Laboratory 4

Bottom Sediment Charts

4-1. BOTTOM SEDIMENT CHARTS

Bottom sediment charts show the distribution and type of material on the sea floor. This information is important in determining the geology of the area, the suitability of the bottom for anchorage of ships, bridge supports, oil platforms, cables, etc. and can even be useful in determining location. Data on bottom sediments in deep parts of the ocean can only be obtained by lowering devices that collect samples. This is both slow and costly. Thus, bottom sediment charts are usually developed from much less data than bathymetric charts.

Proper interpretation of bottom samples requires a knowledge of factors controlling sediment distribution. For water- and wind-transported sediment, particle size is a major control. Erosion of sediment by wind or water results when fluid velocity produces sufficient turbulence to overcome **inertia** (resistance to being moved). Transportation of sediment then requires only sufficient turbulence to overcome a grain's **settling velocity** (how rapidly the grain sinks). Deposition occurs when turbulence is less than settling velocity and the particle sinks to the bottom.

4-2. HJULSTRÖM DIAGRAM

The relationship of particle size and fluid velocity to erosion, deposition and transport is summarized in the **Hjulström Diagram** (Figure 4-1). On this diagram, particle size increases to the right and fluid velocity increases toward the top. The broad U-shaped line separating the areas labeled Erosion and Transportation is the *minimum velocity* for erosion. For a given particle size, any velocity on or above this line is strong enough to cause erosion. The sloping line separating areas labeled Deposition and Transportation represents the *maximum velocity* at which deposition can occur. For a given particle size, a velocity on or below this line is too slow to keep a particle in transport. Deposition then occurs.

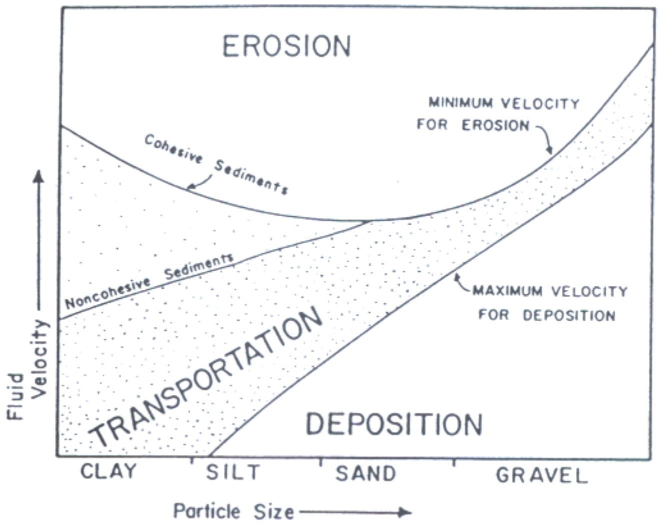


Figure 4-1. Hjulström Diagram.

From this diagram, the following can be concluded:

1. Because of inertia, a greater fluid velocity and turbulence are needed to erode a particle than to transport it.
2. For sand and larger particles, the fluid velocity and turbulence necessary to erode and transport increases with particle size. This is because larger particles weigh more and settle faster.
3. For particles smaller than sand, the fluid velocity and turbulence needed to erode them increases as particle size decreases. This is because small particles tend to be **cohesive** (stick together). A greater velocity is needed to pull the grains apart.
4. As fluid velocity and turbulence decrease, particles are deposited according to size with the largest first and smallest last. Because of weight, larger particles settle faster than small ones.

Numerous examples of these four principles operating in nature can be cited. Where a river flows into the ocean, its velocity gradually decreases. Larger particles are deposited near the river's mouth and finer material is carried far offshore before it settles to the bottom. Waves breaking on a shore will produce considerable turbulence. Larger particles will be moved about, but remain near the shore. Smaller particles will be unable to settle because the turbulence is greater than their settling velocity. These small particles will be transported to quieter areas in deeper water or into protected bays where they will be deposited. As turbidity currents flow from submarine canyons onto the continental rise and abyssal plain, current velocity gradually decreases. **Turbidites**, the sediments deposited by a turbidity current, grade from coarser material near the continental slope to finer sediments on the abyssal plains. They also show a gradation from coarser material at the bottom of the deposit to finer material at the top. In general, for water- and wind-transported sediments, grain size decreases away from the source area.

4-3. ORIGIN OF SEDIMENTS

Sediments can be divided into five groups based upon their origin (Figure 4-2). **Terrigenous sediments** are produced by the weathering and erosion of rocks on land. These sediments tend to be concentrated near their source and decrease in size with distance. **Biogenic sediments** are mineralized structures (shells, teeth, etc.) produced by organisms. **Authigenic sediments**, also called **hydrogenic**, are particles produced by chemical reactions in sea water. **Evaporites** (salts), **ferromanganese** and **phosphorite nodules** are the most common authigenic sediments in the ocean. **Volcanogenic**

sediments are particles, not lava flows, ejected from volcanoes. As with the terrigenous sediments, they tend to be concentrated near and decrease in size with distance from the source. **Cosmogenous sediments** consist mainly of the tiny grains that fall to Earth from space. Unlike other types of sediments, they fall uniformly everywhere, but are seen in abundance only when other sediments are absent. These five types of sediments usually occur mixed together, but typically one type may dominate in a given deposit.

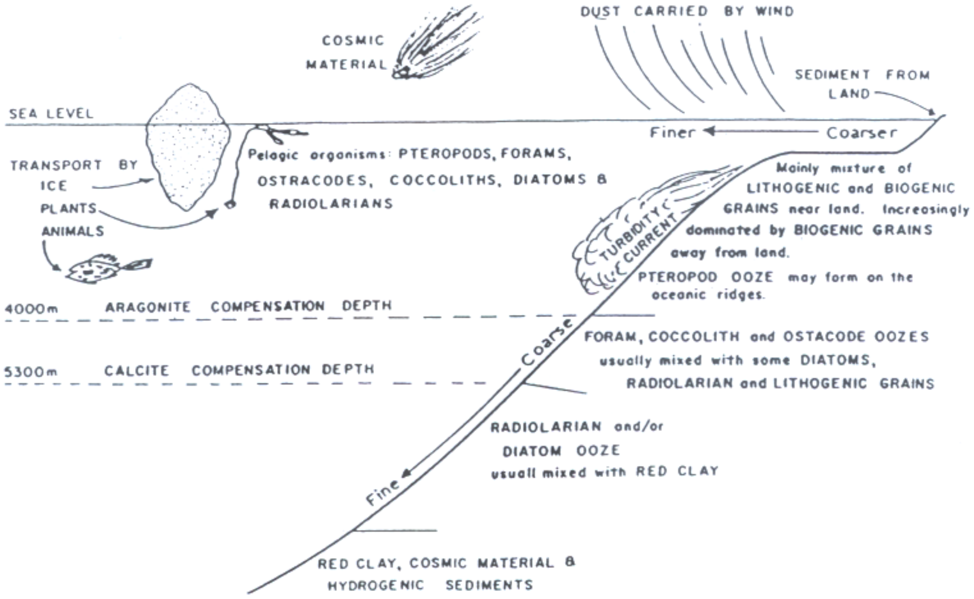


Figure 4-2. Origin of sediments and distribution of biogenic sediments.

4-4. BIOGENIC SEDIMENT DISTRIBUTION

There are a wide variety of biogenic sediment produced in the ocean. Oozes are the major biogenic sediment in the deep ocean basin. An ooze is a fine-grain sediment containing more than 30% biogenic grains from **pelagic** (floating) organisms. Distribution of biogenic sediments is controlled by the chemical stability of the mineral composing the grains, the environmental tolerance of the organisms and the organism's abundance. Oozes typically occur far from land, where inflow of terrigenous sediment is greatly reduced. They are named for the dominant type of biogenic grain. The six types of common oozes are:

Organism	*Ooze*	*Mineral of shell*	*Chemical formula*
Pteropod	Pteropod ooze	Aragonite	$CaCO_3$
Coccoliths	Coccolith ooze	Calcite	$CaCO_3$
Ostracod	Ostracod ooze	Calcite	$CaCO_3$
Foraminifera	Foraminiferal ooze	Calcite	$CaCO_3$
Diatom	Diatom ooze	Silica	SiO_2
Radiolarian	Radiolarian ooze	Silica	SiO_2

Although the minerals aragonite and calcite have the same chemical formula, aragonite is less stable and dissolves at a shallower depth than does calcite. The depth at which a mineral begins to dissolve is called the "**compensation depth**" of the mineral (Figure 4-2). The compensation depth is not an absolute depth, but depends on many factors such as the pressure and temperature of the water, as well as the supply of the soluble material. The aragonite compensation depth averages about 4000 m. Pteropod oozes are usually found only on the shallow peaks (<4000 m) of submarine ridges because pteropods, pelagic snails, are very sensitive to suspended terrigenous sediment and only live far from shore.

Calcite is stable to a depth of about 5200 m and coccolith, foraminifera and ostracod oozes are normally found above this depth. Coccoliths are the remains of a single-cell algae. Foraminifera are single-cell animals and ostracods are small shrimp-like organisms that secrete hinged shells. The oozes made by these three organisms are the most common oozes in the ocean basin.

Silica is stable to great depths and the distribution of silica oozes is mainly controlled by the distribution and productivity of silica-secreting organisms. Diatoms are single-cell algae and they thrive in subpolar environments. Radiolarians are single-cell animals and are most abundant in the tropics. Because these organisms normally reproduce more slowly than calcite or aragonite ooze-forming organisms, the silica oozes occur mainly in areas below the calcite compensation depth.

In the deep ocean regions not dominated by oozes, terrigenous and authigenic (hydrogenic) sediments dominate. Terrigenous sediment consists mainly of **red** (brown) **clay** derived from wind-blown dust, cosmic material and clay particles. Some anomalously large terrigenous grains may be present because of transportation by turbidity currents, ice, animals and/or plants (Figure 4-2). **Ferromanganese nodules** are the most common authigenic grains present in the deep ocean. These may be so abundant as to blanket the sea floor.

4-5. BOTTOM SEDIMENT CHARTS

After bottom samples from an area have been collected and analyzed, the data are recorded on charts. Contiguous samples of like sediment types are mapped together as a unit to obtain a better picture of sediment distribution (Figure 4-3). Comparison with bathymetric charts aids in determining relationships among depth, sediment type and possible sediment source. Common abbreviations for sediment types used on navigation charts are given below. Where mixtures of two or more types of sediments occur, abbreviations may be separated by a slash (/).

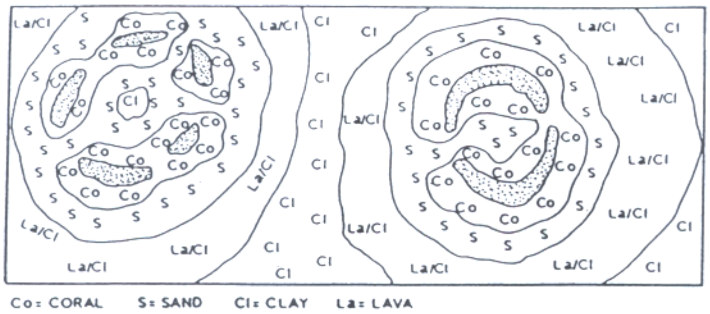


Figure 4-3. Bottom sediment chart.

Abbreviations used on navigational charts:

bk	black	Blds	boulders	br	brown
brk	broken	bu	blue	Ca	calcareous
ch	chocolate	Ck	chalk	Cl	clay
Co	coral	crs	coarse	Di	diatom
dk	dark	fn	fine	Fr	foraminifera
G	gravel	gl	Globigerina	Glac	glacial
gn	green	Grd	ground	hrd	hard
K	Kelp	La	lava	lrg	large
lt	light	M	mud	Mn	manganese nodules
Ml	marl	Ms	mussels	Or	orange
Oys	oysters	Oz	ooze	P	pebbles
Pt	pteropods	Qz	quartz	Rd	radiolarian
rd	red	Rk	rocky	S	sand
sft	soft	Sh	shells	sml	small
St	sticky	vi	violet	Vol Ash	volcanic ash
Vol	volcanic	wh	white	yl	yellow

EXERCISE 1. BOTTOM SEDIMENT CHARTS

1. Commencement Bay Chart (Figure 4-4).
   a. Complete the bottom sediment chart by drawing the boundaries between the various sediment types.
   b. What is the dominant sediment shown on the chart ? ______________
   c. Is this a size class, origin or compositional term? ________________
   d. Is there a relationship between sediment type and depth? (See bathymetry chart for Commencement Bay, Figure 2-8, p. 217.) If so, describe.
   e. What is the most probable type of sediment found at each of the following points on the chart:
   1.____________ 2.____________ 3.____________ 4.____________

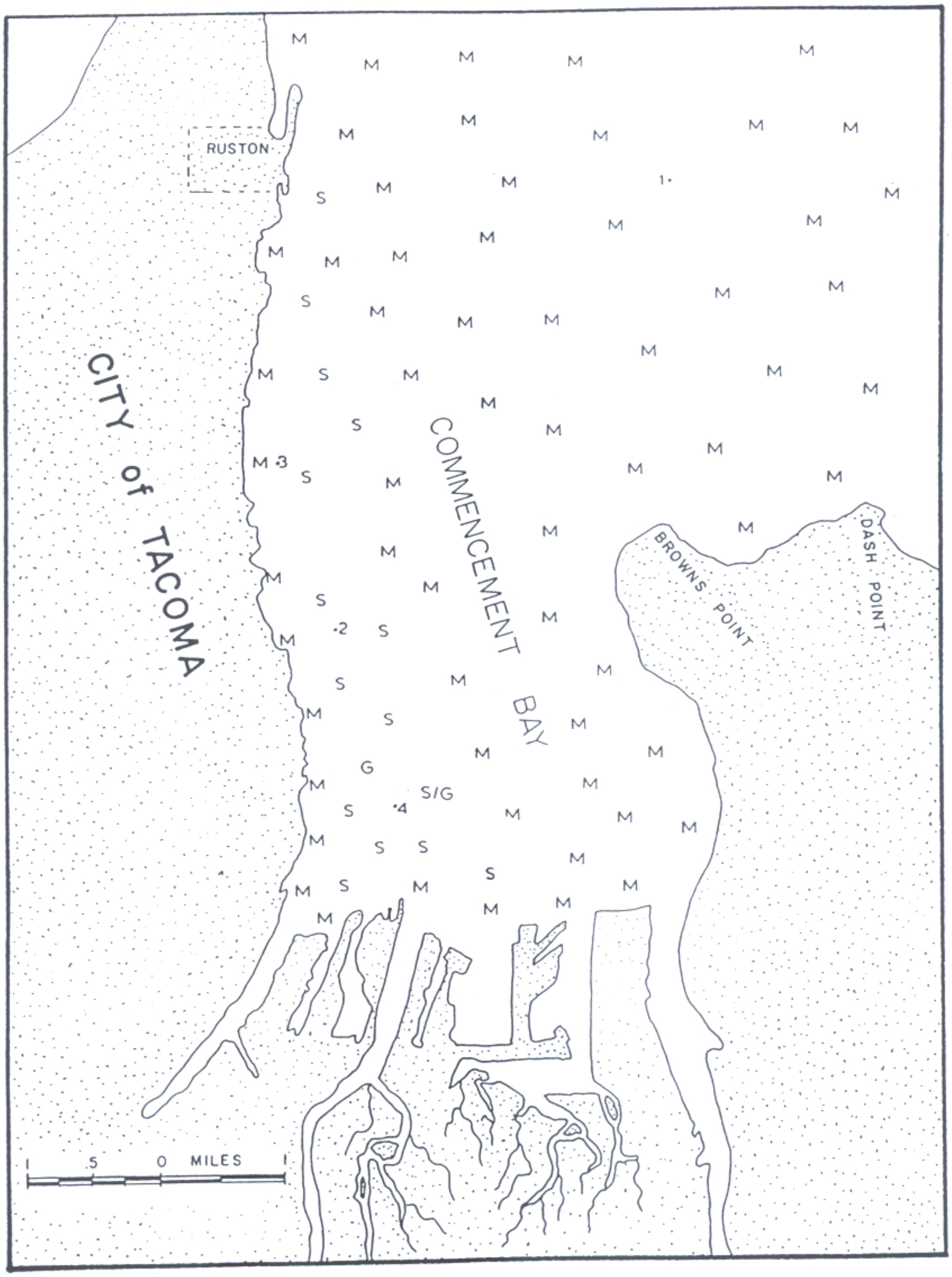


Figure 4-4. Bottom sediment chart of Commencement Bay, Washington.

2. Chart of a portion of the Pacific Ocean (Figure 4-5).
   a. Complete the bottom sediment chart by drawing the boundaries between the various sediment types.
   b. What type of sediment dominates the following areas (See bathymetry chart for a portion of the Pacific Ocean, Figure 2-9, p. 216)?
   Shallow water around islands. ________________
   Deep portion of ocean. ________________
   Central depression surrounded by several islands near lower right-hand corner of chart. ________________
   c. Below are all of the abbreviations used on this chart. Write what each abbreviation means and state if the term indicates origin (terrigenous, biogenic or authigenic), size class or description.

Vol Ash			*dr*		
Oz			La		
G			S		
Co			D		

   d. Does sediment type appear to be related to depth? If so, describe.

   e. Considering the dominant bathymetric feature of the Pacific Ocean basin, what do the rock and sediment types on this chart and the general configuration of the sea floor around the island groups indicate as a probable origin for these islands?

   f. From your knowledge of compensation depths would you expect the ooze on this chart to be mainly aragonite, calcite, silica or a mixture of all three? Why?

   g. Note the area of sand extending outward from the large island along the right edge of the chart. How can this be explained?

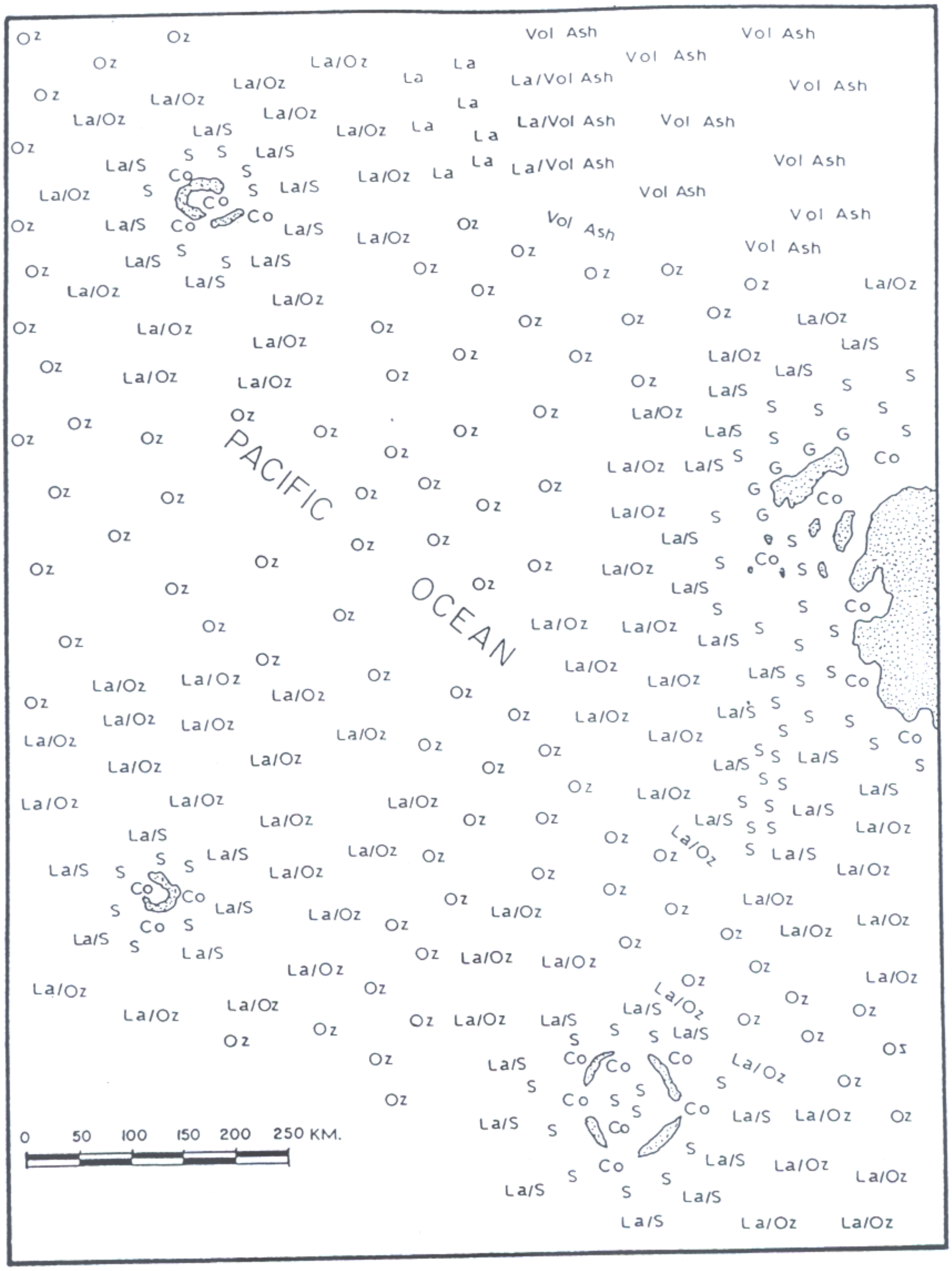


Figure 4-5. Bottom sediment chart of a portion of the southern Pacific Ocean.

EXERCISE 2. OCEAN FLOOR FEATURES AND SEDIMENT TYPES

1. On the three profiles on page 246 (Figure 4-6), identify the most probable type of sediment(s) expected in each of the lettered areas. On each profile a continent is shown on the left and a broad ocean is to the right.

A. ____________ B. ____________ C. ____________
D. ____________ E. ____________ F. ____________
G. ____________ H. ____________ I. ____________
J. ____________ K. ____________ L. ____________
M. ____________ N. ____________ O. ____________
P. ____________

2. The sediment collecting in the open ocean is primarily derived from shells of pelagic (floating) organisms. Explain why the sediment would be much thicker on the flanks of the Mid-Atlantic Ridge than on the ridge crest.

3. How can the presence of granite (continental) cobbles and pebbles in the middle of the North Atlantic be explained?

4-6. SEA FLOOR SEDIMENT THICKNESS

As soon as sea floor forms at the oceanic ridge crest, sediment begins to accumulate upon it. Rate of accumulation can vary depending upon a number of factors such as:

1. Rate of organic productivity in the overlying waters.
2. Amount of wind-transported sediment from the land or fine particles from volcanic eruptions which settle from of the atmosphere.
3. Rate at which cosmic dust falls to Earth.
4. Speed at which authigenic sediments form.
5. Quantity of water-transported sediments that sink to the sea floor.
6. Rate of sediment dissolution or erosion.
7. Amount of ice-rafted sediments released as icebergs melt.

In general, the farther a section of sea floor is from the oceanic ridge crest, the older the sea floor, the longer sediments have had to collect and the thicker the accumulation of sediment. Therefore the three interrelated variables determining the amount of sediment found on the sea floor are the rate at which sediments collect, the age of the sea floor and the distance the section of sea floor is from the oceanic crest. Given any two of these variables, it is possible to determine the third.

Example 1. If the average rate of ocean basin expansion is 3 cm/yr and a studied section of sea floor is 400 km from the crest, how thick should the sediments be if the average rate of accumulation is 2 cm/1000 yrs.?

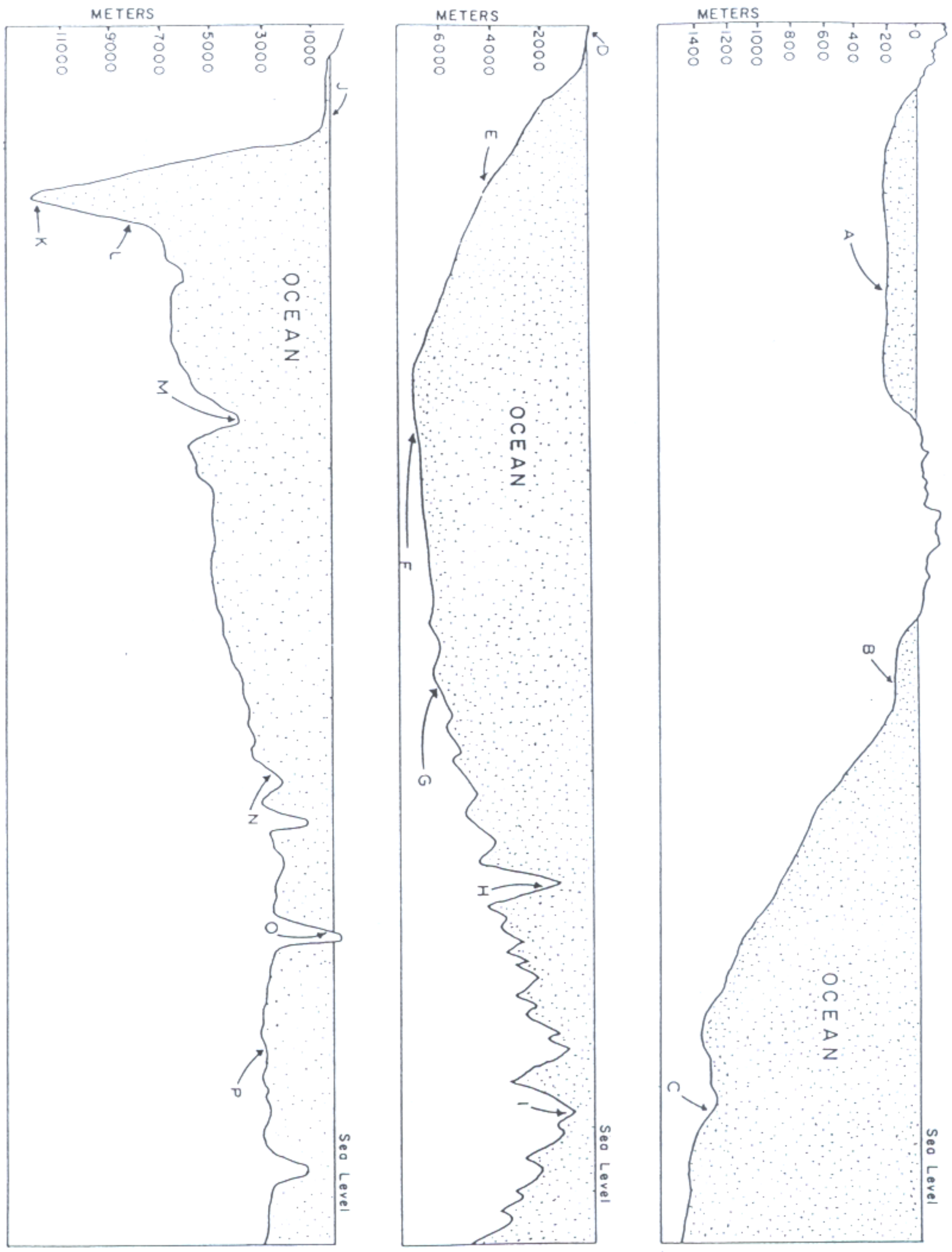


Figure 4-6. Three bathymetric profiles of portions of an ocean.

A. First determine the average sea floor spreading rate.

Average sea floor spreading is the rate at which sea floor moves away from the ridge crest. It is equal to one-half the average rate of ocean basin expansion, the rate at which both sides of the oceanic ridge spread.

Average ocean basin expansion rate = 3 cm/yr

Average sea floor spreading rate = 3 cm/yr x 1/2 = 1.5 cm/yr

B. Determine the age of the sea floor upon which the sediment has collected. This can be accomplished by calculating how long it has taken this section of sea floor to be moved 400 km from the ridge crest. Convert the 400 km into centimeters.

$400\ \cancel{km} \times 1000\ \cancel{m}/\cancel{km} \times 100\ cm/\cancel{m} = 4\times10^7 cm$

To determine the time required for the sea floor to spread 4×10^7cm at the rate of 1.5 cm/yr, divide the distance by the rate of spreading.

$4\times10^7 cm \div 1.5 cm/yr = 4\times10^7 \cancel{cm} \times 1yr/1.5\cancel{cm} = 2.6x107yrs$

The sea floor is 26,000,000 years old

C. Sediment has been accumulating at the average rate of 2 cm/1000 yr. To calculate the expected thickness of sediment, multiply the time interval by the rate of accumulation.

$2.6 \times 10^7 \cancel{yrs} \times 2\ cm/10^3\ \cancel{yrs} = .8666 \times 10^4 cm = 8666\ cm$

D. Convert the thickness into meters

$8666\ \cancel{cm} \times 1\ m/100\ \cancel{cm} \cong 86.66\ m$

Example 2. Sediment has been collecting at the average rate of 3 cm/1000 years. A section of sea floor is covered by 60 m of sediment and is 200 km from the crest of the ridge. What was the average rate of sea floor spreading for this section of sea floor.

A. Determine the time interval required to collect 60 m if sediment was deposited at the average rate of 3 cm/1000 yrs. Convert the 60 m of sediment into centimeters of sediment.

$60\ \cancel{m} \times 100\ cm/\cancel{m} = 6000\ cm$

To determine the time required to deposit 6000 cm, divide the sediment thickness by the rate of accumulation.

$6000\ cm \div 3\ cm/1000\ yrs = 6000\ \cancel{cm} \times 1000\ yr/3\ \cancel{cm} = 2\times10^6 yrs$

If it has taken 2×10^6yrs for the sediment to have accumulated, the sea floor must be at least 2×10^6yrs old and it has required 2×10^6yrs for the sea floor to have spread 200 km from the ridge crest.

B. To determine the average rate of sea floor spreading convert the distance traveled into centimeters and then divide the distance by the time required to travel that distance.

$200\ \cancel{km} \times 1000\ \cancel{m}/\cancel{km} \times 100\ cm/\cancel{m} = 200\times10^5 cm$

$200\times10^5 cm/25\times10^5 yrs = 4\ cm/yr$

Example 3. A section of sea floor is covered by 600 m of sediment and is located 300 km from the ridge crest. Average sea floor spreading rate is 5 cm/yr. What is the average rate per 1000 years at which sediment is accumulating on the sea floor?

A. To determine the age of the sea floor, calculate the time required for the sea floor to spread 300 km from the crest at 5 cm/yr. Convert the distance to centimeters and divide by the average spreading rate.

$300\ \cancel{km} \times 1000\ \cancel{m}/\cancel{km} \times 100\ cm/\cancel{m} = 3\times10^7 cm$

$3\times10^7 cm \div 5\ cm/yr = 30\times10^6\ cm \times 1\ yr/5\ \cancel{cm} = 60\times10^6 yrs$

It has taken 60×10^6yrs to collect 600m of sediment.

B. To determine the average annual rate of sediment accumulation, convert the sediment thickness to centimeters and divide the amount of sediment by the time it took for the sediment to accumulate.

$600\ \cancel{\text{m}}\ \text{x}\ 100\ \text{cm}/\cancel{\text{m}} = 6\text{x}10^4\text{cm}$

$6\text{x}10^4\text{cm} \div 60\text{x}10^6\text{years} = .001\ \text{cm/years}$

Convert to the average accumulation per 1000 years by multiplying the average annual rate of sediment accumulation by 1000/1000

1000/1000 x .001 cm/yr = 1 cm/1000 yr

The average rate of sedimentation is obtained by dividing the total thickness of sediment deposited by the time over which the sediment has accumulated. If the rate of sedimentation has been fairly uniform, the average rate is a good approximation of the rate of sedimentation for any section of the core. In contrast, if the rate of sedimentation has varied greatly, the average rate of sedimentation may not be truly representative of any section of the core.

Cores of deep ocean sediments can be dated at their base if part of the underlying basalt is recovered. Using radiometric dating, it is possible to very accurately determine when the section of sea floor formed. This can also be taken as the date when sediments first began to accumulate because sediments start to be deposited almost as soon as the sea floor rock forms. Within a column of sediment it is possible to determine approximate dates from fossil remains. The average rate of sedimentation between each section of the core can then be determined by dividing the thickness of sediment in the section by the time interval during which that section was deposited.

EXERCISE 3. CALCULATIONS ON SEDIMENTS

1. If the average rate of sediment accumulation is 3 cm/1000 years, how long would be required for sediments to completely bury seamounts 1.5 km high and convert part of the oceanic ridge into a part of the abyssal plains? ________________

2. The Atlantic Ocean began forming about 200 million years ago. If one applies the average sediment accumulation rate of 3 cm/1000 yrs, measured near the center of the ocean basin, to the entire basin, what is the maximum thickness of sediment that would be expected at the basin edge? ________________________
   The actual thickness is much greater. How can this be explained?

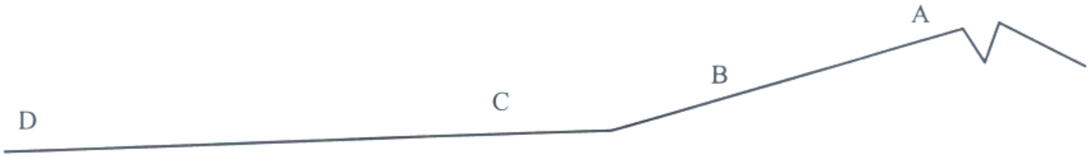
3. Rates of sediment accumulation not only vary with time, but also with location across the ocean basin. In general the rate of sediment accumulation is higher at the oceanic ridge and near the continent, but lower between them where the ocean is deeper. How can this be explained?

4. Given a constant average rate of sediment accumulation across the entire deep ocean basin, should the speed of sea-floor spreading influence the thickness of sediment that would accumulate on a section of sea floor? Why?

5. Below is a cross section of part of an ocean basin. Sedimentary cores are planned to be taken at the points indicated (A-D). It is necessary to know the approximate maximum thickness of sediment in each of these locations to select the correct sampling device. Given the distance of each point from the ridge crest, the average rate of sea floor spreading between each location and the average rate of sediment deposition, calculate the expected thickness of sediment at each location.

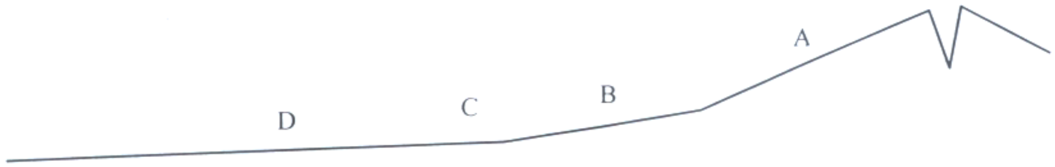
Location	Distance from Ridge Crest (km)	Average Spreading Rate (cm/yr)	Average Sedimentation Rate (cm/10^3 yrs)	Sediment Thickness (m)
A	150	3.0	2.0	______
B	470	4.0	1.5	______
C	650	2.0	1.0	______
D	1600	5.0	6.0	______

6. Below is a cross section of part of an ocean basin. Sedimentary cores have been collected at the points indicated (A-D). Given the distance of each point from the ridge crest, the average rate of sea floor spreading between each location and the thickness of sediment from each core, calculate the average rate of sedimentation at these localities.



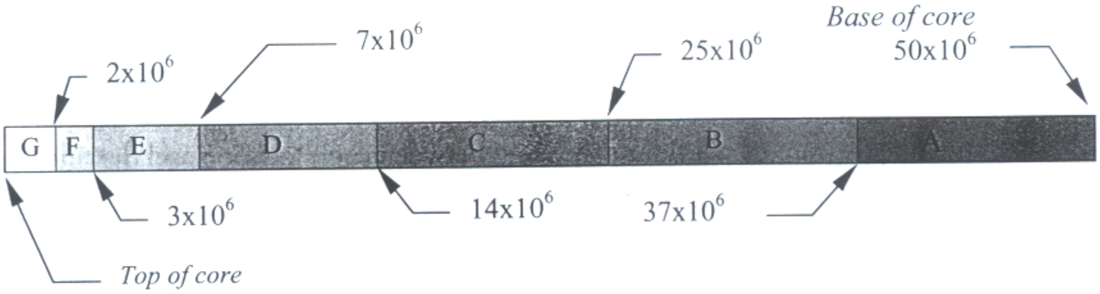
Location	Distance from Ridge Crest (km)	Average Spreading Rate (cm/yr)	Average Sedimentation Rate (cm/10^3 yrs)	Sediment Thickness (m)
A	140	2.0	______	140
B	540	4.0	______	510
C	930	3.0	______	600
D	2910	9.0	______	4100

7. Below is a cross section of part of an ocean basin. Sedimentary cores have been collected at the points indicated (A-D). Given the distance of each point from the ridge crest, the average rate of sedimentation and the thickness of sediment from each core, calculate the average rate of sea floor spreading between each location.



Location	Distance from Ridge Crest (km)	Average Spreading Rate (cm/yr)	Average Sedimentation Rate (cm/10^3 yrs)	Sediment Thickness (m)
A	750	________	1.0	150
B	1200	________	3.0	1050
C	1440	________	3.0	1530
D	1640	________	15.0	13800

8. Below is a diagram (not drawn to scale) of a sedimentary core recovered from the deep sea floor. It is 4.07 km long. The top and bottom of the core are labeled. The core is oriented horizontally because that is the orientation in which they are normally studied. The basalt just below the base of the core has been dated as being 50x10^6 years old. Fossils from within the core have been examined and they provided the additional dates, indicated in millions of years, on the core.



a. Determine the average rate of sedimentation for the entire core. ____________

b. Determine the average rate of sedimentation for each segment of the core.

Segment	Thickness (m)	Average rate of Sedimentation (cm/10^3)
A	1950	________
B	1080	________
C	660	________
D	210	________
E	120	________
F	10	________
G	40	________

c. How representative is the average rate of sedimentation for the entire column compared to the average rate of sedimentation for each segment?