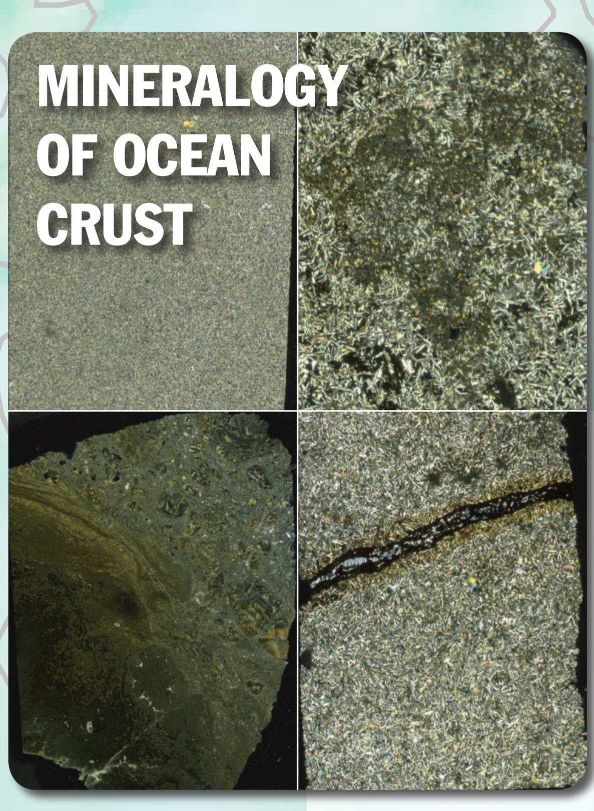
THE "HOLE" STORY ABOUT OCEAN CORES

See notes about core orientation, depth, and sequence

More than 56,000 cores have been recovered since scientific ocean drilling first began! It's a huge job to keep them sorted, a job requiring a meticulous system of organization, labels, and cataloging. This curation system enables scientists to find cores from the exact locations and depths they want to study, and to correlate them with other cores from different locations and ages. *How would you go about organizing 56,000 cores?*

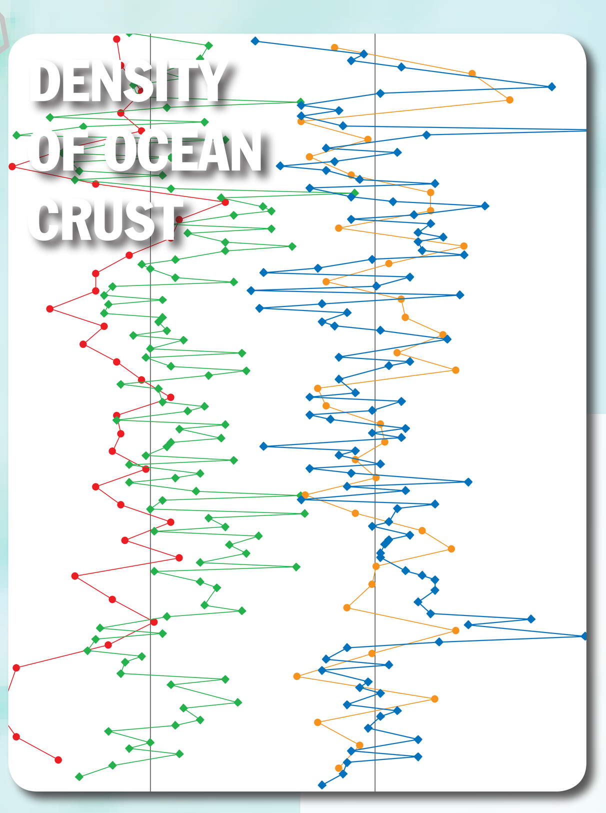
TS (72 - 76 cm)



TS (## - ## cm) - denotes thin section was taken in this interval

Common rock forming minerals make up the ocean's crust. The presence of certain minerals, their grain size, and their abundance in the rock are used to determine the rock type. Thin sections enable scientists to examine and describe the mineralogy of a sample in great detail. *What rock type do you think is most commonly found in oceanic crust? What minerals would you find in that rock?*

1256



What is the difference between the density at the top of the core versus at the bottom of the core?

Some physical properties are easier to determine than others. Density, or the relationship between mass and volume of a rock is not too difficult to measure and calculate. *Density can be used to help identify the rock, but what else can you learn by knowing the density of rock in ocean crust?*

Core 1256D_ 085R_01

depth (in actual cm.) below top of core

Label rock forming minerals

Ol = Olivine
Pl = Plagioclase
Cpx = Clinopyroxene
Opx = Orthopyroxene
Amp = Amphibole
Ox = Oxide
Sp = Spinel

TS (104 - 107 cm)

Core 1256D_ 085R_02 (core section below 085R _01)

top of core

bottom of core

How would density values at 40 cm compare with values at 130 cm?

TS (119 - 124 cm)

How would density values at 130 cm compare with values at 40 cm?

Core 1256D_ 122R_01

Core 1256D_ 170R_02

determine grain size - choose from:

G
cx
ux
fg
mg
cg
vc

TS (107 - 109 cm)

Drillers on the *JOIDES Resolution* work to recover a core from Site 1256 on IODP Expedition 309.

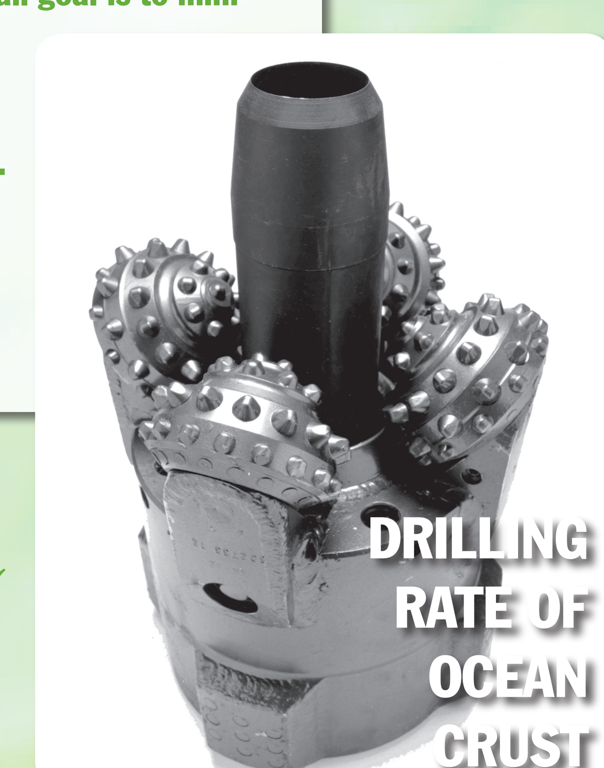
Different rock types have different physical and chemical characteristics; they are formed from different materials, in different environments, and in different ways. Scientists examine cores for specific physical properties that help to identify the rock type and reveal its history. Simple, but detailed visual core description is the first step toward understanding a core. *What observations can you make to unlock the secrets of a core?*

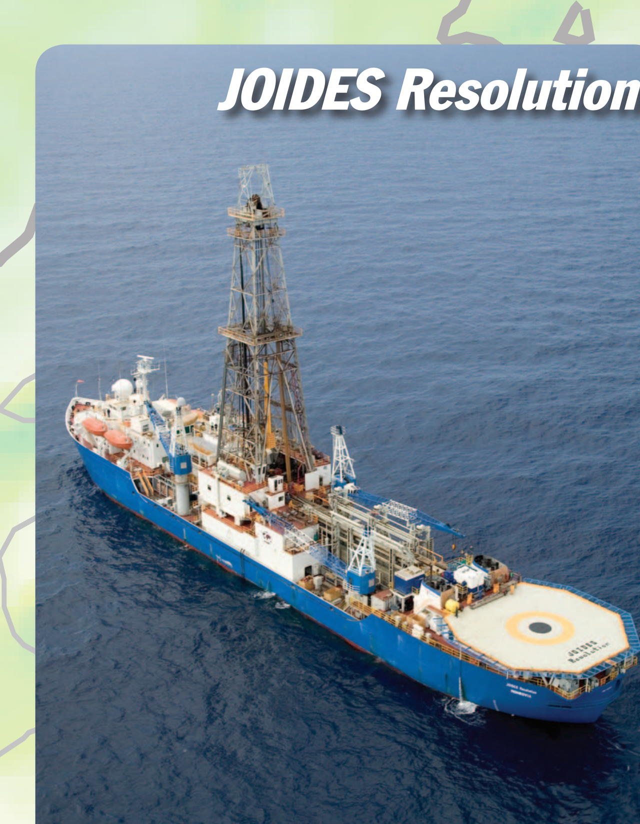
Use these (and other) symbols to record your observations:

slickenline, cataclastic zone, vesicles, vein, shear, ductile deformation, breccia, igneous contact

The drillers on the *JOIDES Resolution* keep a constant watch on their drilling rate through the oceanic crust. Many factors determine how fast they can drill through the rock, including the rock type and structure, as well as the equipment the drillers choose to use. The overall goal is to minimize the drilling time, while maximizing the recovery of core. *How would you calculate the drilling rate for a core section?*

Length of arrow simulates drilling rate - the longer the arrow the greater the rate





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The "Hole" Story About Ocean Cores

The Integrated Ocean Drilling Program (IODP) Expedition 309 – Superfast Spreading Rate Crust 2 was the second of three scientific expeditions to drill into the upper oceanic crust in the eastern equatorial Pacific. Site 1256 is located along the East Pacific Rise in an area that formed during a period of superfast spreading (>200 mm/yr). The core images on the front of this poster are from different depths in this complete section of upper oceanic crust (the first of its kind) recovered from Site 1256. For detailed information about Expedition 309, visit: http://iodp.tamu.edu/scienceops/expeditions/exp309.html.

Alan Gelatt, a high school science teacher from Romulus, New York, sailed on Expedition 309 as the Teacher at Sea. To read Alan's shipboard journal over the course of the two-month expedition, visit: http://iodp.ldeo.columbia.edu/EDU/TAS/309/. With the shipboard scientific party, Alan developed five laboratory exercises that use the scientific results from Expedition 309 to simulate the scientific operations onboard the *JOIDES Resolution*. These exercises (printed below) use near life-size core images to guide students through experimental analyses that are conducted in the laboratories on the *JOIDES Resolution*.

This poster and related laboratory exercises were specifically designed for upper level high school and early undergraduate Earth systems science courses. The text and activities address National Science Education Content Standard D: Earth and Space Science and Standard G: History and Nature of Science for grades 9-12.

Poster Front Images:

Core Section Curation – The Gulf Coast core repository at Texas A & M University in College Station, Texas holds thousands of cores in climate-controlled buildings.

Mineralogy of Ocean Crust – Thin sections taken from the four cores show close-ups of the texture and mineralogy of the oceanic crust.

Visual Core Description – High school science teacher, Alan Gelatt, describes cores onboard the *JOIDES Resolution* for IODP Expedition 309.

Drilling Rate of Ocean Crust – Drilling into the oceanic crust requires special tools like this Rotary Core Barrel drill bit, that uses tungsten carbide inserts to cut through hard igneous rocks.

Credits: Writing - Alan Gellatt, Leslie Peart, Matthew Niemitz; Design - Matthew Niemitz
The authors wish to thank Dr. Neil Banerjee,, Staff Scientist, Dr. Damon Teagle, Co-chief Scientist, Dr. Susumu Umino, Co-chief Scientist, Paula Weiss, Marine Curatorial Specialist, Lisa Crowder, Assistant Lab Officer, the Expedition 309 shipboard science party, and the captain, staff, technicians, and crew of the *JOIDES Resolution.* This poster was made possible by the United States Implementing Organization for the Integrated Ocean Drilling Program. *All* images courtesy IODP-USIO.

We'd like to hear from you! Please contact us with questions or comments. Visit http://www.joilearning.org for other education materials, resources and programs.

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Visual Core Description Lab

Introduction

When a core has been recovered and processed by a core technician, the next steps are photography or imaging and visual description. All distinguishing characteristics must be noted. These techniques, when practiced carefully and with consistency, provide the first general conclusions about the history of the core and the conditions under which it was formed. Visual core description will also begin to establish the need for sampling and further studies. For more about core processing, watch the *Core on Deck* slide show and read the *Core Lab Cookbook* at http://www.joilearning.org/schoolofrock/Library.html.

Objective

Students will use their prior knowledge, classroom resources, and the visual identification key and record sheets used by scientists aboard the *JOIDES Resolution* to identify and describe distinguishable characteristics in one or more core sections.

Vocabulary

Use your textbook and/or geological dictionaries to define the following terms:

Alteration -
Contacts -
Phenocryst -
Structure -
Vesicles -
Veins -

Materials

Color poster of core samples
Visual Core Description (VCD) Record Sheets
Visual Description Key
Metric rulers
Map colors

Procedures

1. First, take a few moments to make sure you understand the symbols and colors in the visual description key, and that you and all of your classmates will use them consistently. For an example of how scientists onboard the *JOIDES Resolution* describe cores like these, see http://www.joilearning.org/schoolofrock/PDFs/SWFs/Ocean_Crust_Core_Description.swf.
2. Place a VCD Record Sheet next to one of the core photos, orienting the top of the record sheet with the top of the photo.
3. Record the core identification information from the poster at the top of the page.
4. Instead of using a scanned image, practice your visual skills by sketching the core in the scanned image column on the left side of the record sheet. (This is the way scientists conducted their work before scanned images were available.)
5. Using the symbols and colors in the visual description key, begin marking all distinguishing features and characteristics in the correct columns at the relative depth of each feature. (Note: these images are about 75% actual size.)
6. Enter all relevant information in the columns provided to the right of the image column.
7. Use the blank half of the sheet to record notes, questions, and your own ideas for further study.

Analysis

Use your prior knowledge and/or textbook to answer the following questions.

1. What are some observable characteristics that help identify a rock?
2. What processes that act on ocean crust may cause identifiable traits?
3. How does the flow of water alter some of the processes that previously acted on ocean crust?
4. How does depth in the crust affect the processes acting on the rock?
5. What columns did you leave blank? Why?
6. Why is consistency so important?

Conclusion(s)

Summarize what you've learned about the core or cores you've described with a few general statements.

Extensions

The science *party*, participants in the expedition, are the only people with access to the data collected for one full year after the ship returns to port. This is called the moratorium. Because Expeditions 309 and 312 are linked by their objectives and Expedition 312 ended December 28th, 2005, the moratorium for these cores will expire on December 28, 2006. At that time you will be able to access all the data about these cores through the *Information by Expedition* link on the *JOI Learning* webpage (http://www.joilearning.org/links).

The physical properties lab brief is full of information about the lab setting where visual core description takes place. You can read or download it from the multimedia page at http://www.joilearning.org/multimedia.

Expedition 309 Visual Description Key

Phenocryst
a – Aphyric (<1%); sp – Sparsely phyric (1%-5%); mp – Moderately phyric (5%-10%); hp – Highly phyric (>10%)

Rock Forming Minerals
Ol = Olivine; Pl = Plagioclase; Cpx = Clinopyroxene; Opx = Orthopyroxene;
Amp = Amphibole; Ox = Oxide; Sp = Spinel

Grain size
G – Glassy; cx – Cryptocrystalline (<0.1 mm); µx – Microcrystalline (0.1-0.2 mm); fg – Fine grained (0.2-1 mm); mg – Medium grained (1-2 mm); cg – Coarse grained (2-5 mm); vc – Very coarse grained (>5 mm)
Blue rectangles or triangles schematically indicate uniform grain size or gradual increase/decrease in grain size, respectively.

Glass
g – fresh glass; ag – altered glass

Structure
Chilled Margin (ticks on quenched side)
Igneous contact
Dyke contact
Vesicles
Pipe vesicles
Primary ductile deformation (e.g., folded flow tops or bottoms)
Magmatic Foliation
Breccia
Magmatic Vein
Vein
Shear Vein
Vein network
Conjugate veins
Joint
Conjugate joints
Metamorphic Foliation
Microfault
Slickenline/ slickenfiber
Apparent sense of shear
Cataclastic zone
Sv – structural ID for measured structure

Alteration
f – Fresh (<2 %); s – Slight (2%-10%); m – Moderate (10%-50%); h – High (50%-95%); c – Complete (95%-100%)
Hydrothermal Mineralization: py = pyrite; cp = chalcopyrite; sp = sphalerite; qz = quartz; chl = chlorite; ep = epidote

Visual Core Description Record Sheet

Piece Number | Scanned Image | Orientation | Shipboard Studies | Lithologic Unit | Structure | Structural Measurement | Glass | Phenocrysts | Constituent Minerals | Grain Size | Alteration

309-xxxx-xR-x (Section top: xxx.x mbsf)

cm: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150

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Core Section Curation Lab

Introduction

Upon recovery from the drill floor, each section of a core must be identified and catalogued. A detailed curation system was developed for identification purposes and to maintain the integrity of the core samples. Every piece of core retrieved from the ocean floor must be labeled and listed. It must also remain in the orientation in which it was formed. Once the core pieces are checked and verified the core is cut lengthwise into two halves, the archive half and the working half. The archive half is kept intact, while the working half is used for sampling and testing purposes. Both halves are equally important and every possible effort is put forth to protect them. Through proper curation techniques, many individuals can study the core for years to come.

Curation and on-board testing should be completed by the time the ship returns to shore, when both core halves are sent to a repository for storage. These facilities provide a climate-controlled environment that allows for the accountable and safe protection of all core sections.

Objective

Students will use their prior knowledge, plus the guides and materials provided, to catalogue and label one or more core samples.

Vocabulary

Use your textbook, the information provided above, and/or geological dictionaries to define the following terms:

Curation -
Orientation -

Materials

Poster with color core photos
Labeling instructions
Report sheets (see below)
Markers/pens
Tape
Sections of broken rock (optional)

Procedures

1. Choose a core section (photo) to label. The more intact the core is, the fewer labels you'll need to make. Align a report sheet with the core you are processing. Use extra sheets (taped together) as needed to sketch the entire core. Be sure to include every piece.
2. Using the labeling instructions, number and label each piece in the core section on the labels provided (small rectangles) on the report sheet.
3. Place arrows along the left side of your drawing to indicate the direction of orientation. The arrows should point toward the top of the core section. (The top of the poster is the top of your core.)

Analysis

1. Why is it important to label core sections before their use in scientific research?
2. Why must the core remain in the formation orientation before, during and after the curation process?

Extensions

1. Use the broken rock provided by your instructor to complete the following:
   a. Carefully (without breaking them) lay out the pieces so that all are visible.
   b. Examine, make a rough sketch and number each piece in the space provided on a new report sheet.
   c. Reassemble the rock if necessary.
   d. Imagine that your rock has been cut in half for curation, and decide which will be your working and archive halves. Sketch what your archive half would look like in the space provided.
   e. Create curation labels for your pieces. What information should/can be included on these labels?
2. Read the curatorial technician's career profile at http://www.joilearning.org/careers/.
3. Learn more about the Gulf Coast Repository through the *Cool Cores* link at http://www.joilearning.org/links.

Labeling instructions (after the Core Lab Cookbook)

All hard rock pieces are labeled with the Integrated Ocean Drilling Program standard identifier: Expedition, Site, Hole, Core, Core type, Section, Piece (and Sub-piece number), an "Up" arrow if the piece is oriented, and a "W" or an "A", indicating whether the piece is from the working or archive half.

Each piece should be numbered consecutively from the top of the section down. Every section should begin with piece number 1, even if a piece is continuous between sections. Sub-pieces (i.e., the pieces which fit together between liner dividers collectively to form a piece), should be consecutively alphabetized from the top of the piece to the bottom of the piece. When the CUT FACE of the WORKING HALF is facing up, the sub-piece to the right, relative to the stratigraphic top of the section, is sub-piece A (see Figure 1).

Whenever possible, sections should be divided between pieces. Remember that curated section lengths may be shorter that the average 150 cm length, however the cut liner should remain 150 cm with "EMPTY" written in the blank space at the bottom.

Please ensure that hard rock cores are curated so the assigned piece and sub-piece numbers are the same in both the archive and working halves. Should there be one piece in the archive half that has broken into two pieces in the working half, then each unit in the working half would be assigned a single piece number (No sub-piece numbers would be assigned).

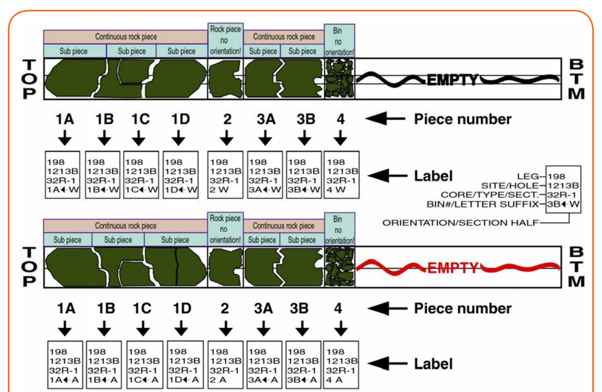
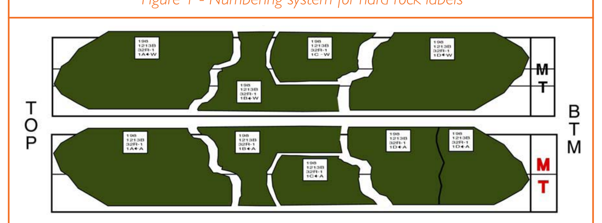


Figure 1 - Numbering system for hard rock labels



1. To identify and distinguish between individual sub pieces of a continuous rock piece, they need to be lettered with suffixes. Mark the sub pieces that fit together or have contiguous features at the bottom and draw connecting lines between them with a red wax pencil. This should be done previous to the labeling when receiving the core on the catwalk and/or when the core is reconstructed in the splitting room.
2. In the example from Figure 2 all the individual sub pieces of the continuous rock piece have the same bin number: 1, but to distinguish between them, different letter suffixes: 1A, 1B, 1C and 1D.
3. All individual sub pieces within a continuous rock piece having a reasonable size must be separated by letter suffixes with the exception of rules I and II:
   I. If a rock or sub piece is broken in only one of the section half's they should be labeled with the same letter suffixes. See the sub pieces labeled 1D.
   II. If the pieces broke while splitting on the saw.

Figure 2 - Labeling hard rock pieces with letter suffixes

Core Labeling Report Sheet

Circle one: core photo, broken rock

Core Labeling Report Sheet

Circle one: core photo, broken rock

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Thin Section Clues to Mineralogy

Introduction

The common minerals that make up most of the ocean crust are called rock-forming minerals. They come from the upper mantle and are distributed at hotspots and spreading centers. The two most common rock types in ocean crust are gabbros that crystallize beneath the surface and basalts that are formed above the surface. Through detailed visual description and geochemistry, we have come to recognize the mineralogy of gabbros, basalts, and other types of ocean crust.

Thin sections are tiny samples that are mounted on a glass slide and abraded (ground) down until the sample is just a few hundredths of a millimeter thick. When placed on a polarizing microscope, mineralogists can magnify the sample, examine, and describe crystal sizes, shapes, colors, relative percentages, and other characteristics. Accurate, fine-scale thin section description requires years of practice with special keys and atlases.

Objective

By defining textural characteristics, the students will be able to examine and match whole thin section photos to the cores from which they were sampled.

Vocabulary

Use the poster, your textbook, and/or geological dictionaries to define the following terms:

Mineral -
Thin section -
Basalt -
ux -
breccia -
porphyritic -
aphyric -

Materials

The "Hole" Story about Ocean Cores poster
Thin section key or atlas (optional)

Procedure

1. Examine and compare thin section photos A – D. Three are very similar, but two have identical descriptions. Match the photos with their descriptions below.

   _____ Aphyric, fine-grained massive flow
   _____ Aphyric, fine-grained massive flow
   _____ Aphyric, ux basalt
   _____ Breccia

2. Now examine the four cores on the front of the poster, looking for the exact locations from which the thin sections were taken. Match each thin section to the core from which it was taken.

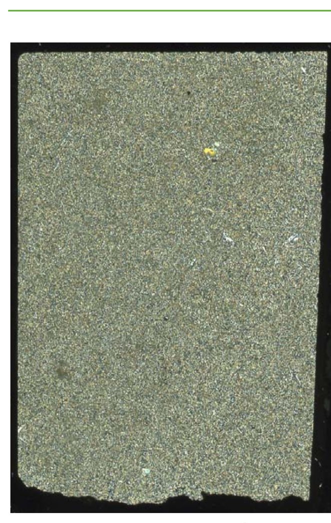
   _____ 1256D_085R_01
   _____ 1256D_085R_02
   _____ 1256D_122R_01
   _____ 1256D_170R_02

Analysis

1. Did the thin sections allow you to see the texture of the core more closely?
2. What features could you describe by examining the thin sections that you could not see by looking only at the cores?
3. Would greater magnification be helpful?

Thin section A

Thin section B



Thin section C

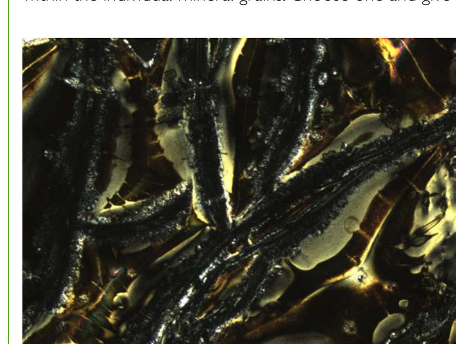
Thin section D

Challenge Activity

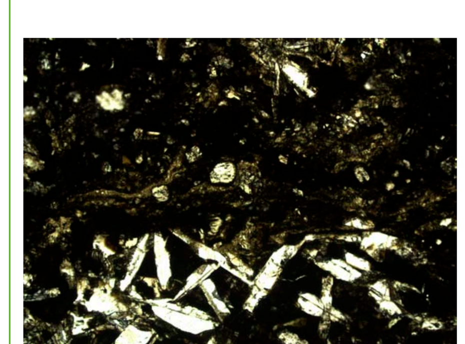
Examine the 5 mm thin section magnifications below. As photos, these magnifications are difficult to use. Full descriptions require the scientist to observe the passing of light through the sample with the polarizing microscope. However, detailed keys and mineralogy atlases can be used to identify the minerals present in a thin section and a core. In addition to showing the individual mineral grains in cross polarized light, these magnifications show microtextures or microstructures within the rock or even within the individual mineral grains. Choose one and give it a try or simply see if you can match the photos with their microtexture or microstructure descriptions below.

_____ Cataclastic zone with straight margin and flow structures
_____ Microcracks in plagioclase
_____ Altered glassy shards in hyaloclastic breccia

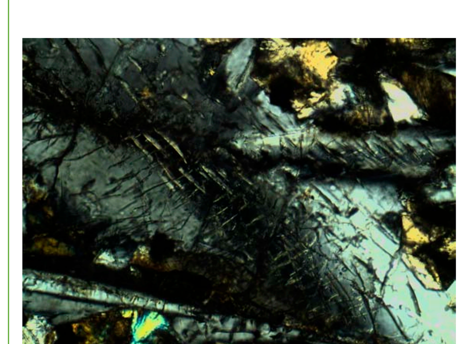
Can you match these photos with the whole thin sections they were made from?



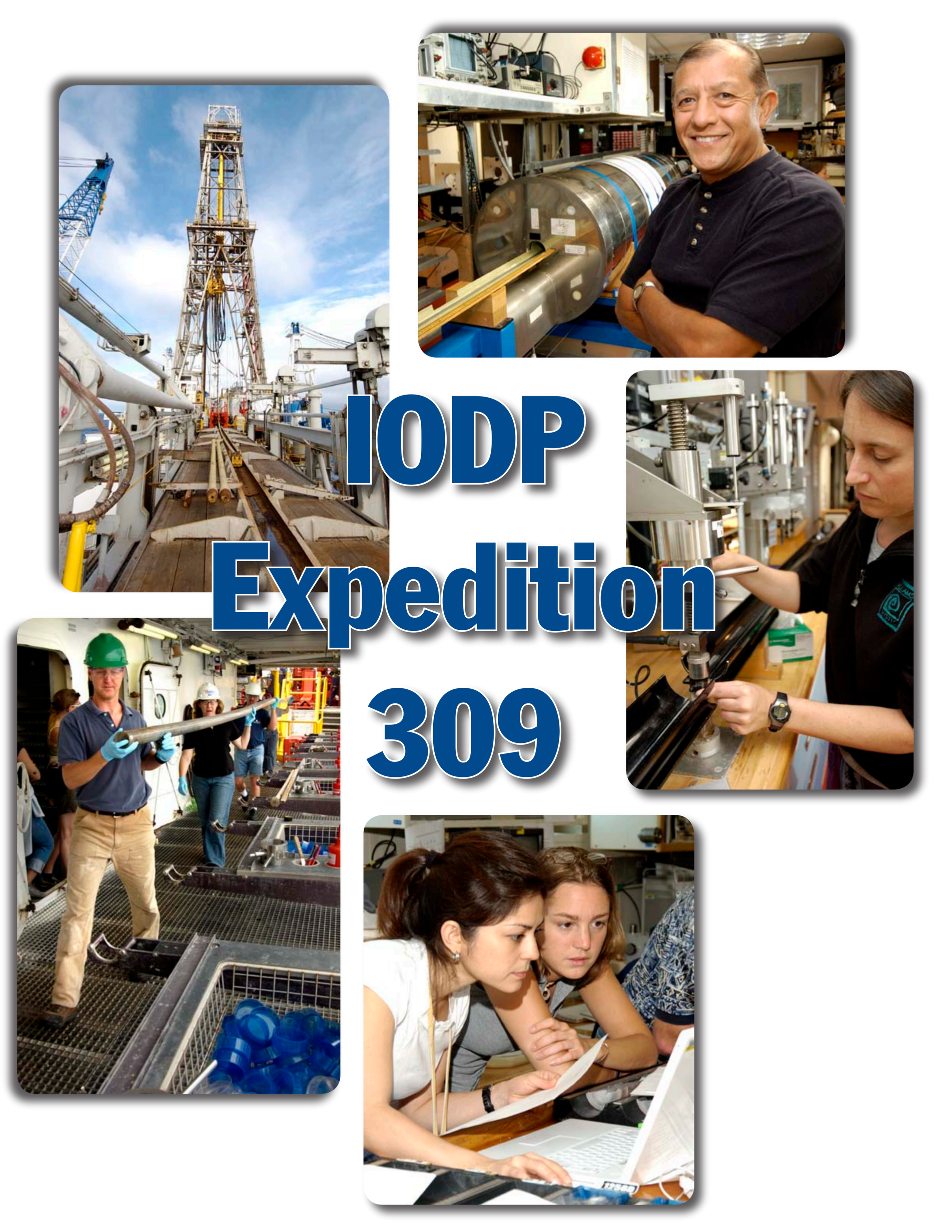
5 mm thin section A



5 mm thin section B



5 mm thin section C



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Drilling Rate of Ocean Crust

Introduction

Composition, structure, fracturing, and other factors may influence the length of time required for drilling through ocean crust. The drilling rate can be determined by noting the distance drilled, the length of time it took to drill, and calculating the ratio between them. Drilling rates are one of many indicators used by drillers and engineers to make important decisions about equipment choices and changes. Good decision-making by the driller provides the highest quality cores for scientific study.

Objective

Using the data provided, students will calculate drilling rates over a three-day period during Expedition 309.

Vocabulary

Use a dictionary to define the following terms.

Rate of Change -
Military time scale -

Materials

Calculators
Additional paper

Procedures

1. Complete the drilling rate table below by filling in the missing data for cores 75 to 89.
   Hints:
   Core top depth = core bottom depth minus length cored;
   Drill time = time elapsed between dropping the core barrel and the time it was brought back on deck;
   Drilling rate = length cored divided by drill time;

Analysis

1. Why is it important to keep track of the drilling rate?
2. What factors could slow the drilling rate (see *The Rough Life of a Drill Bit* available through *Follow Expedition 312* on the *JOI Learning* multimedia page at http://www.joilearning.org/multimedia/.
3. How could a driller increase drilling rates?
4. List some natural factors that could increase the drilling rate.
5. Calculate the average drilling rate for cores 75R and 83R.

Extensions

Four related careers – driller, tool pusher/core technician, offshore installation manager, and operations superintendent – can be downloaded and read from the *JOI Learning* career interactive at http://www.joilearning.org/careers/.

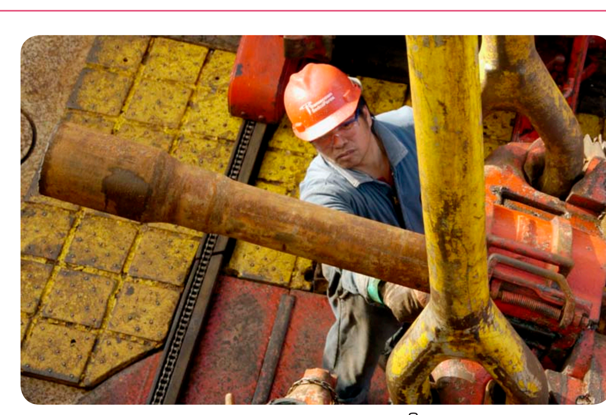
Watch the *Tripping Pipe* video (http://www.joilearning.org/multimedia/) for a view of what it takes to change a drill bit.

Roughnecks onboard the JOIDES Resolution *guide the drill bit through the rig floor and towards the seafloor to begin drilling for cores. (photo courtesy IODP-USIO)*

Drilling Rate Table for Cores 75R – 89R

Expedition 309 Site/Hole 1256D

Core #	Core barrel dropped	Time on deck	Core top depth (mbsf)	Core bottom depth (mbsf)	Length cored (m)	Length of core recovered (m)	Drill time (hr)	Drilling Rate (m/hr)
75R	09:45	14:25		752.0	1.9	1.28		
76R	14:25	20:30		753.9	4.8	1.23		
77R	20:30	04:30		758.7	4.8	1.65		
78R	04:30	11:15		763.5	6.1	2.90		
79R	11:15	17:05		769.6	9.6	2.65		
80R	17:05	21:00		779.2	9.6	3.11		
81R	21:00	05:50		788.8	3.4	0.68		
82R	05:50	09:30		792.2	7.0	1.20		
83R	09:30	15:35		799.2	2.6	1.28		
84R	15:35	01:25		801.8	9.6	2.04		
85R	01:25	06:35		811.4	9.6	7.11		
86R	06:35	18:10		821.0	9.6	3.65		
87R	18:10	04:25		830.6	9.6	3.26		
88R	04:25	11:10		840.2	9.6	1.32		
89R	11:10	13:55		849.8	9.6	0.60		



A roughneck on the JOIDES Resolution *helps guide the drill pipe using the drawworks during the pipe tripping process. (photo courtesy IODP-USIO)*

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Density of the Ocean Crust Lab

Introduction

Certain properties of a substance are both distinctive and relatively easy to determine. Density, the ratio between a sample's mass and volume at a specific temperature and pressure (like standard ambient temperature and pressure), is one such property. Regardless of the size of a sample, the density of a substance will always remain the same. The density of a rock sample can, therefore, be used in the identification process.

While density may vary only slightly from rock to rock, detailed sampling and correlation with other factors like depth may reveal important information about the history of a core, or may help to improve the use of seismic profiles. The average density of ocean crust is 3.0 g/cm^3, while continental crust has an average of 2.7 g/cm^3.

Objective

Using prior knowledge and the formula for density, students will be able to:

1. Calculate the density of samples from a single core;
2. Determine the relationship between density and depth in a given core; and
3. Measure, calculate, and compare continental rock samples

Vocabulary

Use your textbook, the introductory material above, and/or geological dictionaries to define the following terms:

Density -
Inverse relationship -
Mass -
Direct relationship -
Volume -

Materials

Balance or digital scale
Metric ruler
100 ml graduated cylinder
Continental rock samples (see below)
Paper
Colored pencils

Procedures

Part 1

1. Complete Report Sheet 1 by calculating the missing densities. How will you deal with the differences in significant digits? Make sure to include units in your answers.
2. Using the depths and densities from your chart, plot a graph on your own paper (or use an electronic graphing tool) and title it Depth vs. Density. Hint: Think about independent and dependent variables. Using a blue colored pencil, draw a line of best fit from the XY-intercept through the plotted points.

Part 2

1. Find the mass and volume for each of the four continental samples as instructed by your teacher. How will you deal with error in the laboratory? How about significant digits? Record your answers in the space provided.
2. Calculate and record the density for each sample.

Analysis and Conclusions

1. Describe the procedure for determining the density of rock samples.
2. Does the shape of a sample affect its density?
3. What factors could lead to an error in your mass and volume measurements?
4. How do temperature and physical state affect density?
5. Explain the relationship between depth and density for the samples at Site/Hole 1256C?
6. How do the ocean crust densities you calculated compare to the average density for ocean crust?
7. Compare and contrast your ocean crust results with the sedimentary and metamorphic rock samples.

Extensions

Compare your graph of density vs. depth during Leg 206 to the more detailed graph of bulk densities at depths of 750 to 1250 meters compiled in the Preliminary Report for Expedition 309 available through the Information by Expedition link at http://www.joilearning.org/links.

Report Sheet 1: Density vs. Depth at Site/Hole 1256C

Expedition 206 Site/Hole 1256C

Core #	Section #	Piece #	Rock Name	Depth (m)	Volume (cm^3)	Mass (g)	Density (g/cm^3)
5R	1	1	Aphyric basalt	252.5	8.0	19.384	
6R	3	5	Aphyric basalt	262.67	8.0	22.56	
7R	3	5	Aphyric basalt	271.44	8.0	23.08	
8R	3	6	Aphyric basalt	282.59	8.0	23.64	
9R	4	7	Aphyric basalt	294.27	8.0	23.264	
10R	3	4	Aphyric basalt	295.26	8.0	23.28	
11R	4	4	Aphyric basalt	308.61	8.0	23.368	
12R	1	4	Aphyric basalt	317.18	8.0	23.4208	
13R	1	1	Aphyric basalt	322.08	8.0	23.448	

Report Sheet 2: Density of Laboratory Samples

	Mass (g)	Volume (cm^3)	Density (g/cm^3)
Sedimentary Rock			
Limestone			
Sandstone			
Metamorphic Rock			
Gneiss			
Schist			