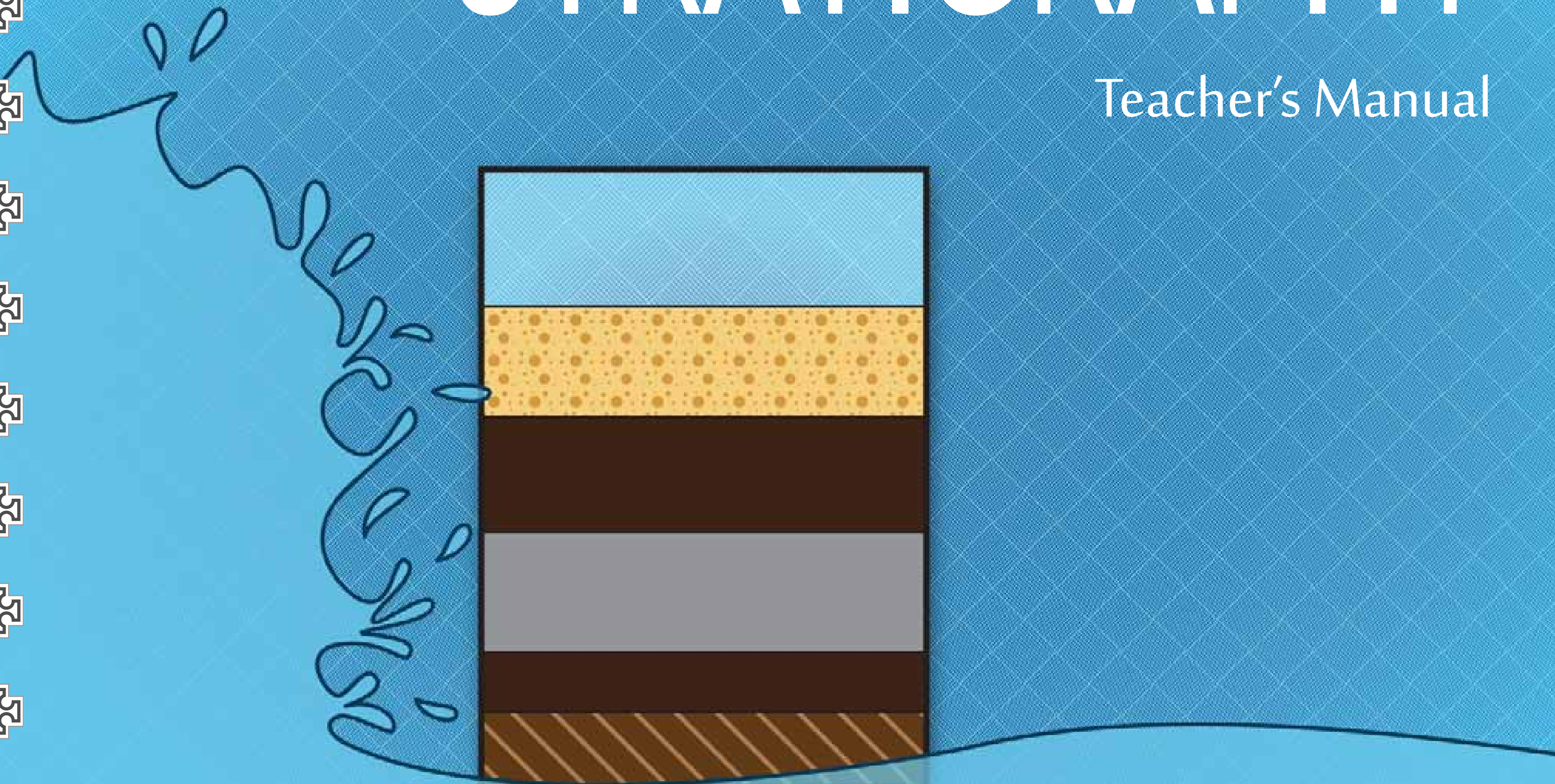
TSUNAMI & STRATIGRAPHY

Teacher's Manual



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Subjects:
Earth Sciences

Duration:
Three class periods (~60 min.) or two class periods + homework

Class size:
10 - 30 students

Summary

Overview:

This module teaches students to use stratigraphy understand how records of past events (in this case past tsunamis and volcanic eruptions) are archived in soils in coastal plains in the Kurils. Students will learn primary research techniques that scientists in the Kurils use to determine how often tsunamis have occurred in the past. Students will be introduced to the concept of correlation, learning how to interpolate points of observation into a defined surface.

Objectives:

Students will learn:

- How geologists study stratigraphy in the field
- How to describe stratigraphic sections
- How to plot stratigraphic sections
- How to correlate stratigraphic units across topographic profiles and between locations
- How to interpret past events from stratigraphy
- How to use observations about past events to make predictions about future hazards

Material Included in the Box:

- Digital and hard copies of illustrations to be used while instructing
- Digital and hard copies of the lesson packet to be distributed to the students
- Samples of peat, tsunami sand, and tephra
- Printout of activity questions

Vocabulary

Exacavation:

A rectangular hole dug by scientists to expose the stratigraphy.

GPS (global positioning system):

A system of satellites that can be used by people to find the latitude and longitude of their location on Earth.

Marsh soil / peat:

A specific kind of soil made of organic matter such as dead leaves and grass.

Soil:

Dark upper layer of earth in which plants grow.

Stratigraphy:

The study of accumulated sediments.

Tephra:

Fragments of rock thrown into the air by volcanic eruption. Tephra is classified into different categories based on the size of the grains:

Name	Grain size
Ash	< 2 mm
Cinder	2 mm < x < 64 mm
Block or Bomb	> 64 mm

Topography:

Study of the shape of the earth's surface, specifically changes in elevation and the shape of a landscape.

Tsunami:

A long-period wave generated by an impulse such as an earthquake, landslide, underwater volcanic eruption, or meteor impact.

Background Information

Stratigraphy and the relationship between the stratigraphy of different sites allow scientists to identify and date past natural disasters. Stratigraphic layers can record tsunamis, volcanic eruptions, and changes in environment. Using many data points, scientists can estimate the size of past natural disasters based on the area affected by a specific event.

During certain types of volcanic eruption a mixture of hot gasses, rock fragments, and molten rock are pushed into the atmosphere. The mixture is carried by the prevailing wind. Recent incidents, such as the shutdown of airports in Europe due to the eruption of an Icelandic volcano, were due to volcanic particles in the atmosphere. Because of gravity and cooling, the mixture falls back to earth, creating layers of unconsolidated volcanic rock, called tephra. Typically the largest grains are found near the volcano and the smallest grains are carried further. Tephra is described based on the size of the grains and the chemistry of the rocks. Different volcanoes and often even different eruptions from the same volcano have different ratios of elements in their tephra. Because these layers are widespread and represent a short period of time (hours to weeks), scientists can date these layers and use them to make correlations between sites.

Tsunamis are long-period waves generated by some type of impulse such as an earthquake or landslide. They differ from normal wind waves because they move the entire water column even in the deep ocean. When the waves come onto shore, they both erode part of the shoreline and deposit sediment over low-lying areas. In the geological record these layers can be identified in areas where sand is not common, such as bogs and marshes. These layers can also contain fragments of marine shell or microscopic marine organisms such as diatoms or foraminifera. These indicate that the sediment originated from the ocean and were transported to the freshwater environment. By counting the number of tsunami deposits in a time period, scientists can find the frequency of tsunami events. By tracing the layers inland scientists can determine the frequency of larger and smaller events.

Tsunami Waves Compared to Wind Waves

Wavelength:

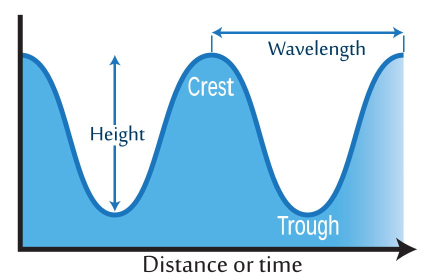
- Wind waves: 100 - 200 m
- Tsunami: 200 - 500 km

Velocity (both types of waves decelerate as they move onto the shore):

- Wind waves: 90 km/hr
- Tsunami: 950 km/hr (as fast as jet planes) in deep water

Period (time between two successive waves):

- Wind waves: 5 - 20 sec
- Tsunami: 10 min to 2 hrs



Lesson Activity 1:

Students learn about tsunami events and stratigraphy. Students learn how geologists study ancient tsunami events. Students practice using Google Earth and plotting distance and elevation data (optional).

Warm up:

Ask students if they know the difference between regular waves in the ocean and tsunami. Ask what recent tsunami events they have heard about in the news. Ask students to remember what stratigraphy is if they had already learned about it from the Chronology lessons.

Procedure:

1. Use the slideshow about tsunami and stratigraphy to fill in the gaps in student knowledge that you discover during the warm up (for example, if students know what tsunami are and how they form, go straight to the first slide about stratigraphy).
2. Discuss why it is important to understand the topography of a shoreline to study tsunami deposits.
3. Have students plot the provided GPS coordinates in Google Earth to see the aerial images of Dushnaya Bay, Simushir Island. The data from this bay is used in following exercises. Ask students what topographic features they see, whether this would be a good place to camp/live.
4. Have students practice constructing a topographic profile from the table with distance and elevation of actual measurements at Dushnaya Bay on Simushir Island. This can be done using Excel's graph capabilities or with pen and paper. The final version of the profile is also provided for teachers who prefer to skip this step if it is too simple/time consuming for their students or computers are not available.
5. Hand out the layer descriptions taken in the field for each of the four stratigraphic sections and the templates for drawing what the researchers saw in their excavation. The first section is filled in as an example for the students. You may have each student draw all three remaining sections or have groups of three in which each student draws one to be put together with the other two.
6. Discuss with the students the deposits that tsunami leave behind. (These are sands, usually less than 25 cm thick). Using this definition ask students to determine how many tsunami deposits are found in each section. Here are the answers:

a. Site 1 – 2
b. Site 2 – 10
c. Site 3 – 5
d. Site 4 – 0

Wrap up:

Discuss these results. In general, we expect to see more tsunami deposits closer to the shore and at lower elevation because smaller tsunamis happen more often that large tsunamis; this pattern is followed in Sites 2 to 4. So why does site one have fewer identified tsunami deposits? There are several possible reasons – one is that this close to shore, the deposit might be thicker than 25 cm (in Indonesia, deposits close to shore were up to 50 cm); also, this close to shore, some tsunamis may be eroding, rather than depositing, sediment. A more complicated reason is that individual deposits here may be difficult to identify because the site is close to the beach and sand can be added by storm waves and wind, as well as by tsunamis. It is possible that the thick sands at Site 1 are tsunami deposits, or accumulations of multiple deposits, without good soil in between to distinguish individual layers. Depending on student level, they may have some of these ideas, or others, for why there are "fewer" tsunami deposits at site 1. Discuss these results (JODY is writing a paragraph about this – why are there different numbers of tsunami deposits at different distances from the ocean?)

Lesson Activity 2:

Warm up:

Review what was done/learned during the previous lesson. Have students take a look at the sections they drew and notice similar layers and discuss what that might mean (they were deposited by same processes maybe during the same time).

Procedure:

1. Discuss with students why layers might be different or differently described (*). Using the table with descriptions of each layer from the excavation notes and the columns students drew, have students draw lines between layers that have similar descriptions (make sure students connect bottom of a layer in one section to bottom of the same layer in another section, and similarly, tops connect to tops. Important—lines of correlation CANNOT cross.

*There are many reasons why the field descriptions of a (the same) tephra layer can differ. The first is because different field workers made the descriptions, some being Russian and some American, with different systems of description or different terminology. The second is that the color of the tephra can vary with water content, light conditions, and comparison to nearby layers. The third is that there is natural variation in a tephra layer, even over short distances—during deposition they may vary due to wind changes, or local bumps on the surface, etc.; after deposition, they be disturbed by plants or animals, or by other soil processes. More reliable is to look at the combination of (generalized) characteristics, as well as the position of the tephra in a column – each tephra is a time line, so it must always lie in the same stratigraphic position relative to other tephras (that is, correlation lines cannot cross).

2. Tephras that can be found in different sections and thus tie them together are called marker tephras. Have students label them with numbers starting with 1 at the topmost marker tephra. Ask students how many marker tephras are in each section. Answers:

a. Site 1 – 1
b. Site 2 – 3
c. Site 3 – 5
d. Site 4 – 5

3. Explain to the class, that the shoreline on this profile has built outward into the sea as time has gone on, so that some land at the seaward sites is younger than the volcanic eruptions that generated some of the tephras. Have students determine how many tsunami deposits are located above each tephra layer in each excavation by filling out this table (leave the space blank if there is no tephra with that number in that excavation; table can be drawn on the board without the answers):

	Site 1	Site 2	Site 3	Site 4
Above tephra 1	2	3	1	0
Above tephra 2		6	2	0
Above tephra 3		9	2	0
Above tephra 4			3	0
Above tephra 5			5	0

3. Have students calculate the thickness of sediment between each tephra layer in each section by filling out this table (leave the space blank if there is no tephra with that number in that excavation; table can be drawn on the board without the answers):

	Site 1	Site 2	Site 3	Site 4
Above tephra 1	80	27	12	9
Above tephra 2		31	9	7
Above tephra 3		14	5	1
Above tephra 4			6	2
Above tephra 5			26	2

Wrap up:

Discuss as a class what happens to the thickness of sand and soil between tephra layers as you travel upward and inland (it decreases) and why that might be the case.

a. The closer to the beach, the more sand is deposited from storms, tsunamis, and wind (these can each be an answer). This adds thickness to the soil.

b. Low, flat areas are typically wetter and more plants grow. This adds more organic material to the soil.

c. Slopes and high points are usually eroding (losing thickness) and low areas store the sediment washed from the slopes and high areas.

Lesson Activity 3:

Warm up:

Review the previous day's materials.

Procedure:

1. Break the class into small groups and hand out the worksheets for the last exercise with 10 questions.
2. After the groups are done, discuss the answers as a whole class. Alternatively, these questions can be used as homework after the second day of activities.

Conclusion:

Discuss with the class how people can be affected by tsunami and volcanic eruptions today and what individuals should do in case of each.

Introduction

Your goal is to determine how often big tsunamis affect the Kuril Island coasts using the same method that tsunami scientists use.

Exercise:
Plotting topographic profiles

Measuring coastal topography is the first step in identifying tsunami deposits and determining how big the tsunamis were. Open the Excel spreadsheet provided on-line or on a CD in the Burke Box. Use Excel to make a graph of the surface of the coastal plain. Distance should be your x-axis and elevation your y-axis; label your axes. Circle the points on your topographic plots where we dug excavations.

How far inland and at what elevation did we dig excavations?
(Refer to the spreadsheet for the most accurate numbers; look at the profile to get an idea of distance and elevation.)

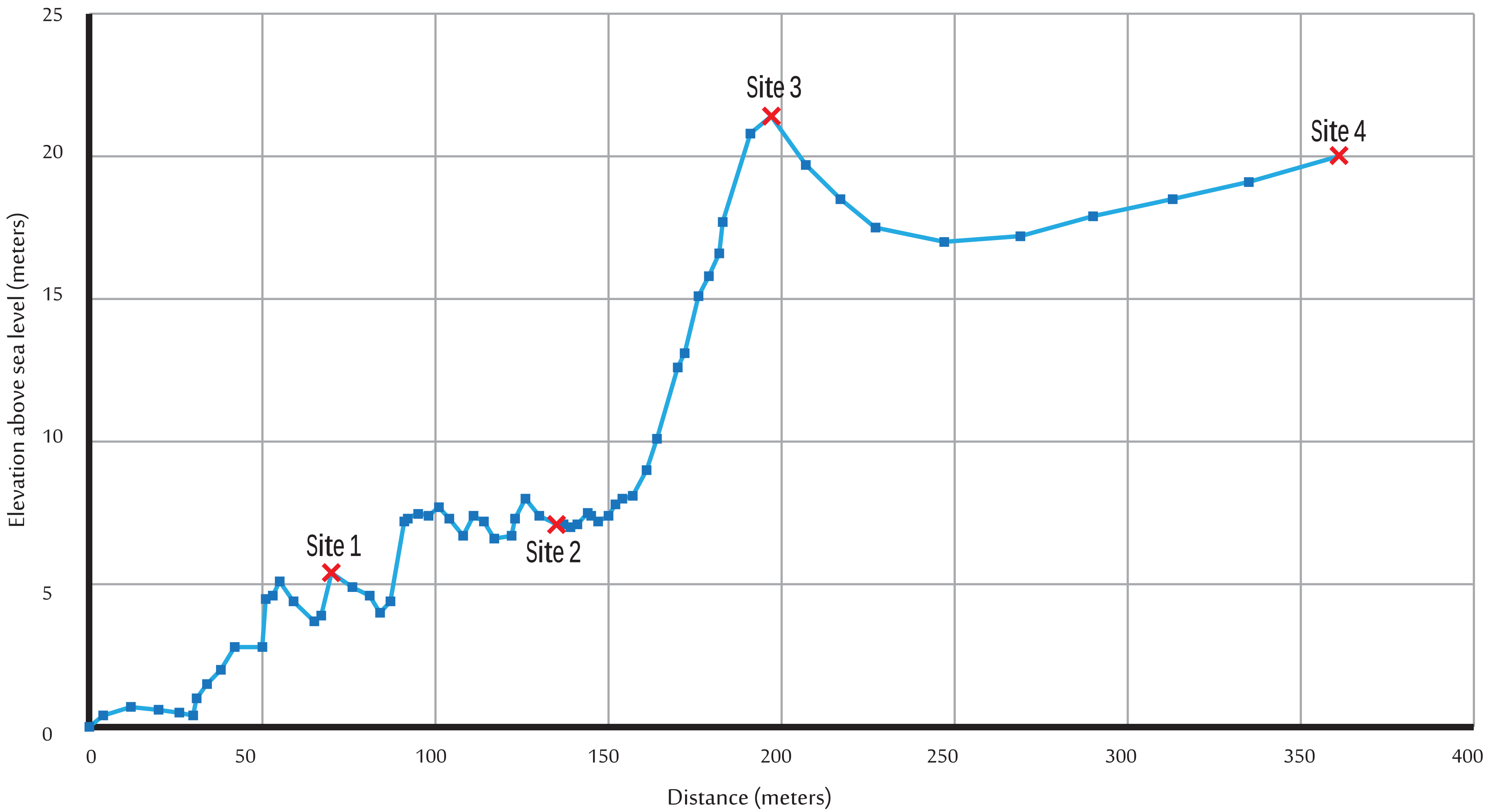
	Site 1	Site 2	Site 3	Site 4
Distance (in meters)	70	135	197	335
Elevation (in meters)	5.4	7.1	21.4	19.1

Student Worksheet guide

Plotting topographic profiles - continued

	distance (in meters)	elevation (in meters)	Notes	
1	361	20.0	edge of birch forest, quite flat past here	
2	335	19.1	excavation 102 near here	SITE 4
3	313	18.5		
4	290	17.9		
5	269	17.2		
6	247	17.0	low point	
7	227	17.5	excavation 101	
8	217	18.5		
9	207	19.7	scattered pine shrubs	
10	197	21.4	top of slope	SITE 3
11	191	20.8		
12	183	17.7		
13	182	16.6		
14	179	15.8	step in slope	
15	176	15.1		
16	172	13.1		
17	170	12.6		
18	164	10.1		
19	161	9.0		
20	157	8.1	base of slope, tall flowers above	
21	154	8.0	small ridge	
22	152	7.8		
23	150	7.4	edge of marsh	
24	147	7.2	mid marsh	
25	145	7.4	edge of marsh	
26	144	7.5		
27	141	7.1	edge of marsh	
28	139	7.0	mid marsh	
29	137	7.1	edge of marsh	
30	135	7.1	marshy area	SITE 2
31	130	7.4	[no point 32]	
33	126	8.0	ridge crest	
34	123	7.3		
35	122	6.7	floated debris, 2006 runup	
36	117	6.6	beach grass starts; people disturbance	
37	114	7.2		
38	111	7.4		
39	108	6.7	trough	
40	104	7.3		
41	101	7.7	ridge crest	
42	98	7.4	people disturbance	
43	95	7.5	excavation near here	
44	92	7.3		
45	91	7.2	edge of ridge	
46	87	4.4	change in slope	
47	84	4.0	trough with short flowers; less beach grass	
48	81	4.6		
49	76	4.9		
50	70	5.4	excavation near here	SITE 1
51	67	3.9		
52	65	3.7	low spot	
53	59	4.4		
54	55	5.1	ridge	
55	53	4.6	beach grass	
56	51	4.5	top edge of scarp; cleaned cliff face for excavation	
57	50	2.8	base of scarp, sandy	
58	42	2.8	top of small berm; a little vegetation	
59	38	2.0		
60	34	1.5		
61	31	1.0	top of stream bank	
62	30	0.4	high tide	
63	26	0.5	stream edge	
64	20	0.6		
65	12	0.7	high point	
66	4	0.4	rock edge	
67	0	0.0	mid-rock outcrop, water level 3:40 PM	
			more rocks about 100 m out to sea	

Dushnaya Bay
Simushir Island
Profile 2



Student Worksheet guide

Drawing stratigraphic sections

On the template provided and using our written descriptions, draw what we saw in each excavation. Site 1 is already drawn for you to help you get started. Each person in a group should draw one section. Then line the sections up from seaward (site 1) to landward (site 4).

Question #1:

How many sand deposits are there in each excavation?

(Tsunamis can leave behind sand layers typically less than 25 cm thick.)

	Site 1	Site 2	Site 3	Site 4
Number of tsunami deposits	2	10	5	0

Question #2:

Are there more tsunami deposits at lower or higher excavations?

Answer: Lower

Question #3:

Are there more tsunami deposits closer to or further from the ocean?

Answer: Closer

Question #4:

What might be the source of other, thicker sand deposits?

Answer: Wind blown sand, beach deposits, river flooding, and landslides (all are acceptable)

Student Worksheet guide

Drawing stratigraphic sections - continued

Notes from excavations, Profile 2 (2006 & 2007) Dushnaya Bay, Simushir Island

Site 1

Excavation 96

Vegetation: beach grass & flowers

Depth (cm)	Description
0-2	gray sand - new in 2007 survey
2-5	soil with roots
5-60	gray sand, top has roots
60-62	soil
62-80	gray sand
80-85	tephra, 3 layers, gray and brown
85-120	sand

Site 2

Excavation 98

Vegetation: moss, sedges, marsh

Depth (cm)	Description
0-4	vegetation mat [soil]
4-6	gray sand
6-13	marsh soil [peat]
13-15	gray sand
15-25	marsh soil [peat]
25-27	gray sand
27-34	tephra, 3 layers, gray and brown
34-40	marsh soil [peat]
40-44	clean gray sand
44-47	marsh soil [peat]
47-49	gray sand
49-51	peat
51-52	clean sand
52-65	marsh soil [peat] with 2 thin sand layers
65-69	coarse gray cinders, sharp edges
69-76	marsh soil [peat]
76-78	sand
78-84	marsh soil [peat] with 1 thin sand layer

Depth (cm)	Description
84-86	tephra [volcanic ash] [red and black cinders]
86-90	peat
90-93	sand
93-94	peat
94-109	sand
109-111	tephra, fine-grained, gray
111-114	sand [peaty]; sample of wood for dating
114-116	marsh soil [peat], sample for radiocarbon

Notes from excavations, Profile 2 (2006 & 2007) Dushnaya Bay, Simushir Island

Site 3

Excavation 100

Vegetation: grasses, flowers, a few pine shrubs

Depth (cm)	Description
0-6	soil with roots
6-10	soil
10-12	gray sand
12-20	tephra, 3 layers, gray & reddish brown
20-24	soil
24-25	gray sand
25-30	coarse gray cinders
30-35	soil with thin sand layer; charcoal sample
35-38	tephra, fine gray and orangish
38-40	soil
40-43	sand
43-44	tephra
44-70	sand
70-80	gray cinders
80-95	sand
95-98	soil
98-115	sand
115-118	tephra, yellow sand

Site 4

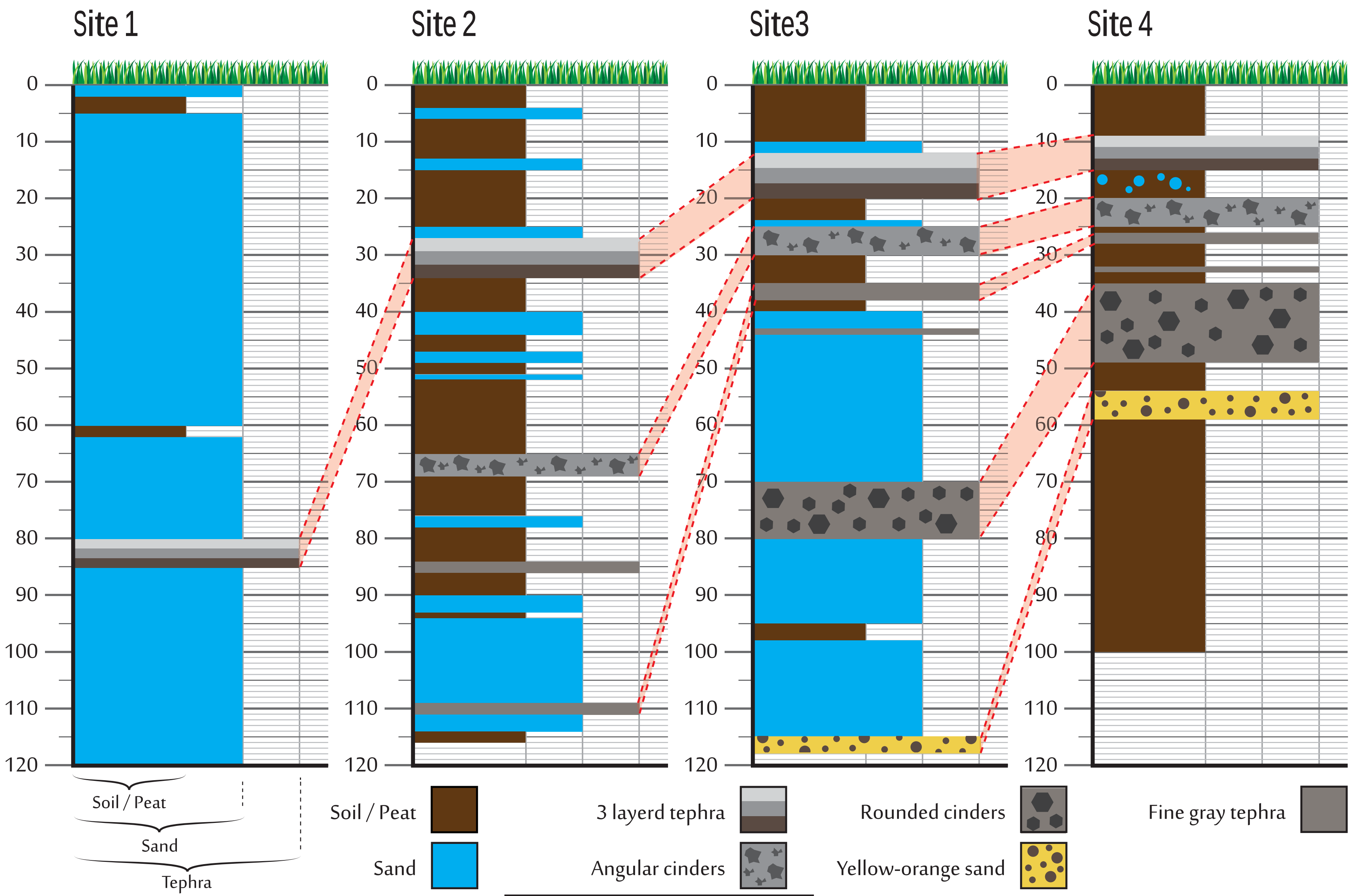
Excavation 102

Vegetation: grasses, flowers, shrubs, near birch

Depth (cm)	Description
0-6	soil with roots
6-9	soil, silty gray
9-15	tephra, 3 layers, red-gray and red-brown
15-20	soil with a little sand
20-25	coarse gray cinders, angular grains
25-26	soil
26-28	tephra, fine, medium gray to reddish
28-32	silty soil, possible volcanic ash
32-33	fine cinders, tephra
33-35	silty soil, possible volcanic ash
35-49	gray cinders, clean, smooth grains
49-54	silty soil, possible volcanic ash
54-59	tephra,orange-yellow sand
59-70	soil, silty
70-100	soil, compact

Student Worksheet guide

Drawing stratigraphic sections - continued



The Kuril Biocomplexity Project: www.kbp.org

Student Worksheet guide

Correlating tephra layers between stratigraphic sections

Write the description from the excavation notes of each tephra layer next to the corresponding layer on your stratigraphic column. Draw a line between layers that have very similar descriptions (similar thicknesses, color, grain size, etc.). These lines represent timelines. We call these tephras marker tephras. Label the tephra with numbers starting with 1 at the topmost marker tephra.

Question #1:

How many marker tephras are in the different sites?

	Site 1	Site 2	Site 3	Site 4
Number of marker tephras	1	3	5	5

Question #2:

The shoreline on this profile has built outward into the sea as time has gone on, so that some land at the seaward sites is younger than the volcanic eruptions that generated some of the tephras.

How many tsunami deposits are located above each tephra layer in each excavation? If the tephra is not present, leave the space blank.

	Site 1	Site 2	Site 3	Site 4
Above tephra 1	2	3	1	0
Above tephra 2	x	6	2	0
Above tephra 3	x	9	2	0
Above tephra 4	x	x	3	0
Above tephra 5	x	x	5	0

Student Worksheet guide

Correlating tephra layers between stratigraphic sections - continued

Question #3:

What is the thickness of sediment between each tephra layer in each site?

	Site 1	Site 2	Site 3	Site 4
Above tephra 1	80	27	12	9
Between 1 & 2	x	31	9	7
Between 2 & 3	x	14	5	1
Between 3 & 4	x	x	6	2
Between 4 & 5	x	x	26	2

Question #4:

How do the thickness of sand and soil between tephra layers change as you travel inland and uphill?

Answer: The thickness of soil between tephra layers decreases.

Question #5:

What might be two reasons for the change in thickness of marshy soil/peat along the profile?

Answer:

1. The closer to the beach, the more sand is deposited from storms, tsunamis, and wind (these can each be an answer). This adds thickness to the soil.

2. Low, flat areas are typically wetter and more plants grow. This adds more organic material to the soil.

3. Slopes and high points are usually eroding (losing thickness) and low areas store the sediment washed from the slopes and high areas.

Student Worksheet guide

Adding time to your stratigraphic sections

We just received from the lab the results of radiocarbon dating of organic material for our summer's fieldwork. The charcoal in Site 3 is dated to be 900 yrs BP and the wood in Site 2 is 1,100 yrs BP. Your volcanology colleagues have chemically identified the 3-layered tephra as being a 200-yrs-BP eruption of the local Prevo volcano and the yellow sandy tephra as being from a gigantic eruption of Medvedzhia Volcano ~2,000 yrs BP. Add notes on your stratigraphic sections to indicate the age of all these layers.

Questions #1:

About how old is the tephra made of gray cinders?

Answer: between 900 and 200 yrs BP

Student Worksheet guide

Homework

Based on all that you now know about the coastal stratigraphy, you can calculate how often tsunamis affect this region. How many tsunami deposits are located between known dates in your stratigraphy?

Question #1:

Write the number of sand layers (tsunami deposits) that are in each site (Write an "X" if there are no sediments in a certain age-range in a site.)

Yrs BP	Site 1	Site 2	Site 3	Site 4
in the last 250 yrs	2	3	1	0
0-1000	x	6	2	0
1000-2000	x	x	3	0
0-2000	x	x	5	0

Question #2:

What is the maximum number of tsunamis per 1000 years we observed?

Answer: 6

Question #3:

What is the maximum number of tsunamis per 2,000 years we observed?

Answer: 6

Question #4:

Take the numbers in the chart above, and divide by the time interval to get tsunami frequency: For example, in Site 2, there are three sand layers above the 250-year-old tephra 1 (from Prevo volcano). The frequency at site 2 for this time period is therefore 250 years divided by 3 tsunamis, or about 80 years – one tsunami on average per 83 years.

Frequency of tsunami deposits (years)

Yrs BP	Site 1	Site 2	Site 3	Site 4
in the last 250 yrs	125	83	250	0
0-1000	x	167	500	0
1000-2000	x	x	333	0
0-2000	x	x	400	0

Question #5:

What is the frequency of tsunamis (total time/ total # of tsunamis) for this one particular bay:

- for low-lying areas (Site 2)? 1 tsunami per (Answer: 167) years
- for high areas (Site 3)? 1 tsunami per (Answer: 400) years

Question #6:

If the average lifespan of a person is 80 years old, how many tsunamis would they see in their lifetime?

Answer: between 0 and 1 (There is a 1-in-2 chance that they would see a small tsunami [low-lying areas] and a 1-in-5 chance that they would see a large tsunami [high areas].)

Question #7:

How does the frequency of tsunamis you calculated for the Kuril Islands compare with the general frequency on the pacific coast of Washington State (1 large tsunami per 500 years)? Why do you think that is the case?

Answer: Tsunamis occur more frequently in the Kuril Islands than they do on the Pacific coast of Washington.

The difference is due to different rates of subduction and different ages of the subducted plates. The plates are coming together at a higher rate at the Kuril subduction zone than the Cascadia subduction zone (~8 mm/yr vs ~4 mm/yr), resulting in more earthquakes. The downward moving oceanic plate at the Kuril subduction zone is older, colder, and more brittle than the down going plate in the Cascadia subduction zone. Scientists hypothesize that more earthquakes happen when the down going plate is older.

Question #8:

How long has the low-lying part of the coastal plain existed (excavation 1 and 2)? Why are there only young tephras in the seaward excavations?

Answer: The low-lying coastal plain has existed for less than 2,000 years. The shoreline is building seaward through time, so therefore only young tephra are found near the beach.

Note that the shoreline is moving seaward with time due to two factors:

1. The volcano on the island adds a large volume of sediment to the near shore area through eruptions and rivers eroding volcanic sediments, transporting them to the ocean. This sediment is reworked by waves and deposited along the coast, adding to the width of the coastal plain.

2. The coastal plain can be uplifted during large earthquakes. Uplift brings areas that were formerly underwater above sea level and therefore widens the beach area. Through time vegetation grows on this surface and it can become part of the coastal plain.

Question #9:

Compare variations in the thickness of tephra and tsunami deposits in your stratigraphic sections. Where do you find the thickest tsunami deposits and why? Why do tsunami deposits vary in thickness more than tephra layers?

Answer: Tsunamis lose energy as they travel across land; they are most energetic near the beach. Therefore, the tsunami will be able to carry more sediment and leave a thicker deposit closer to the beach. In contrast, tephra falls out of the air and blankets the ground surface in a uniformly thick layer.

Note: Tephra layers do vary in thickness over a wide area— tephra deposits are thicker closer to their source volcano. However, over the small area covered in the exercise, they will not vary much in thickness.

Question #10:

You are planning to build a community at Dushnaya Bay. Your community will depend on boats to fish for food. How can you use the information from this exercise to help you plan your village? What would you consider when choosing the site of your village? What frequency of tsunamis do you think is acceptable for a community?

Note: this is meant to be an open-ended question. The main points to consider are

1. Your community will experience tsunamis and volcanic eruptions in the future.

2. You do not want a community right on the ocean. Building it at a higher elevation would provide more protection from tsunamis and storms. Locations in Dushnaya Bay seem to be equally affected by volcanic eruptions, so location is not a factor when deciding how to protect your community from tephra fall.

3. A national or global "acceptable" level of tsunami frequency is not established. Many cities in the US and around the world are built in areas that can be inundated by tsunamis. Determining what is "acceptable" is up to the student.