **mottling** (i.e., variable color, splotchy appearance**)** in gray sediments between 80-85 cm?
    a. Mixing by burrowing animals
    b. Settling of suspended sediment
    c. Erosion by wind
    d. Erosion by water

4. Based on what you see the core section, what do you think the environmental conditions were like during the time this sediment was deposited?
    a. Unchanging
    b. Experienced a slow gradual change in environmental conditions
    c. Experienced a rapid change in environmental conditions
    d. Experienced a rapid change in environmental conditions (represented by the lower 10 cm of the core) followed by a return to similar environmental conditions (represented by the upper 3 cm of the core).

5. List **two** ways a core is **similar to an outcrop** (i.e., rock or sediment exposure on land along a road or stream) and **two** ways is it **different from an outcrop**?
    Same Different

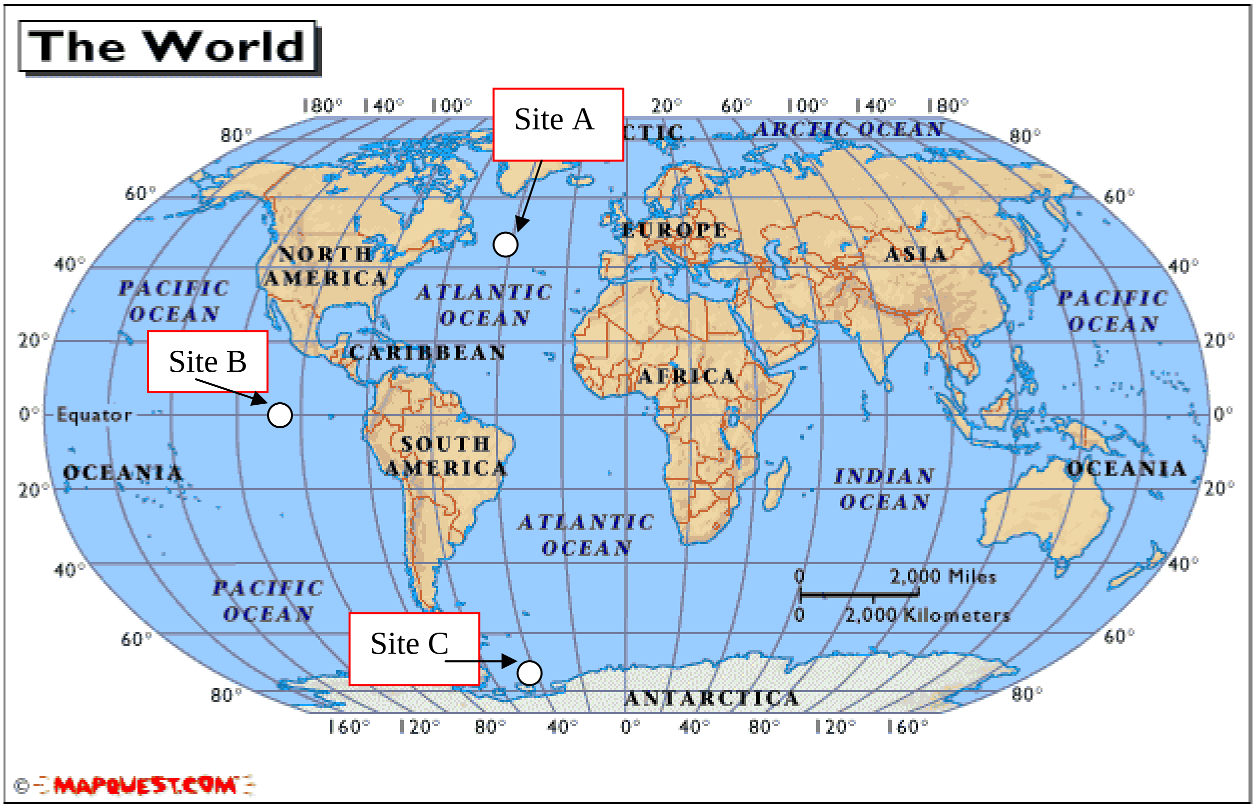
6. Marine sediments derived from **land** are
    a. Terrigenous
    b. Hydrogenous
    c. Cosmogenic
    d. Biogenic
    e. All of the above

7. Which of the following primary sediment types would you dominantly expect to find at Site A? (see map below)
    a. Red clay

b. calcareous ooze
c. siliceous ooze
d. coarse terrigenous sediment

8. Which of the following primary sediment types would you dominantly expect to find at Site B? (see map below)
   a. Red clay
   b. calcareous ooze
   c. siliceous ooze
   d. coarse terrigenous sediment
   e. glaciomarine sediment

9. Which of the following primary sediment types would you dominantly expect to find at Site C? (see map below)
   a. Red clay
   b. Calcareous ooze
   c. Siliceous ooze
   d. Course terrigenous sediment
   e. Glaciomarine sediment



(2) Since the focus of this activity was on the Pacific Ocean, with some additional cores selected from the north Atlantic Ocean the instructor could select locations on the physiographic map of the sea floor that are in the Indian Ocean and south Atlantic Ocean and ask students to predict what the primary sediment would be at that location and why. The instructor could use Rothwell (1989) map as his/her key.

(3) In addition, the instructor could select additional scientific ocean drilling cores and develop an assessment instrument that models the activities in this exercise. The core description sheet (VCD) and the affiliated smear slide table can serve as the instructors "key". To access additional core location, core photos, and smear slide data refer to the following online sources:

- DSDP, ODP, and IODP **core location map** and the related visual core description (VCDs) sheets can be found using Google Earth map. Instructions for accessing this is given at: http://www.iodp.org/borehole-map and is also copied below:

> *The Google Earth Scientific Borehole map has been improved. Now, in addition to viewing the location of all holes drilled during DSDP, ODP, and IODP, web users can select links to newly digitized online expedition publications that correspond to drill sites. Proposed drill sites also have been updated and linked to the IODP Site Survey Data Bank.* ***Move a mouse over borehole locations to display links that lead to corresponding online data.*** *Drilled holes are displayed by default. Select Proposed Sites and/or the Site Survey data link from the left menu in Google Earth to view that additional information (it will take up to 30 seconds for Google Earth to react because of the huge amount of data.) Be patient, once loaded, the navigation is fast. Do not use these files on a slow computer or with a slow Internet connection." To view this program, you must download Google Earth to your computer (on Mac: minimum Google Earth 4.2.0x).*
> *http://earth.google.com/download-earth.html*
>
> ....
>
> *To experience this new IODP web-based program, follow these easy steps:*
> 1. *Download and Install Google Earth into your computer.*
> 2. *Set Google Earth to open in "GL Mode."*
> 3. *Add the IODP web-based program:*
>   a) *Use Google Earth's top menu to select Add – Network Link.*
>   b) *Customize the "Name" of the link (e.g. "IODP Boreholes").*
>   c) *Copy and paste the following link: http://campanian.iodp-mi-sapporo.org/google/data/iodp.kml into the "Link" field.*
>   d) *Hit OK.*
>   e) *Under Google Earth Places, check the named link you added to become active.*
>
> *Wait 10 to 15 seconds for Google Earth to start loading data.*
> *When the process is complete, the locations of boreholes drilled during DSDP, ODP, and IODPS will be shown on the map. If you have problems installing the file please contact webmaster@iodp.org.*

- After selecting a site of interest using Google Earth, click on the borehole to display links to online data. For newer core locations the **visual core description sheets** (VCDs) will have a direct link. For older core locations, you will need to click on the Initial Reports link. Then for very old cores (e.g., DSDP cores) you will need to scroll through the pdf file until you see the core description pages which are usually near the end of the site chapter. In most cases the DSDP core description pages contain the smear slide composition data embedded in the page. For older ODP cores you will need to click on the **Cores** link to assess the VCDs and the **Smear Slide** link to access the smear slide composition tables.
- **Core photos** of individual cores can be downloaded by going to http://iodp.tamu.edu/janusweb/imaging/photo.shtml and entering the pertinent Leg-Site-Hole-Core information for the core of interest then clink on Submit Request. A link to the core photo requested usually pops up in a few seconds.

State of the Science:

- To find out where in the global ocean the IODP scientific ocean drill ships are working today go to the Expedition Schedule: http://www.iodp.org/expeditions/
- To read about recent news-making ocean drilling science go to: http://www.iodp.org/recently-in-the-news

Supplemental Materials:

- [1]Introductory text is adapted in part from Mazzullo and Graham, 1998. Handbook for Shipboard Sedimentologist, *ODP Technical Notes No. 8*, Texas A&M University. This is a great reference for graduate students about to sail as a shipboard sedimentologist for the first time.
- [2]To watch a video on how smear slides are made go to: http://www.nisd.net/jay/joides/index.htm and click on Preparing smear slides from core samples with Dr. St. John.
- [3]The online Curatorial Reference Pages http://www.noc.soton.ac.uk/gg/BOSCORF/curatorial/grain_id.html show many more marine sediment grain types than are included in this exercise. These reference images were originally compiled in a book by Rothwell, *Minerals and Mineraloids in the Marine Sediments*, which is now out of print. Additional smear slide images of microfossils taken by teachers on the 2005 School of Rock expedition are included a free poster *Microfossils: The Ocean's Storytellers* obtained through Deep Earth Academy: http://www.oceanleadership.org/learning/posters
- For a 1-page reference sheet on core identification nomenclature (i.e., Expedition-Site-Hole-Core-Section-Sample) go to:

http://www.oceanleadership.org/classroom/cores and click on the link for: *What is a core?*

- To see pictures and descriptions of some of the most interesting cores stored in the refrigerators at the Gulf Coast Repository at Texas A&M University in College Station, Texas go to: http://iodp.tamu.edu/curation/gcr/display.html
- *To learn about drilling technology and the tools that are used go to: http://iodp.tamu.edu/tools/specs.html*

References:

Aumento, F., Melson, W. G. et al., 1977. Initial Reports of the Deep Sea Drilling Project, Volume 37: Washington (U.S. Government Printing Office), 1008 p. Available from World Wide Web: http://www.deepseadrilling.org/37/dsdp_toc.htm. [Cited 2008-05-22]

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