Kuril Burke Box

Biocomplexity of an island chain

Teacher's Manual

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Overview

Purpose:

The Kuril Biocomplexity Education Kit is an educational resource for teachers in Middle and High School science and social science classes, particularly for students in grades 7-10. We designed the kit around an actual interdisciplinary research project that combined the research interests and skills of archaeologists, ecologists, geologists, and climate scientists. The kit itself provides curriculum and activities to teach students about aspects of each of these disciplines and to encourage them to think about how sciences need to be integrated to better understand the relationships between physical, biological, and social processes.

We based the curriculum and activities in this kit on research conducted in the volcanic Kuril Islands between northern Japan and the Russian Kamchatka Peninsula. The researchers on this project sought to understand the relationships between geological processes (such as volcanic eruptions, earthquakes, and tsunamis), climate changes (increased or decreased sea ice, temperature, and storms), ecological processes (such as changing population dynamics and biogeographical distributions of plants and animals), and human settlement histories and economies. Scholars recognize that earth systems are connected in numerous ways over different spatial and temporal scales. Even so, research that explores the connections between traditionally-bounded scientific disciplines is often challenging to conduct and neglected in scientific education and practice. The Kuril research project and this education kit capitalize on the growing awareness that we cannot neglect interdisciplinary research. In this kit, you will find the resources to teach both disciplinary and interdisciplinary science to your students.

Project Background:

University of Washington initiated the Kuril Biocomplexity Project was initiated officially in 2005 when the National Science Foundation (NSF) granted the university a research award to begin work on a study of the "Biocomplexity of coupled natural and human systems" in the Kuril Archipelago. "Biocomplexity" was a term coined by then NSF Director, Rita Colwell in 1999 to refer to the complex and integrated nature of ecological systems. Scientists began to research biocomplexity to gain a better understanding of the ways that biological organisms and populations are dynamically intertwined with other systems. Humans have always been actors in the ecosystems in which they live (with impacts extending far beyond), and the Kuril Biocomplexity Project sought to disentangle some of these complex relationships by looking at the history of geological, climatic, biological, and anthropological developments in a relatively simple geographical context – a string of small islands for which the complexities would naturally be reduced. By virtue of its geography, the Kuril archipelago serves as a sort of yardstick, ranging from near continental islands at the margins (where migration into and out of the archipelago by plants, animals, and people was always relatively easy), to remote (and smaller) islands near the center of the chain (where migrations were more limited and, as a result, biodiversity much lower). Geography and biology are therefore closely related. When climatic factors are also considered, including the existence of a climatic gradient along the island chain and long-term climate change that have affected the archipelago directly and indirectly over the millennia, our understanding of the system is further complicated. Superimposed on these variables are the geological consequences of living in a subduction zone where volcanic eruptions, earthquakes, and tsunamis were relatively common occurrences. Finally, when we include the human hunter-gatherers who settled the Kurils, made a living there, engaged in trade with outside communities, and abandoned the archipelago numerous times throughout the last 4,000 years, our understanding of the region's biocompliexity reaches truly staggering proportions.

We started the project with many broad questions. For example: What was the history of catastrophic geological events across the island chain? What was the nature of climate change? When did people move into the islands and did they abandon parts or the entire chain at different times in the past? If so, why? How did human settlement relate to differences in the biodiversity (high on the ends, low in the center)? Were people more vulnerable to extinction/abandonment if they lived in some places compared to others? Did people cause ecological crashes/species extinctions through overharvesting or habitat disruption, and if so, was this more common on remote and more ecologically precarious islands? How did islanders interact with each other in different regions or with people outside of the island chain? Were people who were living in the remote central islands more insulated from changes occurring outside of the island chain? Were they more vulnerable to isolation from opportunities connected to the outside? Three seasons of field work and six years of analysis have yielded answers to some of these questions and opened up many new questions that we continue to pursue. The exercises in this education kit will help students to get a taste for what it is like to try and study a few of these questions.

Educational Objectives:

The purpose of this education kit is to use the Kurils as a focus for scientific education. We designed every exercise in this kit with the goal of teaching basic scientific concepts and applications to students. The most important goal is to give students an understanding of what it means to be a scientist and how field scientists collect and analyze data. Students who complete the exercises in this kit should be able to see themselves as scientists. By focusing on the practice of field work linked to data analysis, this exercise should expand student understanding of scientific practice beyond the laboratory experiments that are often central in scientific curricula. Also, with a range of different sciences covered, the kit gives students a broader survey of the diversity of scientific activities (at least in the earth, atmospheric, life, and human sciences). By providing insights into how several different scientific fields engage in research in a common region, the modules in this kit should help students see the interrelationships between fields of knowledge and how the earth, atmosphere, life, and social systems are in fact connected in dynamic systems. It should prepare students to see the world more holistically and perhaps become interested in scientific careers that pursue interdisciplinary research questions.

Washington State "Essential Academic Learning Requirements" (EALRs)

Introduction:

While this kit should be well-suited to middle and high school curricula elsewhere, we specifically developed this kit toward satisfying some of the core elements prescribed by the Washington State EALRs. The kit is especially focused on exposing students to the practice of **science** but also covers related areas in **social studies.**

Science Requirements:

6th - 8th Grades

EALR 2: Inquiry
6-8th grade: Questioning and Investigating.
LESSON: All lessons

6-8 INQA: Scientific inquiry involves asking and answering questions and comparing the answers with what scientist already know about the world.

6-8 INQC: Collecting, analyzing and displaying data are essential aspects of all investigations

6-8 INQE Models are used to represent objects, events, systems, and processes. Models can be used to test hypothesis and better understand phenomena, but they have limitations.

EALR 3: Application
6-8th grade: Science, Technology, and Problem Solving
LESSON: Artifacts

6-8 APPH: People in all cultures have made and continue to make contributions to society through science and technology.

EALR 4: Earth and Space
6-8th grade: Cycles in Earth Systems
LESSON: Tsunami & Stratigraphy, Natural Hazards

6-8 ES2G Landforms are created by processes that build up structures and processes that break down and carry away material through erosion and weathering.

6-8th grade: Evidence of Change
LESSON: Tsunami & Stratigraphy, Natural Hazards

6-8 ES3A: Our understanding of Earth History is based on the assumption that processes we see today are similar to those that occurred in the past.

6-8 ES3B: Thousands of layers of sedimentary rock provide evidence that allows us to determine the age of Earth's changing surface and to estimate the age of fossils found in the rocks.

6-8 ES3C: In most locations sedimentary rocks are in horizontal formation with the oldest layers on the bottom. However, in some location, rock layers are folded, tipped or even inverted, providing evidence of geologic events in the distant past

6-8 ES3D: Earth has been shaped by many natural catastrophes, including earthquakes, volcanic eruptions, glaciers, floods, storms, tsunami, and the impacts of asteroids.

EALR 4: Life Science
6-8th grade: From Cells to Organisms
LESSON: Zooarchaeology

6-8 LS1E: In classifying organisms, scientists consider both internal and external structures and behaviors.

6-8th grade: Flow of Energy Through Ecosystems
LESSON: Paleoclimate, Biogeography

6-8 LS2D Ecosystems are continuously changing. Causes of these changes include non-living factors such as the amount of light, range of temperatures, and availability of water, as well as living factors such as the disappearance of different species through disease, predation, habitat destruction and overuse of resources or the introduction of new species

9-12th grades

EALR 2: Inquiry
9-12th grade: Conducting Analyses and Thinking Logically
LESSON: All Lessons

9-12 INQA: Scientists generate and evaluate questions to investigate the natural world.

9-12 INQC: Conclusions must be logical, based on evidence, and consistent with prior established knowledge.

9-12 INQE: The essence of scientific investigation involves the development of a theory or conceptual model that can generate testable predictions.

9-12 INQF: Science is a human endeavor that involves logical reasoning and creativity and entails the testing, revision, and occasional discarding of theories as new evidence comes to light.

EALR 3: Application
9-12th grade: Science, Technology, and Society
LESSON: All Lessons

9-12 APPD: The ability to solve problems is greatly enhanced by use of mathematics and informational technologies.

EALR 4: Physical Science
9-12th grade: Chemical Reactions
LESSON: Chronology

9-12 PS2F: All forms of life are composed of large molecules that contain carbon. Carbon atoms bond to one another and other elements by sharing electrons, forming covalent bonds. Stable molecules of carbon have four covalent bonds per carbon atom.

9-12 PS2J: The number of neutrons in the nucleus of an atom determines the isotope of the element. Radioactive isotopes are unstable and emit particles and/or radiation. Though the timing of a single nuclear decay is unpredictable, a large group of nuclei decay at a predictable rate, making it possible to estimate the age of materials that contain radioactive isotopes.

Social Studies Requirements:

EALR 4: Earth and Space Science
9-12th grade: Energy in Earth Systems
LESSON: Settlement, Biogeography, Paleoclimate

9-12 ES2D: The Earth does not have infinite resources; increasing human consumption impacts the natural processes that renew some resources and it depletes other resources including those that cannot be renewed.

9-12th grade: Evolution of the Earth
LESSON: Chronology, Paleoclimate, Tsunami & Stratigraphy, Natural Hazards

9-12 ES3A Interactions among the solid Earth, the oceans, the atmosphere, and organisms have resulted in the ongoning evolution of the Earth system. We can observe changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hunderds of millions of years.

9-12 ES3B: Geologic time can be estimated by several methods.

9-12th grade: Maintenance and Stability of Populations
LESSON: Paleoclimate, Biogeography

9-12 LS2B: Living organisms have the capacity to produce very large populations. Population density is the number of individuals of a particular population living in a given amount of space.

EALR 2 Economics: The student applies understanding of economic concepts and systems to analyze decision-making and the interactions between individuals, households, businesses, governments, and societies.
LESSON: Natural Hazards, Paleoclimate, Biogeography, Settlement

2.1 Understands that people have to make choices between wants and needs and evaluate the outcomes of those choices.

6th grade: GLE 2.1.1

2.4 Understands the economic issues and problems that all societies face.

9/10th grade: GLE 2.4.1

12th grade: GLE 2.4.1

EALR 3: Geography: The student uses spatial perspective to make reasoned decisions by applying the concepts of location, region, and movement and demonstrating knowledge of how geographic features and human cultures impact environments.

Washington State "Essential Academic Learning Requirements" (EALRs)

Continued

LESSON: Natural Hazards, Paleoclimate, Biogeography, Settlement

3.1 Understands the physical characteristics, cultural characteristics, and location of places, regions, and spatial patterns on the Earth's surface.

6th grade: GLE 3.1.3, 3.1.2

7th grade: GLE 3.1.1, 3.1.2

9/10th grade: GLE 3.1.2

11th grade: GLE 3.1.1

3.2 Understands human interaction with the environment.

6th grade: GLE 3.2.1, 3.2.2, 3.2.3

7th grade: GLE 3.2.2

9/10th grade: GLE 3.2.1, 3.2.3

EALR 4: History The student understands and applies knowledge of historical thinking, chronology, eras, turning points, major ideas, individuals and themes of local, Washington State, tribal, United States, and world history in order to evaluate how history shapes the present and future.

LESSON: Chronology, Natural Hazards, Settlement

4.1 Understands historical chronology

9/10th grade: GLE4.1.1

4.2 Understands and analyzes causal factors that have shaped major events in history

7th grade: GLE 4.2.2

4.4 Uses history to understand the present and plan for the future.

6th grade: GLE 4.4.1

7th grade: GLE 4.4.1

EALR 5: Social Studies Skills The student understands and applies reasoning skills to conduct research, deliberate, form, and evaluate positions through the processes of reading, writing ,and communicating.

LESSON: All lessons

5.1 Uses critical reasoning skills to analyze and evaluate positions.

6th grade: GLE 5.1.2

5.2 Uses inquiry – based research

6th grade: GLE 5.2.1

7th grade: GLE 5.2.1

Overview and objectives of each module

Chronology:

Overview:

In this module, students will be introduced to the radiocarbon dating method, which archaeologists and geologists frequently use to determine when the events which interest them occurred. During this lesson, the teacher will instruct the students about the concepts foundational to the radiocarbon dating method. This lesson will require students to identify suitable and unsuitable materials for radiocarbon dating, use a graph to determine the age of samples based on the amount of radiocarbon that is present in them, and do a take-home writing assignment in which they will design a plan for constructing a timeline of events at an archaeological site.

Objectives

- To understand the difference between timelines based on relative dating and absolute dating.
- To understand how radiocarbon dating works, what objects can be dated, and the limitations of the method.
- To understand how archaeologists use radiocarbon dating to reconstruct human history and investigate links between natural hazards and human occupation.

Tsunami & Stratigraphy:

Overview:

This module uses stratigraphy to teach students to 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.

Natural Hazards:

Ojectives:

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 to make predictions about future hazards

Overview:

Humans primarily care about natural hazards when events affect individuals by destroying or disturbing habitation, livelihoods, food resources, and daily activities. Natural hazards contribute to difficulties encountered in surviving in the remote, harsh landscape in the Kurils.

This module teaches students to understand how environment (with a focus on natural hazards) contributes to daily life, human activities, and cultural decision-making.

Students will be introduced to the natural hazards that occur in the Kuril Islands, including volcanic eruptions, earthquakes, tsunamis, and landslides, as well as to how and why these events occur. Students will learn to assess hazard potential and relate this to where and how one would want to live. Students will practice communication skills, including distilling and relaying complicated information.

Objectives:

- Students will learn to assess hazard potential and relate this to where/how one lives or wants to live.
- Students will practice distilling complicated information, effectively conveying it to their classmates, and discussing decision-making.
- Students will consider the difference between oral and written histories.
- Students will practice reading and interpreting maps.

Overview and objectives of each module

Continued

Paleoclimate:

Overview:

Students are introduced to methods that palynologists use to interpret past landscapes and associated climatic conditions. Through the introduction to basic concepts such as biostratigraphy, proxy data, and analog analysis students will reconstruct the vegetation and climate histories of the southern Kuril Islands over the last ~8,000 radiocarbon years. Students will explore: 1) the relationship between modern climate and modern vegetation; 2) the relationship between modern and ancient vegetation using pollen data; and 3) the application of these relationships to infer past climatic change. Through the exercises the students will: 1) learn how to apply the basic principles of palynology; and 2) improve their appreciation of the dynamic nature of the environment, recognizing that modern ecosystems and climate patterns are not static and can change dramatically through time. Reconstructing paleoenvironments is a key tool that aids archaeologists to better understand possible human-environmental interactions, such as how changes in past environments may or may not have influenced human activities.

Objectives:

- To teach students how palynologists infer past plant communities and how paleovegetation reconstructions act as proxy measurements of past climate.
- To engage students in the analysis and interpretation of biostratigraphic data.
- To allow students to explore the relationship of vegetation types to broader climatic conditions.
- To engage students in the examination of how past conditions may help us understand possible responses of the environment to future climate changes.

Biogeography:

Overview:

This module deals primarily with the geography of the Kuril Islands and the constraints that this geography puts on the numbers and kinds of animals (including humans) able to inhabit the islands. The scientific study of this relationship is called island biogeography. For information on the distribution of plants (phytogeography) and how this might have changed through deep time, please consult the Paleoclimate teaching module.

Goal:

To familiarize students with the science of biogeography, as well as the wide range of physical and geological processes that help to structure biogeographic patterns.

Overview and objectives of each module

Continued

Zooarchaeology:

Objectives:

- Students will be able to explain how animals can populate islands.

- Students will be able to compare animal distributions in time and space and create hypotheses for changes over time or differences in space.

Overview:

This unit provides an introduction into the science of zooarchaeology. This includes information on skeletal anatomy of birds, fish, and mammals, as well as specific information on how zooarchaeologists identify different species of animals based only on skeletal remains. Finally, methods of quantifying identified bones will be covered.

Objectives:

- Students will be able to explain how skeletal anatomy reflects the organization of the Linnaean Hierarchy and how that knowledge can help identify species or class of animal fro bones.

- Students will learn the patterns of bone growth in mammals and will practice using this knowledge to identify age and sex of animals based on their bones.

- Students will learn some of the techniques used by zooarchaeologists when analyzing archaeological bone samples.

- Students will practice using zooarchaeological data to create hypotheses about past interaction of animals, humans, and their environments.

Settlement:

Overview:

In this module, students will be introduced to statistical distributions to address questions about historical changes in human settlement patterns and to raise questions about the causes of these changes. Through an exercise designed to engage students in statistical data manipulation, they will learn how archaeologists use radiocarbon-dated settlements to reconstruct changes in the intensity of occupation in different locations. They will then compare these patterns to explore changes in settlement over time and space. The final component of this module gives students a chance to think about possible causes of historical changes in settlement distributions through correlation with environmental phenomena such as volcanic eruptions. Exercises engage students in quantitative and basic descriptive statistical manipulations (data aggregation and histogram construction) and in hypothesis formation and testing. The exercise is designed to convey the important realization that human settlement is not static but changes, sometimes dramatically, over time.

Goals:

- To teach students how archaeologists interpret settlement history based on site distributions and radiocarbon dates, and how they seek to explain change through analysis of correlations with environmental phenomena and changes in culture.
- To engage students in the analysis and interpretation of distribution data.
- To engage students in interpretations about human-environment interactions.
- To engage students in integrative/ systemic thinking exercises

Objectives:

- Students will learn how to observe changing frequencies of dated archaeological settlements by organizing data into histogram form and they will learn how differing the intervals (“bins”) of a histogram can change the graphical representations. This is a basic aspect of scientific data analysis and a descriptive statistical procedure.
- Students will learn to compare proxy data for environmental events and human settlement and to develop and evaluate hypotheses about the causes of human settlement change. Correlation is a basic aspect of scientific reasoning. Students will also learn to examine critically the methods used and the strength of conclusions.

Artifacts:

Overview:

This module focuses on the artifacts recovered in the Kuril Islands. Students will examine, identify, and analyze replica artifacts included in the kit to learn how ancient people lived and what they ate.

Goals:

- To introduce the basic features of artifacts and their value to archaeologists.
- To develop students' critical thinking skills about how people used material objects to live and interact with the environment around them.

Objectives:

- Students will examine and analyze artifacts using skills such as drawing, measuring, and writing.
- Students will identify the different material types used by ancient humans to make artifacts (stone, ceramic, bone).

Conclusion

Field research in the remote Kuril Islands is exotic, especially for American scholars and students, and as such has the potential to captivate student attention in some of the same ways that cultural icons such as Indiana Jones have done for generations. Conducting cooperative field research with a team of American, Russian, and Japanese scholars in remote settings, involving travel on ships and small boats (often in fog and sometimes in rough seas), set against the dramatic backdrop of the vast ocean, snowcapped volcanic peaks, lush green vegetation, and vibrant wildlife, makes the experience captivating for the adventurous spirit. We have tried to convey some of this drama and beauty in the slide shows and narratives. On the other hand, the reality of research anywhere is one of hard, careful, and systematic work. Students are exposed to this dimension of research as well in the lessons and exercises. We hope that this combination of captivating imagery and scientific reality both engages students and encourages them to learn more about scientific practice. While the Kurils are far from the Western U.S., the issues examined in this research are of direct relevance for the residents of the western seaboard of the U.S., where residents face earthquakes, tsunamis, volcanic eruptions, ongoing and dramatic climate changes, struggles with the preservation of wildlife, and the survival of economic systems dependent on both wild and cultivated plants and animals (salmon, sea lions, orca whales, spotted owls, forests, agricultural productivity, etc.). The Kuril Biocomplexity Education Kit provides an opportunity for teachers to engage students with research activities drawn from an actual interdisciplinary project – using real scientific data in most cases – with both exotic appeal and practical relevance for the lives of students in the Western U.S.

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Core members of the UW Kuril Biocomplexity Project created and adjusted all scientific/ educational content. They include:

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ARTIFACTS

Teacher's Manual

Table of contents

Subjects:
Social Studies, History, Archaeology

Duration:
Option 1: 45 to 60 minutes
Option 2: 75 to 90 minutes
(Plus homework)

Class size:
10 - 30

Summary

Overview:

This module focuses on the artifacts recovered in the Kuril Islands. Students will examine, identify, and analyze replica artifacts included in the kit to learn how ancient people lived and what they ate.

Goals:

- To introduce the basic features of artifacts and their value to archaeologists.

- To develop students' critical thinking skills about how people used material object sto live and interact with the environment around them.

Objectives:

- To examine and analyze artifacts using skills such as drawing, measuring, and writing.

- To identify the different material types used by ancient humans to make artifacts (stone, ceramic, bone).

Material Included:

- "Treasure out of Trash" slideshow with teaching script
- Stone, bone, and ceramic artifact collections (objects labeled KBP Burke 001 - KBP Burke 091)
- Artifact analysis worksheets for stone, bone, and ceramic artifacts

Vocabulary

Adze:
A stone blade that is ground, shaped, polished, and usually hafted to a handle to be used for woodcarving.

Applique:
The addition of low-relief clay forms to a preformed vessel.

Archaeological material:
Remains found in archaeological sites such as artifacts, plant and animal remains, and features (e.g., house structures, monuments, hearths, etc.).

Artifact:
An object made or used by people.

Assemblage:
An archaeological grouping of artifacts (such as pottery) from a site according to their form or function.

Awl:
A tool with a pointed end used for sewing, punching holes in hides, or basket weaving, usually made from animal bone.

Base:
The underside of a vessel, or that part of the vessel which comes into contact with the surface upon which it rests during normal use.

Bipoint:
A small piece of bone pointed at both ends; bipoints were usually attached to fishhook sor shafts for catching fish.

Body:
The portion of a vessel between the orifice and the base, also sometimes called the belly.

Chisel:
A tool with a tapered, beveled end that was usually attached to a handle and used for woodcarving.

Coiling:
A method for hand-building an object of clay by successive additions of ropes or coils of clay.

Cord-marked:
Impressing cord into the interior or exterior surface of an object, often used in reference to cord impressions found on ceramics.

Core:
The piece of stone that remains after outer sections of stone have been chipped or flaked off of it to make tools.

Cortex:
The natural outer layer of rocks, formed by processes of chemical and mechanical weathering.

Debitage:
Pieces of stone that have been removed from a tool during manufacture, resharpening, or repair.

Drilling:
A method to create a perforation, hole, or hollowed-out area.

Vocabulary

Fabric:
The composition of a fired ceramic, including clay, inclusions, and pores, but excluding surface treatment. Synonymous with body, paste, or ware.

Flake:
A piece of stone that has been chipped away from a core or a larger flake. Flakes were either used, shaped into other tools, or discarded.

Flintknapping:
The process of making stone tools by shaping pieces of stone by various flaking methods.

Graver:
A tool with a sharp point or edge, usually hafted to a handle, and used for incising fine lines or carving thin grooves in wood or bone artifacts.

Grinding:
Rubbing an abrading stone against the surface of an artifact to achieve a smooth finish.

Hammerstone:
A hard cobblestone used by flintknappers to strike flakes off of lumps of tool stone.

Harpoon:
A spear-like weapon with a barbed head, used for hunting marine animals such as whales, sea mammals, and large fish.

Incised:
Figures or letters carved by hand or impressed by machine into the surface of an object. Often used to refer to marks on pottery and ceramics.

Incising:
Cutting or engraving fine lines into the surface of an object.

Inclusion:
Particulate matter (usually minerals) which is present in the fabric of ceramics, and which either naturally occurs in clay or is added by potters.

Indirect percussion:
A flintknapping method in which the hammerstone does not directly hit the stone tool but instead strikes an intermediary, blunt-pointed tool.

Neck:
The part of a vessel between the shoulder and rim, typically characterized by a marked constriction of the body diameter.

Pecking:
A flintknapping method in which the stone is shaped by sharply and repeatedly hitting it with a stone of greater hardness.

Percussion Flaking:
A flintknapping method in which a percussion tool such as a hammerstone is used to remove flakes from an artifact to to shape it.

Pressure Flaking:
A flintknapping method in which small flakes are removed from the edges of an artifact, using a bone or antler tool, to refine the shape of the tool in precise detail.

Vocabulary

Procure:

To collect resources by special effort, e.g., hunting, gathering, and fishing.

Projectile point:

A stone tool that is pointed on one end and usually attached to a shaft on the other, for example the tip of an arrow, spear, or dart used for hunting or fishing.

Rim:

The area between the lip and the side wall or neck of a vessel.

Scraper:

A stone tool that is used for tasks such as scraping fish scales and animal hides.

Sherd:

A broken fragment of pottery. This is a technical term used in archaeology, rhyming with "herd," and should not be confused with the more common term "shard" (as in "glass shard").

Subsistence:

Activities required to meet basic biological needs, usually referring to the quest for food.

Unipoint:

A bone tool pointed on one end.

Wedge:

A tool usually used with mauls and adzes for heavy woodworking tasks such as splitting wood planks for houses and canoes, and usually made of bone or antler.

Background Information

The thousands of artifacts recovered from the Kuril Islands are incredibly diverse, representing many different types of tools and ornaments. Stone, ceramic, and bone artifacts constitute the majority of the archaeological materials collected from the Kuril Islands. The stone artifacts represent numerous types of stone tools, including cores, flakes, projectile points, blades, scrapers, and hammerstones. These tools were made from a wide variety of raw stone materials, including basalt, chert, and obsidian. Some of these stone materials (e.g., basalt and chert) were locally available in the islands, but some (e.g., obsidian) naturally occur only on the island of Hokkaido and the Kamchatka Peninsula, both located beyond the far ends of the archipelago.

Other artifacts found in the Kuril Islands include ceramics and bone artifacts. The most commonly discovered ceramic artifacts are pieces of broken pots, called “sherds.” Ceramic vessels were most likely made locally on islands, using a combination of clay and sand, and hardened through firing in open-air fires. The ceramic artifacts discovered in the Kurils also often have decorations on them, the most common decoration being cord-marking, formed by impressing a cord onto the surface of the vessel before firing. Bone artifacts are also found throughout archaeological sites in the Kuril Islands. Bone artifacts are extremely versatile and were used for a wide variety of tasks including hunting, fishing, and sewing, and some bone artifacts were even used as jewelry or ornaments. The bone tools were made from the bones of a variety of different animals, but most commonly from sea lion, seal, and occasionally bird bone.

Procedure

1. Display the "Treasure out of Trash" slideshow (available in PowerPoint or PDF format), using the script that has been prepared for the slideshow to help narrate the slides.

2. At the prompt in the slideshow, divide the class into three groups of approximately equal size, and distribute the artifact analysis worksheets to the students. Have each group start with one of the artifact collections (stone, bone, or ceramic) and complete the artifact worksheets.

   Option 1: Each group of students analyzes only one artifact type (stone, ceramic or bone) for 8-10 minutes.

   Option 2: Each group of students analyzes all artifact types for 8-10 minutes and then rotates to a different artifact type, 24-30 minutes total.

3. Return to the "Treasure out of Trash" slideshow and discuss the questions highlighted in the slideshow as a class.

Collection of stone and ceramic artifacts from the Kuril Islands

Student Worksheet guide

Analysis of Artifacts:

Describing Stone Artifacts

Introduction:

Stone artifacts are some of the most commonly found artifacts by archaeologists. Stone tools can be used for a wide variety of tasks, and they are durable, lasting for a long time in the archaeological record. Using the collection of stone tools collected from your site, analyze the artifacts to help answer questions about how past humans lived.

Step 1:

Look at the whole collection of stone artifacts and divide the artifacts into two smaller groups based upon their size. Record the number of artifacts in each group.

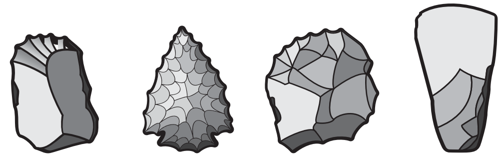
Small Group:

Answer: Group sizes will differ between different students' classifications (and this is the point!)

Large Group:

Answer: Group sizes will differ between different students' classifications (and this is the point!)

Types of Tools:



Scraper Point Flake Adze

Step 2:

Choose one artifact from each group and describe the artifact following the example:

Small Stone Artifact

Length: __________ cm
Width: __________ cm
Color: __________
Texture: __________

Type (circle one below):
Point
Blade
Flake
Adze

Large Stone Artifact

Length: __________ cm
Width: __________ cm
Color: __________
Texture: __________

Type (circle one below):
Point
Blade
Flake
Adze

Step 3:

Instead of sorting the stone artifacts based upon their size, try sorting them by their tool type. Once again, record the number of artifacts belonging to each tool type.

Scrapers:

Answer: 2

Flakes:

Answer: Around 20

Points:

Answer: 9

Adzes:

Answer: 1

Step 4:

Answer the following questions based on the tools from this site.

Looking at the variety of stone tools from the Kuril Islands, what activities were Kuril inhabitants likely engaging in?

Answer:

Projectile Points: The projectile points are not all the same size but range from small to large. Differences in the size of different projectile points likely relate to the size of the animals that people hunted, with the smallest points (the triangular points) likely used for birds or small mammals, the medium points likely used for medium mammals like foxes, and the largest points likely used for larger mammals such as deer.

Scrapers: Scrapers likely suggest the processing of hides from either marine or terrestrial mammals.

Adzes: The adze suggest the use of stone tools to perfrom wood-working or tree clearing tasks.

The various rocks Kuril inhabitants used to make stone artifacts is quite diverse. What can this diversity in stone resources tell you about the mobility of people who lived in the Kurils Islands? What additional information might be helpful in answering this question?

Answer: The tools are made out of a wide variety of raw materials, including chert or flint (the grey and red/orange material), obsidian (the black, shiny material), and basalt (the black, dull material). The diversity of raw materials clearly shows that the past inhabitants of the Kuril Islands had access to a wide variety of materials and used it in various ways. To really investiage this question, we would want to know the distribution of the various stone resources from throughout the island chain. For instance, we know from geologic evidence that obsidian does not occur locally in the Kurils and could only be obtained by trading with other groups living in Hokkaido or Kamchatka.

Student Worksheet guide

Analysis of Artifacts:

Describing Ceramic Artifacts

Introduction:

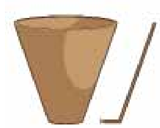
Ceramic artifacts are found throughout the Kuril Islands, having many different shapes, and with many different designs associated with them. Using the collection of ceramic artifacts from your site, analyze the pottery to help understand why and how ancient people used these artifacts.

Step 1:

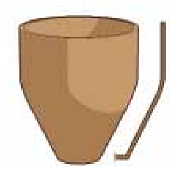
Using the assemblage of pottery sherds, attempt to refit the pottery vessel back together.

Hint: Focus on fitting the rims and the bases back together and don't worry too much about the body sherds.

Which of these vessels shapes do you think best represents the shape of your vessel? (Circle your answer).



Answer: Assemblage 1: Flat base with full conical body



Answer: Assemblage 2: Flat base with conical lower half and straight upper half

Answer: Assemblage 3: Flat base, conical lower half leading to a shoulder, constricted neck and expanding rim

What sort of activities do you think ancient people might have used this vessel for?

Answer: All three of the vessels were likely used for cooking purposes. This probably included the cooking of animal products such as marine mammals and boiling plant products. The best evidence suggests that there is no major difference in the functional properties of each of these different vessel shapes. The differences are more likely a product of different personal or cultural styles.

Student Worksheet guide

Analysis of Artifacts:

Describing Ceramic Artifacts - continued

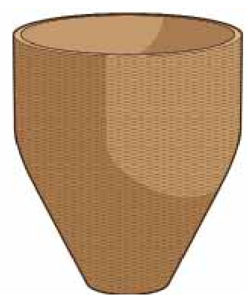
Step 2:

Looking at your ceramic vessel, study the decorative patterns and draw a sample of the decoration in the box provided below:

Step 3:

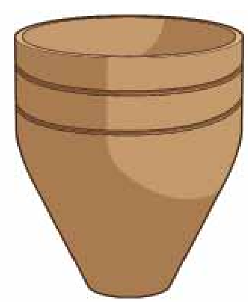
Given the examples below, how would you best describe the pattern on your vessel?

Cord-Marked



Applique

Incised



The decoration on my vessel is best described as:

Answer:

Assemblage 1: Cord-Marked

Assemblage 2: Cord-Marked and Incised

Assemblage 3: Incised

Step 4:

Now compare the ceramic vessel pieces that you have with the other two ceramic vessel sherds. What are some of the similarities between them? What are some of the differences?

Similarities

Vessel 1 and Vessel 2:

Answer: Both have cord-marking and a similar shape

Vessel 2 and Vessel 3:

Answer: Both have circular incisions (or "punctates")

Vessel 1 and Vessel 3:

Answer: Little to no similarities

Differences

Vessel 1 and Vessel 2:

Answer: Vessel 1 does not have any incisions (specifically circular incisions/"punctates")

Vessel 2 and Vessel 3:

Answer: Different shapes, vessel 3 clearly has a neck

Vessel 1 and Vessel 3:

Answer: Vessel 1 has cord-marking and Vessel 3 is different in shape (has a neck)

Thinking critically, what might be some of the reasons why two pieces of pottery might look similar or different?

Answer: The similarity of two objects is often seen by archaeologists in two different ways: similarity due to functional properties and those due to stylistic properties. For example, when cooking pots are compared to skillets, any two cooking pots will look more like one another than they do skillets, because pots having similar functional traits such as higher walls since they are often used for holding and heating liquids. Additional traits such as decorations are often considered as stylistic traits. These traits are more culturally determined and are therefore often used to hypothesize connections between groups of people. If ceramic artifacts at one site are very similar to ceramic artifacts at another, it is possible that pottery might have been traded between the two communities or that people from the one community might have moved or migrated to the other community.

Introduction:

Bone artifacts are extremely useful for populations living in the cold, maritime environment of the Kuril Islands. Using the collection of bone artifacts from your site, analyze the various ways ancient people used these artifacts to survive in the harsh environment.

Step 1:

Using the collection of finished bone tools, sort the tools into groups that relate to their function. Please give your group a name that relates to its function and briefly describe the artifacts in that group.

Hunting/Harpoon Group:
The function of this group of tools is **hunting**.
Description: All of the artifacts in the harpoon group have at least one pointed end used for piercing animal skins. Student could possibly split the harpoons into two or three different groups such as the toggle harpoons (2-holes), the non-toggle harppon (1-hole), and the leister point (long and barbed).

Sewing Group:
The function of this group of tools is **sewing**.
Description: Three of the four artifacts in the group are needles and can be described as small and pointy. The fourth artifact is a needle case designed to prevent the needles from being damaged.

Ornamental Group:
The function of this group of tools is **decoration.**
Description: The bone disc is decorated with geometric patterns suggesting its ornamental use. The circular shape of the bone disc also suggests possibly use as a spindle whorl, used in the spinning of fibers.

Step 2:

Using the collection of finished and unfinished bone tools, further investigate the function of the bone tools and try to identify the process of making bone tools by matching the finished product with their earlier forms.

Bone Artifact KBP Burke 0175

1. What do you think the function of this artifact was?
Answer: The function of this artifact is not entirely clear to archaeologists. It clearly has some decorative designs suggesting it might be an ornmental artifact worn like a pendant or brooch. Its circular shape with a hole in the center also indicates it could have been used as a spindle whorl, which were useful pieces in the spinning of fibers.

2. Which of the unfinished tools would have likely been turned into this type of artifact? (Provide the artifact number.)
Answer: The most likely unfinished bone that would have been turned into the finsihed artifact is KBP 0179. This is a dense piece of whale bone that likely comes from a much larger piece of whale bone such as a femur or verterbrae.

3. Do the bones most likely used in the manufacture of this artifact come from a mammals or birds? How can you tell?
Answer: These are most likely from a mammal, specifically a whale. This is because of the thickness and density of the bones and that the bones are not hollow (birds bones are usually hollow).

Bone Artifact KBP Burke 0185 or 0186

1. What do you think the function of this artifact was?
Answer: These artifacts are known as leister points. Given their long and pointed shape, they are most likely used for the hunting of fast moving animals such as fish or other river animals.

2. Which of the unfinished tools would have likely been turned into this type of artifact? (Provide the artifact number and skeletal element if possible.)
Answer: The most likely preform of the leister points are the three whale bone pieces (KBP Burke 0176, 0177, 0178). This is because the whale bone is very dense and strong, allowing it to be easily shaped into durable bone harpoon points.

3. Do the bones most likely used in the manufacture of this artifact come from mammals or birds? How can you tell?
Answer: These are most likely from a mammal, specifically a whale. This is because of the thickness and density of the bones and that the bones are not hollow (birds bones are hollow).

Bone Artifact KBP Burke 0183 or 0184

1. What do you think the function of this artifact was?
Answer: These artifacts are known as non-toggling harpoon points. They are most likely used for the hunting of marine mammals located on the near shore or shallow waters (as opposed to hunting on or near sea ice).

2. Which of the unfinished tools would have likely been turned into this type of artifact? (Provide the artifact number and skeletal element if possible.)
Answer: The most likely preforms of the non-toggling harpoon points are the three whale bone pieces (KBP Burke 0176, 0177, 0178). This is because the whale bone is very dense and strong, allowing it to be easily shaped into durable harpoon points.

3. Do the bones most likely used in the manufacture of this artifact come from mammals or birds? How can you tell?
Answer: These are most likely from a mammal, specifically a whale. This is because of the thickness and density of the bones and that the bones are not hollow (birds bones are hollow). You can feel how the texture of the harpoon points and the whale bone is similar.

Student Worksheet guide

Analysis of Artifacts:

Describing Bone Artifacts - continued

Bone Artifact KBP Burke 0206-0209 (Toggling Harpoons)

1. What do you think the function of this artifact was?

Answer: These artifacts are known as toggling harpoons. They are most likely used for the hunting of marine mammals, such as seals, walruses, or whales from a boat and near areas that contain sea ice. The main advantage a toggling harpoon provides is that the two holes in the harpoon head allow the hunter to insert the harpoon vertically and then lodge the harpoon head horizontally inside the animal, which helps to hang onto the animal in the water or ice.

2. Which of the unfinished tools would have likely been turned into this type of artifact? (Provide the artifact number and skeletal element if possible.)

Answer: The most likely preforms of the toggling harpoons are the four seal rib pieces (KBP 0202-0205) or possibly the three whale bone pieces (KBP Burke 0176, 0177, 0178). This is because seal rib bones and whale bones provide a dense, strong bone that is easily shaped into a toggling harpoon.

3. Do the bones most likely used in the manufacture of this artifact come from mammals or birds? How can you tell?

Answer: These most likely came from a mammal, either a seal or whale. Similar to other harpoons, this is because of the larger thickness and density of the bones and that the bones are not hollow (birds bones are hollow).

Bone Artifact KBP Burke 0182, 0193, 0194, 0195

1. What do you think the function of this artifact was?

Answer: These are all artifacts associated with sewing. The three smaller aritfacts (KBP 0193, 0194, 195) are all needles and the larger artifact (KBP 0182) is a needle case to store the needles.

2. Which of the unfinished tools would have likely been turned into this type of artifact? (Provide the artifact number and skeletal element if possible.)

Answer: The most likely preforms of the needles are the thin, hollow bones (KBP 0199, KBP 0200 KBP 0201). The most likely preforms of the needle cases are the larger, but still hollow, bird wing bones (KBP 0180, KBP 0181).

3. Do the bones most likely used in the manufacture of this artifact come from mammals or birds? How can you tell?

Answer: The bones most likely used to create the needles and needle case come from bird bones. This is mainly because they are hollow so can be easily splintered to make thin needles. Larger pieces can be sectioned to make needle cases.

CHRONOLOGY

Teacher's Manual

Table of contents

Subjects:
Archaeology, Earth Sciences, Chemistry

Duration:
3 class periods

Class size:
up to 40 students

Summary

Overview:

In this module, students will be introduced to the radiocarbon dating method, which archaeologists and geologists frequently use to determine when the events which interest them occurred. During this lesson, the teacher will instruct the students about the concepts foundational to the radiocarbon dating method. This lesson will require students to identify suitable and unsuitable materials for radiocarbon dating, use a graph to determine the age of samples based on the amount of radiocarbon that is present in them, and do a take-home writing assignment in which they will design a plan for constructing a timeline of events at an archaeological site.

Objectives:

- To understand the difference between timelines based on relative dating and absolute dating.
- To understand how radiocarbon dating works, what objects can be dated, and what the limitations of the method are.
- Understanding how archaeologists use radiocarbon dating to reconstruct human history and investigate links between natural hazards and human occupation

Material Included in the Box:

- Slide Show to assist in the presentation of the information.
- Digital and hard copies of illustrations to be used while instructing.
- Digital and hard copies of the lesson packet to be distributed to students.

Vocabulary

Absolute Dating:
The process of determining when an event occurred along a calendrical timeline.

Biosphere:
The component of the Earth system which consists of all life on earth, including all avian, terrestrial, and aquatic species. The biosphere can be understood in terms of the abundance of living organisms on earth (global biomass) and in terms of its internal organization or systemic process (ecosystems).

Carbon-12 (^{12}C):
The most abundant stable carbon isotope occurring in nature. ^{12}C contains 6 protons and 6 neutrons.

Carbon-13 (^{13}C):
A naturally occurring, stable carbon isotope, which is considerably less abundant in the atmosphere than is ^{12}C but considerably more abundant than ^{14}C. ^{13}C contains 6 protons and 7 neutrons.

Carbon Cycle:
The process by which carbon flows throughout and is exchanged between various physical and biological systems (for example, the atmosphere, the oceans, and the biosphere). Because carbon is an essential ingredient for life on earth, it is critical that carbon be continuously available to organisms, so understanding how carbon is recycled through the carbon cycle is of central importance for biologists.

Carbon dioxide (CO_2):
A molecule consisting of two oxygen atoms and one carbon atom. Carbon dioxide molecules form in the atmosphere, and their carbon atoms can be either ^{12}C, ^{13}C, or ^{14}C atoms.

Dated event:
An event which is directly dated by a particular dating method. In the case of radiocarbon dating, the dated event is the time of death of an organism from which a sample is taken. The dated event may or may not be of direct interest to archaeological research.

Isotope:
A variant form of an element. Different isotopes of the same element have different numbers of neutrons in their atomic nuclei. For example, a ^{12}C atom has six neutrons in its nucleus, ^{13}C has seven, and ^{14}C has eight, yet all three are still carbon atoms and interact in the same chemical reactions in the same way.

Vocabulary

Continued

Law of superposition:

A principle of geology which states that, in a sequence of geological layers, a lower layer of sediments was deposited before, and therefore is older than, overlying layers. This law only applies in cases where such layers have not been disturbed or mixed since the time of their deposition.

Neutron:

A subatomic particle which has no charge. Together with protons, neutrons are one of the building blocks of the nuclei of atoms, but they can also occur free in nature.

Nitrogen-14 (^{14}N):

A common, naturally occurring, stable nitrogen isotope. ^{14}N contains 7 protons and 7 neutrons.

Radiocarbon (^{14}C):

A naturally occurring, radioactive carbon isotope, which is considerably less abundant than both ^{12}C and ^{13}C.

Relative dating:

The process of determining whether an event came before or after another event in time, without consideration for how much time intervened between the two or how long ago in the past they occurred.

Stratigraphy:

A sequence of layers at an archaeological site or a geological locale that represents the depositional history of that location.

Stratum (plural: strata):

A layer in a geological deposit having characteristics (age, color, composition) that make it distinguishable from other layers.

Target event:

An archaeological term used to refer to the event which is of interest to an archaeologist and for which they would like to estimate a date. Linking a particular "dated event" to the "target event" is one of the biggest challenges of historical sciences like archaeology and geology.

Years BP (years before present):

The amount of time which has passed between the occurrence of an event and the year A.D. 1950. To prevent confusion, radiocarbon scientists defined A.D. 1950 as the 'present' so that radiocarbon ages always refer back to this same fixed point in time. For example, 537 years BP will always refer to the year which preceded A.D. 1950 by 537 years, in other words A.D. 1413.

Background Information

When cosmic rays excite atmospheric neutrons, some of these neurons collide with atmospheric nitrogen-14 (^{14}N), which is transformed into radiocarbon (^{14}C) as a result (see Figure 1). This ^{14}C constitutes a miniscule proportion of atmospheric carbon, alongside two considerably more abundant carbon isotopes: carbon-12 (^{12}C) and carbon-13 (^{13}C). All three of these carbon isotopes combine with atmospheric oxygen atoms to form carbon dioxide molecules. Through the process of photosynthesis, plants incorporate carbon from these carbon dioxide molecules into their tissues, maintaining a ^{14}C to ^{12}C ratio in equilibrium with the atmosphere as long as they are alive. In turn, animals eat plants or other animals, and the carbon in the plant or animal tissues that they consume is incorporated into their own tissues. When plants and animals die, they cease incorporating new carbon into their tissues and the "radiocarbon clock" starts ticking.

Radiocarbon is a radioactive isotope which decays back into ^{14}N at a constant rate: after approximately 5,700 years, half of the amount of ^{14}C which was originally in the sample converts back into ^{14}N. After another ~5,700 years, half of the remaining ^{14}C converts into ^{14}N. This process of radioactive decay continues indefinitely through time, but the amount of ^{14}C remaining in a sample becomes so small after approximately 50,000 years that laboratory machines have a hard time detecting it. Conversely, ^{12}C is a stable isotope, so the amount of ^{12}C that is present in a sample at the time of its death should remain constant over time.

Technicians who work at radiocarbon laboratories measure the amount of ^{14}C and ^{12}C remaining in a sample of organic material (such as wood, charcoal, bone collagen, shell, hair, seeds, or plant fibers). If they assume that the ratio of ^{14}C to ^{12}C that was originally present in the sample is identical to the ratio of modern atmospheric ^{14}C to ^{12}C, then they can use their measurement of the amount remaining in a sample to estimate the amount of time that has passed since the death of the organism that the sample came from, assuming a constant rate of radiocarbon decay.

If an archaeologist or geologist has good reason to believe that the death of a sample (the “dated event”) corresponds closely in time with its deposition at an archaeological or geological site (the “target event”), they can use this sample’s date to determine when it was deposited at the site, allowing them to begin to construct a timeline for the archaeological or geological history of that site.

^{14}C (pronounced "radiocarbon" or "carbon 14") is a radioactive isotope of carbon.

An isotope is a variant form of an element. Different isotopes of a single element have the same number of protons in their nuclei but vary in the number of neutrons they have. A carbon atom, for example, has six protons in its nucleus, but there are three naturally occurring carbon isotopes — ^{12}C, ^{13}C, and ^{14}C — which have six, seven, or eight neutrons in their nuclei, respectively.

What makes some isotopes such as radiocarbon radioactive is that they are "unstable," meaning that the ratio of neutrons to protons in their nuclei is too high above 1.0 and as a result they end up "giving up" parts of their nuclei, resulting in a more stable atom. This process is called radioactive decay or simply radioactivity. Radioactive isotopes contrast with stable isotopes, whose neutron-to-proton ratios are close enough to 1.0 that they stay in their form barring external intervention.

The formation and radioactive decay of ^{14}C

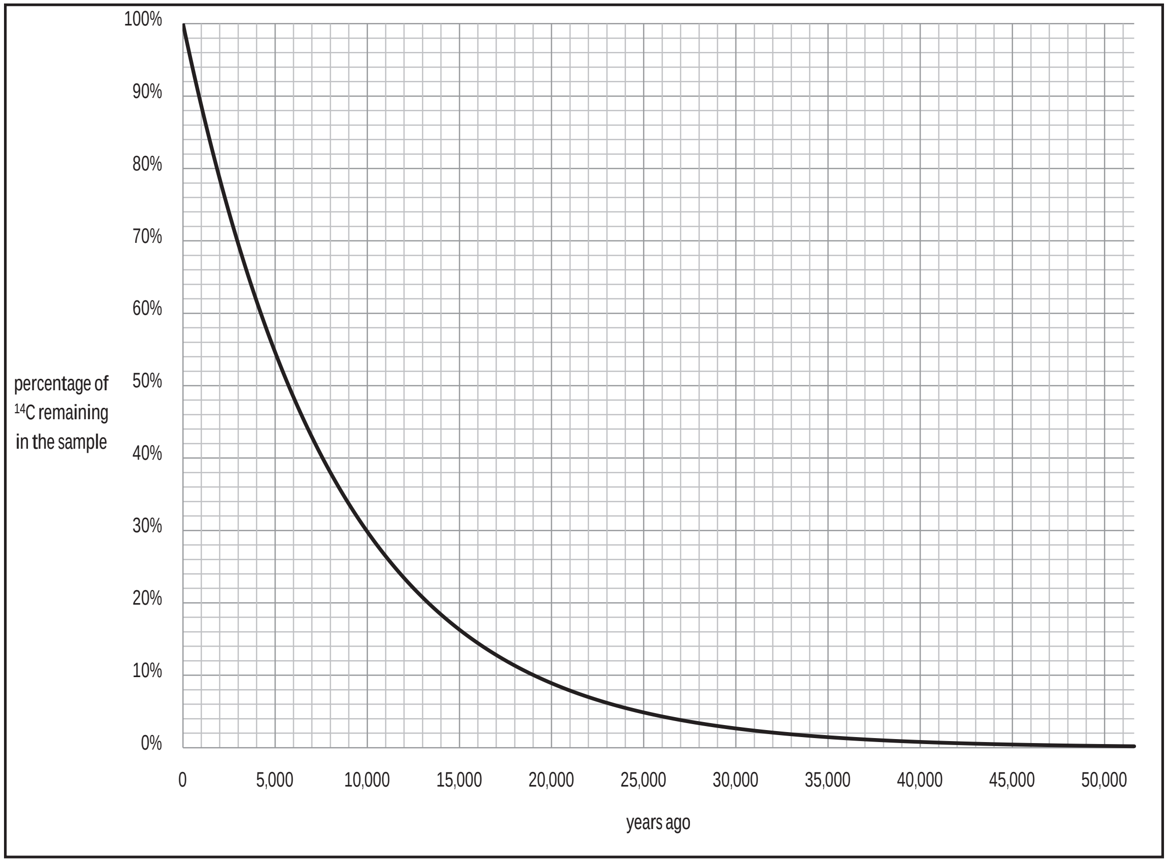
In the upper atmosphere, nitrogen atoms are bombarded by cosmic rays. As a result of this bombardment, the stable isotope ^{14}N (pronounced "Nitrogen-14"), which has seven protons and seven neutrons in its nucleus, loses one of its protons and gains an extra neutron, converting it into ^{14}C (six protons, eight neutrons).

Over time, ^{14}C decays back into ^{14}N through a process called ß emission (ß is pronounced "beta"). A ß particle is a negatively charged electron, located in the nucleus of the atom, and each ß emission event involves not only emitting a ß particle from the nucleus of the ^{14}C atom but also an exchange of its eighth neutron for an additional proton. As a result, the nucleus of the atom is balanced back to the seven neutrons and seven protons that constitute ^{14}N (n:p ratio = 1.0).

^{14}C decays to ^{14}N at a constant rate, which can be expressed in different ways:
The most common expression of this decay rate refers to a radioactive element's "half-life" (labeled $t_{1/2}$). A $t_{1/2}$ is the amount of time it takes for one half of a given amount of a radioactive element to decay, leaving the other half in the radioactive isotope form. Willard Libby, the creator of radiocarbon dating, thought that ^{14}C's $t_{1/2}$ was approximately 5,568 years long, but we now know that it is closer to approximately 5,730 years long.

A less common way of talking about radioactive decay is to talk about its annualized decay rate (labeled λ, pronounced "lambda"). λ refers to the amount of the radioactive isotope that decays in a single year, expressed as a percentage of the amount existing at the beginning of the year. In other words, the amount of the radioactive isotope at the beginning of the year is reduced by a certain percentage by the end of the year. For example, the λ associated with the Libby $t_{1/2}$ of 5,568 years is 0.0124488% lost per year, while the λ associated with the Oxford $t_{1/2}$

of 5,730 years is 0.0120968% lost per year.



Knowing these decay rates, it is possible to graph the relationship existing between the amount of ^{14}C present in a sample at the time of its death and the amount of time that has elapsed since then.

Assuming that we know how much radiocarbon was originally present in the sample, we can calculate the amount of time which has elapsed based on the amount of radiocarbon remaining in the sample.

Radiocarbon in the carbon cycle:

Approximately one out of every one trillion carbon atoms in the atmosphere is a ^{14}C atom. Just like other atmospheric carbon, most atmospheric ^{14}C atoms bond with oxygen atoms to create carbon dioxide (CO_2).

Most of this carbon dioxide enters the oceans, but terrestrial plants consume some of it through the process of photosynthesis, fixing the carbon in their tissues. In turn, animals that eat these plants fix the plant's carbon in their tissues, and predators that prey upon these animals in turn fix the prey's carbon in their tissues.

As long as the plant or animal is alive, it continually rejuvenates the carbon in its tissues, exchanging old carbon for newly consumed carbon, and thereby insuring that the ratio of ^{14}C out of all carbon in its tissues is in equilibrium with (in other words is more or less identical to) the ratio of ^{14}C out of all carbon in the atmosphere.

When the organism dies, however, it can no longer rejuvenate the carbon in its body. The ^{14}C fixed in its tissues at the time of death begins to decay into nitrogen, as discussed earlier.

Measuring radiocarbon in samples and calculating radiocarbon ages:

Because we know that there was approximately one ^{14}C atom for every 999,999,999,999 carbon atoms in an organism's tissues when it died, we can determine the percentage of ^{14}C lost through radioactive decay, if we can also measure the current ratio of ^{14}C to all other kinds of carbon in a sample taken from a deceased organism's tissue. If we can take such a measurement and calculate the percentage of ^{14}C remaining, we can then use this knowledge to calculate the amount of time that has elapsed between the organism's death and the present, and can thereby determine its time of death.

There are two ways of measuring the amount of ^{14}C present in a sample, labeled conventional dating and AMS dating. *Conventional* dating involves counting the number of ß particle emissions that occur over a given amount of time and using this to calculate the amount of ^{14}C necessary to produce ß emissions at the measured frequency. *AMS dating* uses a machine called an accelerator mass spectrometer (or AMS for short) to directly measure the mass of ^{14}C and of all other kinds of carbon present in a sample.

Typically, after about eight or nine half-lives (approximately 45,840 to 51,570 years), there is too little ^{14}C left in a sample to reliably measure. When a sample which is submitted to a dating lab comes back with an undetectably small amount of ^{14}C remaining in it, we say that it is "radiocarbon dead" or has "infinite age" (meaning that we know that it can be no less than eight or nine half-lives old but that we don't know how much older than eight half-lives it is).

Limitations in a radiocarbon date's accuracy and precision:

An archaeologist's or geologist's ability to make effective use of a ^{14}C date is limited in important ways.

First of all, there is an issue of precision in measurement. Precision refers to how close a measurement comes to the value that the researcher is trying to measure. All instruments that scientists use to make measurements of the phenomena that interest them have limited precision. In other words they rarely get exactly the right measurement. For example, if you were to measure the width of your desk with a ruler to the nearest millimeter or the nearest sixteenth of an inch, and if you were to do this multiple times, you would probably come up with multiple nonidentical measurements. Yet, your measurements would also come close to each other, and this allows you to estimate what the width of your desk is within a certain margin of error. Similarly, both conventional and AMS dating methods involve some measurement error. When radiocarbon laboratories report an age estimate for a particular sample, the estimated age is always reported along with a margin of error, called an standard error, for example 5,000±50 (read "5,000 plus or minus 50") years before present. The standard error is associated with a 68% probability, so we can say that the real date of the sample falls between 4,950 and 5,050 years before present, with a 68% probability (in other words, a 32% chance of being wrong). If the standard error is doubled (e.g., to ±100 years in our example), the resulting margin of error is associated with a 95% probability, so in our example we can say that the date of the sample falls between 4,900 and 5,100 years before present, with a 95% likelihood (in other words a 5% chance of being wrong).

Secondly, there is an issue of accuracy. Accuracy refers to the connection between the date estimated for a given sample and the date of the phenomenon that the researcher actually wants to date. Recall that the method calculates the amount of time elapsed since the organism died. Yet, archaeologists and geologists are usually not interested in the organism's time of death. They are usually interested in knowing such things as when a particular village was occupied, when people manufactured a particular style of pot, when a certain volcano erupted, or when a particular stratigraphic layer was deposited. We refer to the organism's time of death as the dated event, whereas we refer to the time that the researcher actually wants to date as the target event. The fact that the two events are not the same does not, however, mean that we cannot use the dated event to infer the age of the target event. But in order to do so we must demonstrate that the two events lie very close to each other in time. In some situations, this is not easy. For example, when people use driftwood as fuel for fire, there is a possibility that the driftwood they burn had died a long time before they burned it. If an archaeologist then wants to know when that fire was made and collects a charcoal sample from its ashes for ^{14}C dating, the date which the archaeologist gets back from the lab may in fact be older than the date at which the fire was made because of the driftwood problem. If the archaeologist has good reason to suspect that the prehistoric people whom they are studying harvested driftwood for fire-making purposes, they may therefore not want to use charcoal as a material to date. On the other hand, if the archaeologist has no reason to believe that driftwood was an important resource, or to believe that the driftwood which was available could have been very old by the time that past people harvested and used it, then he or she may choose to date wood or charcoal samples with confidence. The trick is therefore to pick the right kind of material to date in order to reliably date the target event.

Lesson Activity 1: The Basics

Students learn the Law of Superposition and the difference between absolute and relative dating used by archaeologists and other earth scientists.

Warm up:
Review what archaeologists study. Ask students why time and dating might be an important component in an archaeological project (answer: archaeologists want to know when a village was occupied, when a specific type of tool was used first, when some change in technology happened, etc.).

Procedure:
1. Ask students to think of 5 events from their life; for some of these events they should remember the exact date (example: sibling's birth), but for others they should not remember the exact date, but be able to place it into sequence relative to the events they do know exact dates for (example: a play at school, an important sports game, an injury, family vacation, visit from a relative). Ask the students to write them in a column, with the oldest event on the bottom and the most recent event on the top.

2. Explain the difference between absolute and relative dating (just like with the events in our lives, sometimes we can put a specific number on the age of some event (absolute date), and other times we can only say that something is older than, younger than, or same age as something else (relative date).

3. Ask students which of their events would fall under relative or absolute dating. As a class, discuss examples provided by several students.

4. Introduce the Law of Superposition.

5. Ask students to discuss the law using a trash can activity: have students draw a trash can and fill it with the remains of three meals in the order in which they went in. Ask students which of these objects could provide them with absolute dates (newspaper, yogurt container – expiration date), and how you could use relative dating for the rest of the items. You may decide to do this as a demonstration with an actual trash can.

6. Give students the Rasshua Island stratigraphic profile (laminated handouts) and ask them to work in small groups to explain the sequence of deposition according to the Law of Superposition (which layer is oldest and which came after?). Ask them if they could tell without absolute dating if object #6 or object #2 was older.

Wrap Up:
Ask students what they already know about dating methods used by archaeologists (from movies, documentaries, or books). Make a transition to radiocarbon dating – one of the most useful and most often used absolute dating methods.

Lesson Activity 2:

Students learn the environmental chemistry of carbon, from the formation of radiocarbon in the atmosphere, to its introduction into the biosphere, to its transmission throughout the biosphere, to the decay of radioactive carbon.

Procedure:

1. Use the powerpoint provided on CD or online to explain how radiocarbon dating works. The teacher may choose to include more detail in their explanation of the process to the class, depending on the students' interest and knowledge of molecular physics and chemistry [Slides 1-7]. After these slides, students should be able to identify items that are ^{14}C datable.

2. Use the "Dating Game" [Slides 7-20] to solidify the understanding of what can be used for radiocarbon dating: the students are shown a series of photographs depicting different objects, and they are asked whether these objects can be ^{14}C dated and why. Here are the answers:

Rock: Because stone does not contain organic carbon, we cannot use the radiocarbon method to date it. However, there are other dating methods which can provide dates for some types of stone.

Bone: Bone was part of a living organism and contains organic carbon, so it can be radiocarbon dated. However, before this can be done the organic portion of the bone, called collagen, has to be isolated from the inorganic portion, called bone apatite.

Pure Beach Sand: Because beach sand consists of inorganic mineral grains, it does not contain organic carbon, so we cannot use the radiocarbon method to date it.

Charcoal: Charcoal is burned wood and contains organic carbon, so it can be dated using the radiocarbon method. In fact, it is probably the material most commonly dated by archaeologists to establish the age of human settlements.

Seed: Though rarely recovered in archaeological sites because they are fragile, seeds are organic and can be dated using the radiocarbon method.

Shell: Shell can be radiocarbon dated because it contains calcium carbonate.

Metal Artifact: Metal does not contain carbon, so it cannot be radiocarbon dated. However, sometimes rust on metal tools contains organic carbon, which can be used to indirectly date the metal artifact.

Stone Projectile Point: Just like unmodified stone, artifacts made out of stone do not contain organic carbon, so we cannot use the radiocarbon method to date them. However, stone tools sometimes have organic residues on them, which can be used to indirectly date the stone artifact.

Hair: Hair was a part of a living organism and contains organic carbon, so it can be radiocarbon dated. Technological advances in radiocarbon dating allow as little as 20 micrograms of carbon (about 2–4 cm of hair) to be radiocarbon dated.

Wood: Wood contains organic carbon and can be dated using the radiocarbon method. However, in most cases unburned wood does not preserve as well as does charcoal, so archaeologists encounter wood less often than charcoal.

Plastic Bottle: Plastic is a petroleum-based product. Petroleum is an organic substance, containing organic carbon from organisms that

Lesson Activity 2 (continued):

lived hundreds of millions of years ago. However, because these organisms lived so long ago, any radiocarbon that was once in their tissues has effectively disappeared. The commercial use and mass manufacture of bottles also did not begin until the mid-20th century A.D., so while the material from which plastic bottles are made is too old to be dated using the radiocarbon dating method, the plastic bottle itself is also too young to be dated using the method.

Cotton Fabric: Cotton is made from organic fibers from cotton plants belonging to the genus *Gossypium*. It can be dated using the radiocarbon method.

Pottery: Pottery itself cannot be radiocarbon dated because it consists of inorganic clay and sand minerals. However, if there is organic residue, for example remains of food that was cooked or stored in the vessel, then these materials can be dated and used to indirectly date the pot's manufacture.

3. Discuss the results of the Dating Game

4. Demonstrate the dynamics of ^{14}C and ^{12}C after the organism dies using the online or hardcopy Decay Illustration of a seal [Slide 21]. This series of drawings shows how many atoms of each isotope are contained in the bones after each half-life (5,730 years). Please note that the condition of bones does not determine the amount of ^{14}C present, i.e. the deterioration of bones is illustrated to represent time, not the amount of radiocarbon present. The illustration also shows that the radiocarbon method is not reliable for objects older than about 50,000 years because too few ^{14}C atoms are present to accurately detect and measure them. However, many archaeologists are interested in human activities within this period and organics preserve at many sites, so radiocarbon is a very popular method of dating, especially in North America.

5. The teacher will illustrate how to “reflect” lines against the radiocarbon decay curve (get x from y or y from x) to determine the age of a sample based on how much radiocarbon is left in it, using the decay curve illustration [Slide 22]. The teacher can then ask questions based on this curve:

a. What is the approximate age of an organic sample with 75% radiocarbon remaining?

Answer: approximately 2,500 years.

b. How much radiocarbon remains in a sample after 3 half-lives?

Answer: $3 \times 5730 = 17{,}190$ years. Approximately 12%

c. What is the approximate age of an organic sample with 1/512 of the original radiocarbon remaining?

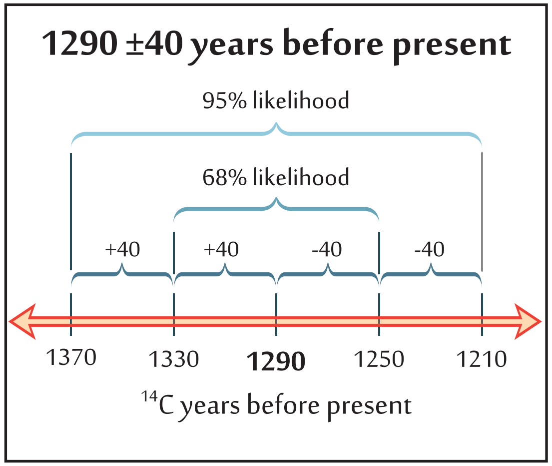
Answer: $1/512 \approx 0.2\%$. 1/512 is associated with 9 half-lives ($2^9 = 512$). However, this amount of remaining radiocarbon is too small for most laboratories to measure or detect, so no reliable date can be obtained; all we can say is that it is >9 half-lives old, in other words >51,570 years old).

d. How much radiocarbon remains in a sample after 25,000 years?

Answer: approximately 5%.

6. Show the students what a radiocarbon date looks like when the lab sends the result back to

the researcher using an illustration like this one.



Explain what Before Present means (before 1950) and why there is a +/- (standard error measurement) attached to the date -- our instruments are not perfect, there is some uncertainty to each measurement. We leave it up to the teacher to decide in how much detail to cover this concept in class, but students should understand that radiocarbon dating does not determine the age of events with exact precision but instead provides a restricted range of possible ages, which can be efficiently communicated using the central date and standard error as a shorthand for this range. However, for the sake of simplicity, students should use the central estimate in any exercise that requires the manipulation of radiocarbon dates throughout the modules in this box. Then give students another random date (for example 5,275+/-60) and have them explain what the date means (the true radiocarbon age has a 68% chance of lying somewhere between the measured age plus the standard error and the measured age minus the standard error).

Conclusion:

Have students summarize and review how radiocarbon dating works in their own words (you can display the fox illustration to help them).

Lesson Activity 3: Interpreting radiocarbon dates

Students use their knowledge of dating methods to interpret an archaeological site.

Warm up:
Review the Law of Superposition, Absolute and Relative Dating, and the principles of Carbon Dating. Ask students to give examples of how each is used.

Procedure:
1. Ask students to think about whether archaeologists are interested in when an organism died. Ask them to think about the definition of archaeology – study of **people**. Discuss the idea that archaeologists are more interested in human activities than when an organism died. Consider what archaeologists call the target events and dated events, using the illustration as a visual aid that emphasizes the difference between target and dated events [Slide 23]. Students should understand that

a. While archaeologists date layers and objects, what they are really interested in dating are the human behaviors or events that might have influenced humans.

b. The death of an organism is a "dated event." Human behaviors or geological events of interest are "target events."

c. Archaeologists have to make arguments to link dated events and target events for example, the wood is found in the same layer and it's a short-lived twig.

2. Use the Rasshua test pit illustration (laminated handouts) to talk about whether things that can be dated on that illustration will provide dates close to target dates. For example, bone is usually a good way to get a date close to target date of human occupation, because people normally eat animals soon after they kill them, whereas wood could provide a date older than human occupation if, for example, old driftwood was being used (for firewood or tools).

3. Tell the class that they will now use this Rasshua Island site to interpret using what they've learned about dating.

4. Hand out the Research Plan worksheets (you can print out the Rasshua stratigraphy and radiocarbon dates for each student on the last two pages of the Research Plan worksheet or use the laminated handouts). Ask students to answer the questions and write a narrative about the site layers. The narrative should include how people lived at the site and what events they experienced. You may decide to do this as a small group activity:

A. Divide the class into small groups of 2-3 students. Hand out the first worksheet and the Rasshua Test Pit profile. Ask students as a small group to complete the first worksheet and to identify what levels they want to date and why.

B. Discuss the answers to worksheet as a class. Ask students to report on which layers they would like to date and why.

C. Distribute Worksheet Two and the Test Results. Ask students to answer the questions relating to their test results in their small group. Reconvene the class to discuss the answers and what they might tell us about the people who lived at the Rasshua site.

Conclusion:
As individuals (or in small groups), students will write a site report describing who lived at the site, how they lived at the site and what they experienced. Tell students that they should use evidence from their study to support their narrative. Discuss the findings as a class.

How ^{14}C works

1. Cosmic rays enter the earth's atmosphere and collide with atoms there, creating energized neutrons.
2. If one of these energized neutrons collides with a nitrogen atom (^{14}N, having seven protons and seven neutrons), this atom turns into a ^{14}C atom by capturing the energized neutron and losing a proton.
3. Both ^{14}C and ^{12}C combine with oxygen in the atmosphere to form carbon dioxide molecules, which are then absorbed into the tissues of plants during photosynthesis.
4. Animals eat plants or other animals and absorb the ^{14}C and ^{12}C into their tissues continuously throughout their life.
5. Following the death of a plant or animal, it no longer absorbs ^{14}C or ^{12}C into its tissues, and its tissues begin to lose ^{14}C atoms because these atoms change back into ^{14}N by losing a neutron and regaining a proton. This process is called beta emission.

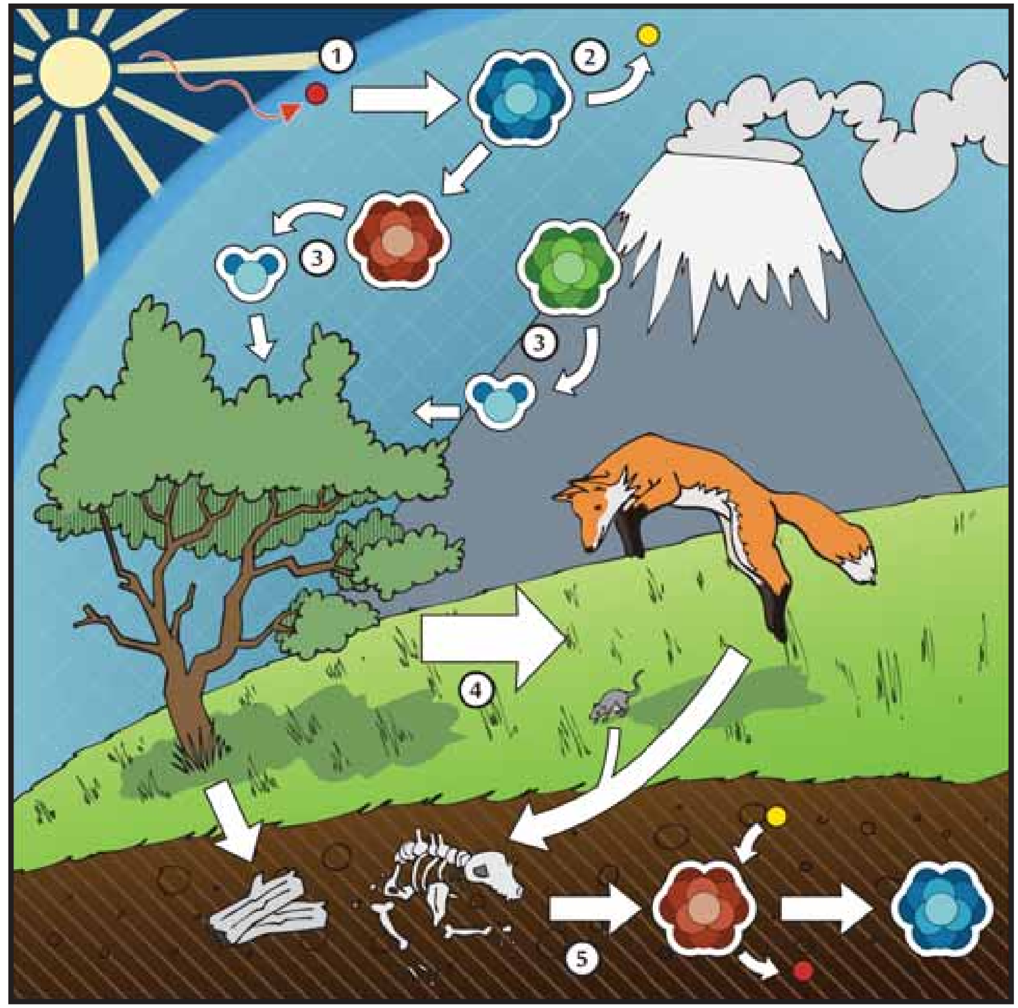


Figure 1

= Proton
= Energized neutron
= ^{14}N
= ^{14}C
= ^{12}C
= CO^2

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Questions to ask in class:

- What is the approximate age of an organic sample with 75% radiocarbon remaining?

  Answer: approximately 2,500 years.

- How much radiocarbon remains in a sample after 3 half-lives?

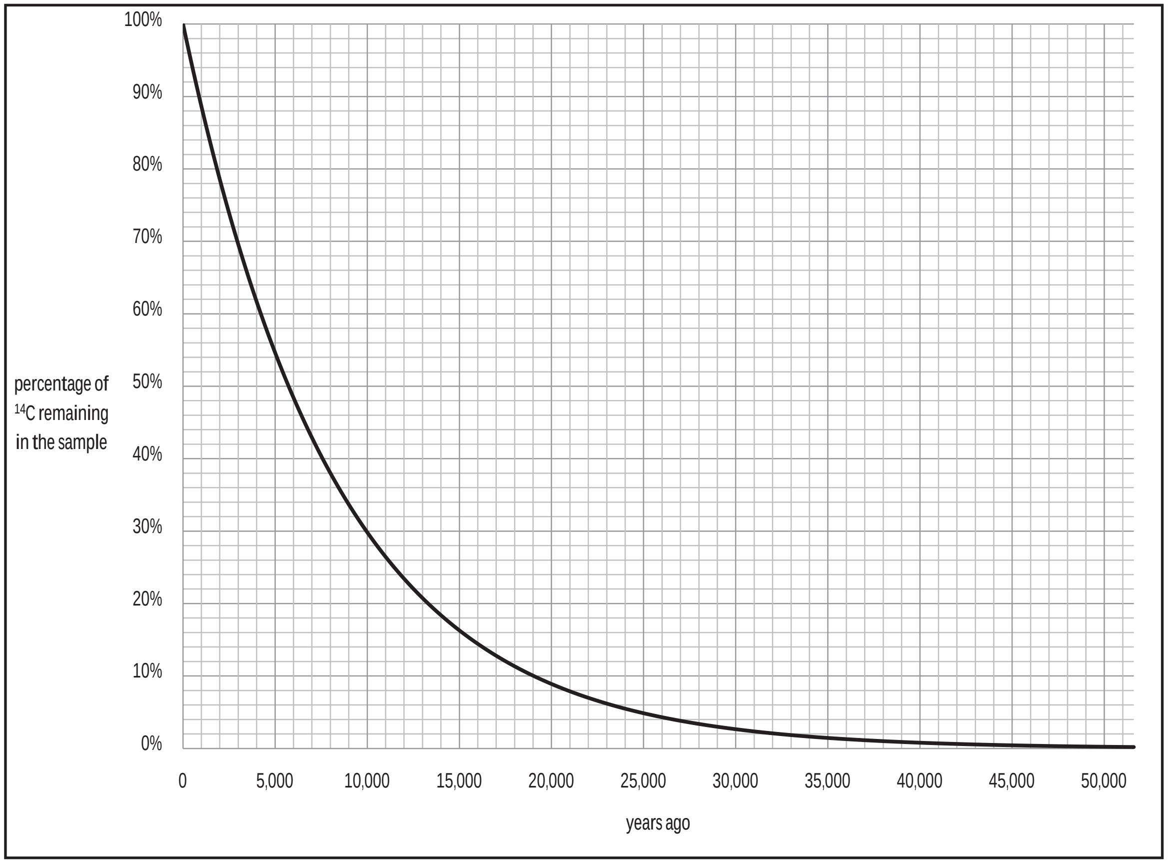
  Answer: 3 × 5,730 = 17,190 years. Approximately 12%

- What is the approximate age of an organic sample with 1/512 of the original radiocarbon remaining?

  Answer: 1/512 ≈ 0.2%. 1/512 is associated with 9 half-lives ($2^9 = 512$). However, this amount of remaining radiocarbon is too small for most laboratories to measure or detect, so no reliable date can be obtained; all we can say is that it is >9 half-lives old, in other words >51,570 years old).

- How much radiocarbon remains in a sample after 25,000 years?

  Answer: approximately 5%.



Dated Event

A radiocarbon date approximates the time of death of an organism, because this is the point in time when that organism stops incorporating new ^{14}C into its tissues and the ^{14}C already in its tissues begins to decay. For example, a radiocarbon date on wood or wood charcoal indicates when a tree died, either from natural causes or when it was cut by people for use. Similarly, a radiocarbon date on an animal bone indicates when that animal died, either from natural causes or when it was killed by people for use. This date is referred to as the "dated event." In the case of radiocarbon dating, the dated event always refers to the time of an organism's death

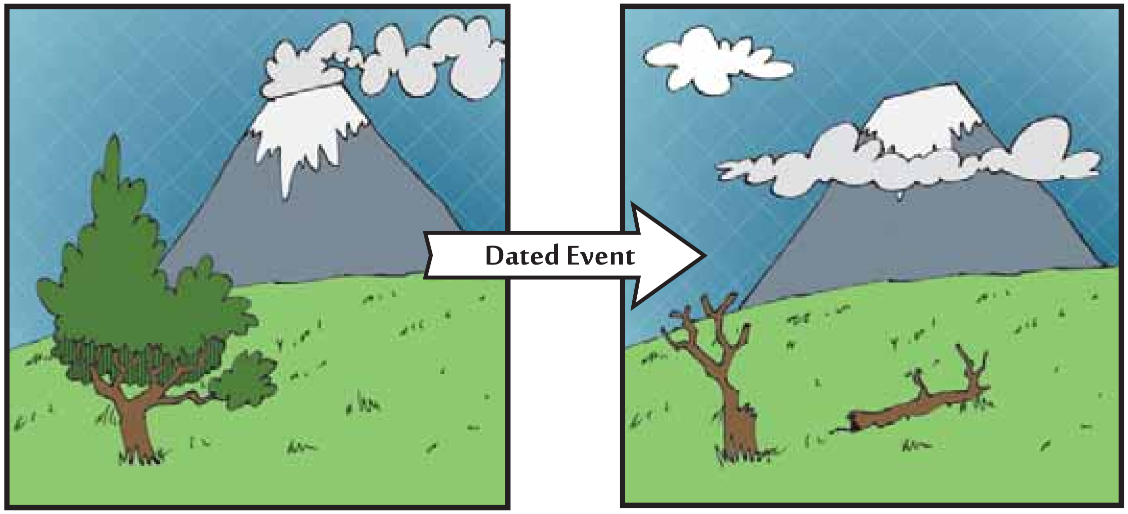


Figure 3

Target Event

Archaeologists are actually interested in dating when humans occupied certain locations or when they engaged in particular activities in the past. The activities that humans undertook when they occupied particular locations often involved the use of organic materials (bones, wood, shell, etc.), which were then thrown away nearby. If these materials have been preserved (in other words, did not decompose, were not eaten or carried away by animals, etc.), they can be collected by archaeologists and dated. Human activities are referred to as "target events," and their age can be approximated by the age of the dated event. In some situations, the dated event and the target event occurred very close in time to one another, for example if people cut wood from a tree to burn it. In other situations, the dated and target events may be separated by a few centuries (or more), for example if people use old driftwood from a beach as fuel for fire. Because of this possibility, archaeologists have to develop convincing lines of reasoning to justify using a particular sample to estimate a date for a target event, and they should check their dates by dating several samples and dating different materials (bones and charcoal, for example). Geologists struggle with these issues too, because organic materials contained in geological layers may be anomalously old or young, for example if burrowing rodents have disturbed the layers.

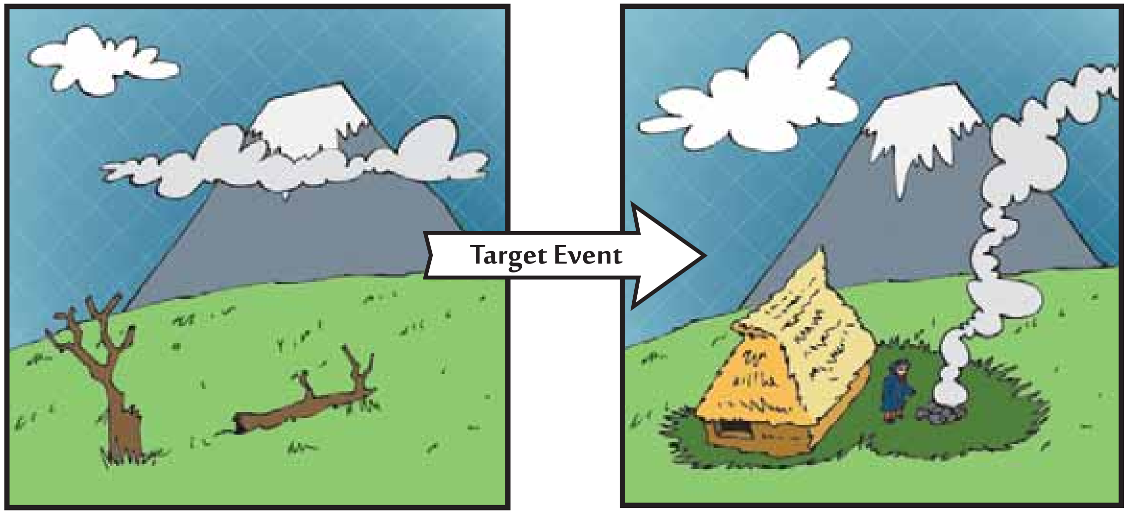
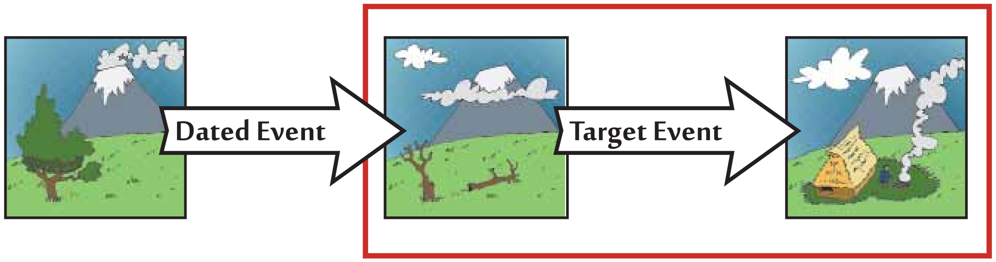


Figure 4



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Student Worksheet guide

The Research Plan

Part One:

You are the head of an archaeology crew. You and your crew just returned from an excavation of a Test pit (Test Pit 1) at the Rasshua 1 site on Rasshua Island in the Kuril Island chain. After the excavation, your field assistants drew the stratigraphic column of one of the walls of the excavation. Using the drawing of the stratigraphy, you now have to answer the following questions in order to decide how you are going to establish the chronology, or the sequence of events, of this site.

Written questions:

1. Which layers can you date using ^{14}C? Why do you think so?
2. What materials would you date to find out the age of cultural occupations? Why?
3. What would you date to find out the age of Layer B?
4. What materials would you date to find out the age of Ushishir tephra (Layer C)?
5. How would you test the idea that volcanic eruptions had a devastating consequence for human occupation?

Part Two:

After you answered these questions and decided which levels you wanted to date, you sent your radiocarbon samples to a radiocarbon dating laboratory. Take a look at the table of results that they sent back. Now answer the following questions to interpret what events took place at this site and how they are related to each other in time.

Written questions:

1. Are there any dates which are out of order? How would you explain them? (**Hint:** Think back to target and dated events and human or natural activities that can disturb certain levels).
2. How long did humans occupy the site? Were there any gaps in occupation?
3. What is the age of artifact X? How did you determine it? What are the dated and target events for this sample?

Part Three:

The last step in the process of archaeological analysis of a site is to write a narrative about how the layers of the site got there. This is the story about how people lived there and what events they experienced. In the space below, write the history of people at Rasshua 1 as you understand it from the dates you obtained and the stratigraphic sequence. Start from the bottom and explain how each layer formed, as well as what its chronolgical relationships are with other layers. (In other lessons in this education kit, you will learn more about the artifacts and food remains discovered at this site and will be able to better understand the everyday lives of the people who once lived here.)

Student Worksheet guide

The Research Plan - continued

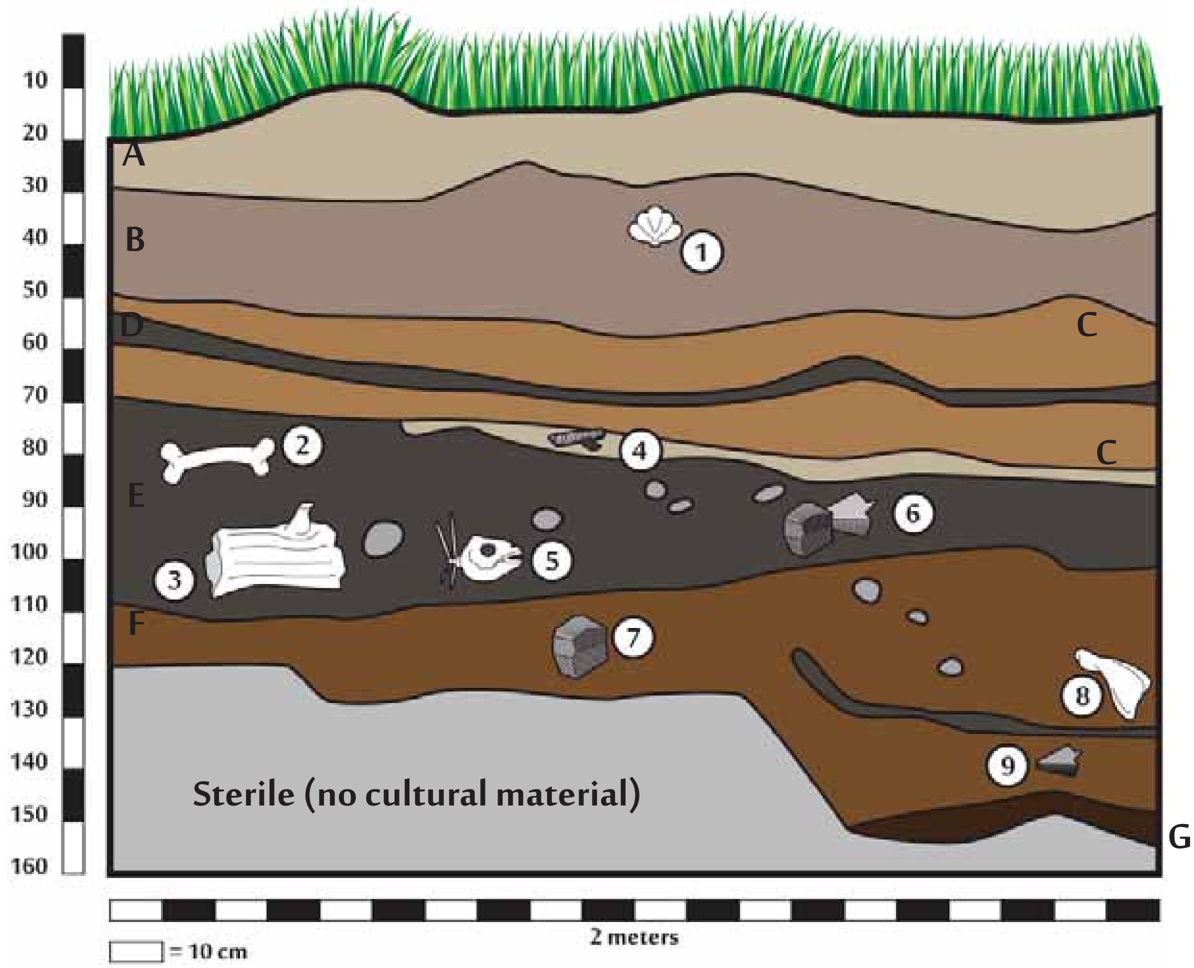
Available as laminated handout

Material 1

Rasshua 1 Test Pit 1 Excavation Profile

July 15, 2008

Erik Gjesfield and Molly Odell



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Material 2

Results of the Radiocarbon Dating of Rasshua 1 - Test Pit 1 Samples

Site	Lab Number	^{14}C Age (years BP) reported with standard error	Material	Stratigraphic position
Rasshua 1	OS - 79668	1,950 ± 25 years BP	Shell	Position #1
Rasshua 1	OS - 79669	2,080 ± 25 years BP	Bone	Position #2
Rasshua 1	OS - 79865	2,020 ± 30 years BP	Wood	Position #3
Rasshua 1	OS - 79670	2,110 ± 25 years BP	Charcoal	Position #4
Rasshua 1	OS - 79671	2,210 ± 25 years BP	Bone	Position #5
Rasshua 1	OS - 79720	2,430 ± 25 years BP	Charcoal	Position #6
Rasshua 1	OS - 79665	2,860 ± 25 years BP	Charcoal	Position #7
Rasshua 1	OS - 79666	2,480 ± 35 years BP	Bone	Position #8
Rasshua 1	OS - 79667	2,660 ± 25 years BP	Charcoal	Position #9

ZOOARCHAEOLOGY

Teacher's Manual

Table of contents

Subjects:
Biology (Anatomy), Social Studies

Duration:
2-4 class periods, depending on which extension activities are used

Class size:
10 - 30

Summary

Overview:

This unit provides an introduction into the science of zooarchaeology. This includes information on skeletal anatomy of birds, fish, and mammals, as well as specific information on how zooarchaeologists identify different species of animals based only on skeletal remains. Finally, methods of quantifying identified bones will be covered.

Objectives:

- Students will be able to explain how skeletal anatomy reflects the organization of the Linnaean Hierarchy and how that knowledge can help identify species or class of animal fro bones.
- Students will learn the patterns of bone growth in mammals and will practice using this knowledge to identify age and sex of animals based on their bones.
- Students will learn some of the techniques used by zooarchaeologists when analyzing archaeological bone samples.
- Students will practice using zooarchaeological data to create hypotheses about past interaction of animals, humans, and their environments.

Material:

Introductory Slide Show
- Teacher's Edition
- Student worksheets
- Bones (82 specimens, labeled KBP Burke 092 through KBP Burke 209, in 5 sets):
    - Reference materials
    - Class ID
    - Age and Growth
    - Quantification
    - Species ID

Vocabulary

Adaptation:
An evolutionary change in a species in response to changing environmental conditions or moving into/utilizing a new habitat.

Articulate:
To intersect with another bone, either in a relatively mobile joint like a hip or shoulder, or a relatively immobile joint like ribs articulating with vertebrae.

Cancellous bone:
The inner portion of bone that is filled with a fine network, or lattice, of bony struts.

Cortical bone:
The dense outer layer of a bone.

Diaphysis:
The main shaft portion of a bone.

Distal:
The end of a longbone that is oriented away from the core of the body.

Epiphysis:
The end portion of bones; in juvenile animals the epiphysis and diaphysis are separate bones that gradually fuse together as the individual matures.

Epiphyseal plate:
A thin layer of cartilage between the epiphysis and the diaphysis; this is where most bone growth occurs.

Femur:
The thigh bone, or upper leg bone.

Humerus:
The upper arm bone.

Island biogeography:
The scientific study of the distributions of animal species living on islands.

Linnaean Hierarchy:
The system used to organize all living things in a way that reflects their evolutionary histories.

Medullary bone:
The hollow inner portion of a longbone shaft; medullary bone is variously filled with marrow, oil, or air.

Ossification:
The process of converting cartilage into bone.

Paleontology:
The scientific study of animal remains that reflect natural (i.e., non-human) patterns of animal activities or behavior.

Phytogeography:
The scientific study of the distributions of different plant species.

Vocabulary
Continued

Proximal:

The end of a longbone that is oriented towards the core of the body.

Quadrupedal:

Uses all four limbs for walking.

Zooarchaeology:

The scientific study of animal remains that reflect patterns of human activities or behavior.

Background Information

Introduction

This module introduces students to the discipline of **zooarchaeology** (pronounced either "zoh-ark-e-ol'-o-gee" or "zew-ark-e-ol'-o-gee") and highlights how zooarchaeology has been used in the Kurils Biocomplexity Project. Students will

- Examine and identify bones
- Learn how to determine age and sex of the bones, and
- Analyze zooarchaeological data from their lab work and (optional) data from the KBP Expeditions.

Zooarchaeology is an interdisciplinary field that combines zoology (the study of animals) and archaeology (the study of past human activities). Like its sister discipline, **paleontology**, zooarchaeology is focused on the study of bones, teeth, and shells. The difference between the two disciplines is that zooarchaeological samples are found in association with human activities and reflect human behavior (the "archaeology" part). Paleontological samples come from deposits that reflect natural geological processes but do not have any evidence of human activity.

How does zooarchaeology work?

The first step in any zooarchaeological analysis is to identify what animal the bone or shell sample has come from. Zooarchaeologists rely on the fact that animals that are closely related to each other tend to have similar-looking skeletons. Animals that are not closely related tend to have different-looking skeletons. The degree of difference or similarity usually scales with how closely related two species are.

Once a bone has been identified, there is a wide range of data that are typically documented for any given bone, including age-at-death, degree of fragmentation, presence of any cultural modifications such as cut-marks or burning, and so on.

One incredibly important aspect about zooarchaeological data is that the kinds of data recorded depend entirely upon what the research question is. If a zooarchaeologist is working in a region where little or nothing is known about how prehistoric peoples made a living, simply documenting what species of animals were used for food would be a significant contribution to our understanding of that culture.

In contrast, in an area where the basic diet is well-known, as in many areas of the Pacific Northwest, more elaborate research questions can be addressed, such as "How did the occurrence of tsunamis affect the availability of shellfish?" or "How did deer populations respond to human hunting pressure?" The kinds of data needed to answer these types of questions can vary quite a bit. But it all starts with being able to identify what species any given bone (or shell) comes from.

Procedure

Lesson 1:

Warm up:
Brainstorm with the class on the question of how prehistoric people used animals and what evidence of that use would be left in archaeological sites. Introduce the concept of zooarchaeology - study of faunal remains from archaeological sites.

Procedure:
1. Use the slideshow to introduce the students to determining class, species, and age of the animals from bones. You can use the bones from the set "Class ID" as a visual prop; have students look at the bones and pass them around. The slideshow also touches briefly on how archaeologists quantify bones.

2. Divide the class into three groups and hand out the three exercises, one to each group:

A. **Species Identification** (Students learn in more detail how zooarchaeologists identify what species any particular bone has come from. Examples of mammals and birds will both be used).

B. **Age and Growth** (Students will find out how much information about age-at-death zooarchaeologists can exract from any given bone. Using the same tools that forensic scientists use, students will learn how patterns of growth can be used to determine age-at-death from their bone samples).

C. **Quantification** (Students will learn how zooarchaeologists keep track of their identifications, and how they present their data in a way that other zooarchaeologists can know what they are talking about. This section presents a few of the wide variety of quantification methods that zooarchaeologists routinely use).

After some time, have students rotate to the next "station." Repeat so that all students get a chance to work with all three sets of bones.

Wrap up:
Discuss why it may be important to determine what animals people were eating or using for their tools (prehistoric diet change could indicate that some animal was being over-hunted or that taste preferences were changing, for example).

Lesson 2:

Warm up:
Review material from the previous day (how do archaeologists study animal bones from sites?).

Procedure:
Students do an activity (part 1), which asks them to examine and analyze a table of raw data generated from a hypothetical analysis of zooarchaeological samples from three sites within the Kuril Islands. This activity can be run either in small groups or individually (either in class or as homework). Optional additions are parts 2 and 3 (accessing real zooarchaeological data from anywhere in the continental United States, as well as from the Kuril Biocomplexity Project). These can be assigned as homework.

Wrap up:
Discuss the answers with the entire class.

Step 1:

Lets start with some terminology for different parts, or landmarks, of the bones. These are the anatomical parts that help zooarchaeologists be consistent in the ways they describe bones from various species, as well as specific identification characteristics, or features, that can be used to distinguish different species from each other. (See figure) .

Assignment for students for the empty space in their packet:
Start with reference bones. Use either the set of mammal bones or the set of bird bones. Choose one bone and sketch (or trace) the outline of the bone. Now label at least four of these characters on the drawing.

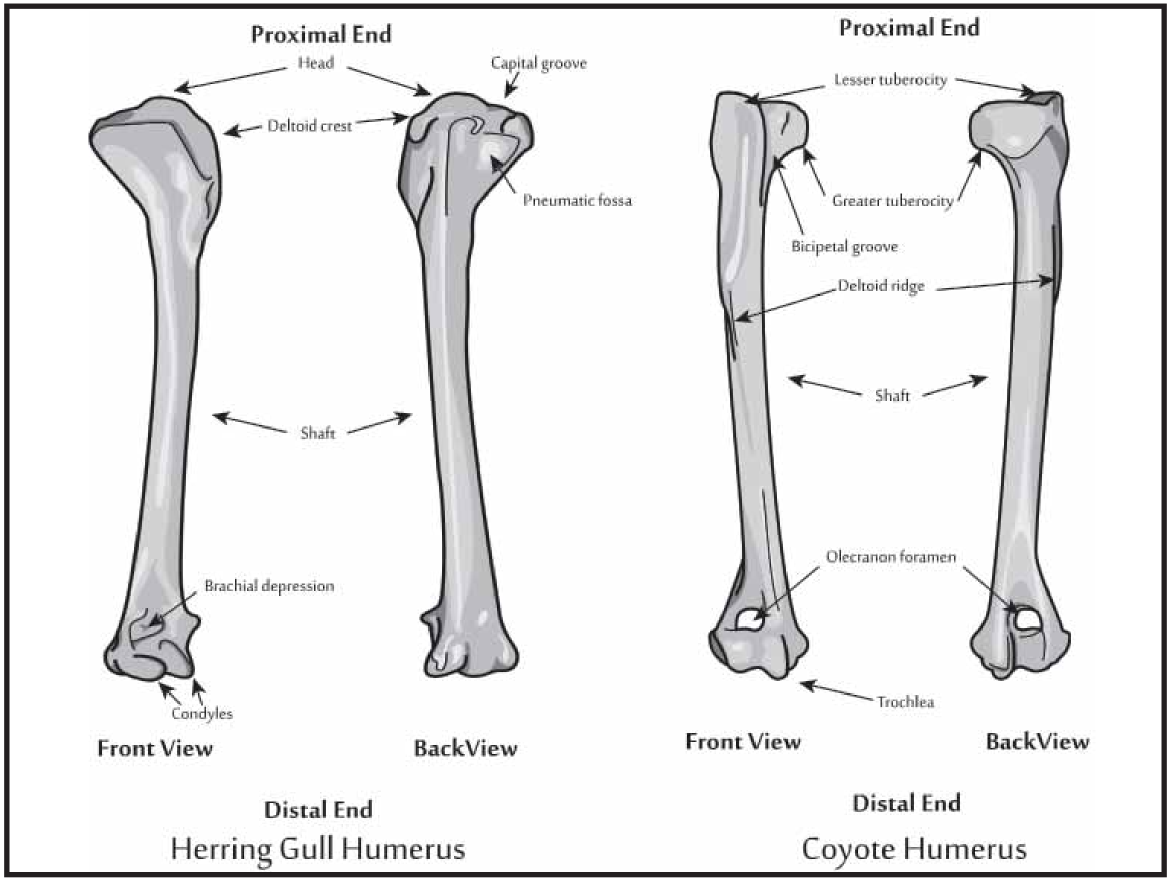


Illustration of the humerus from one bird and one mammal species showing key landmarks, or features, used to describe the anatomy of the bone.

Student Worksheet guide

Identifying Species

Step 2, 3 & 4

Step 2:

Using the landmarks identified in the drawings, describe how each of the four reference bones in the set you have selected (either mammals or birds) is different from each other. Some important aspects of the landmarks may be their size or shape.

Answer: Answers will vary. Some characters the students might notice include:

1. harbor seal: the presence of a foramen, or hole, that passes through the bone on the distal end
2. fur seal: lacks the foramen seen in harbor seal
3. gull: proximal end has thin, angular projections; distal end has a spur of bone projecting out

Step 3:

Now, identify the fragmentary bones in the "Unknowns" bag from the appropriate set of bones (birds vs. mammals). Remember that size and shape are the two characters that are most helpful in identifying a species. All of the species illustrated here (4 bird species, 4 mammal species) are represented. But there are also bones from at least one species not represented here.

Record the appropriate species for each specimen in the table (see next page). Each species will be represented by one or more fragments of bone. If you think a bone specimen is not a good match to any of the species in your list, mark it as "unknown."

Examine the "unknown" bone/s closely. Which of the four reference species does it (or do they) most resemble? (Hint: Remember that closely-related species typically have bones that look similar to one another.) (Answer: Coyote bone resembles the fox, but is larger).

Step 4 (Additional Explorations):

All of the bone sketches in this module were developed from three-dimensional digital images created by the Virtual Zooarchaeology of the Arctic Project (VZAP). These images are stored as portable document files, otherwise known as PDFs, and can be viewed on most computers. Each of the illustration files is included on the DVD in the Burke Box. Once the files are opened and activated, you can view the illustrated bone from any angle by simply dragging the mouse/cursor.

To view the three-dimensional illustrations, double-click on the PDF file you are interested in.

Single-click on the image to "activate" the 3D capabilities.

Click and hold the mouse, and then rotate the bone by "dragging" it in any direction.

Student Worksheet guide

Identifying Species

Step 3 table

Specimen number	Species	Answer		Specimen number	Species	Answer
KBP Burke 0134		Cormorant		KBP Burke 0154		Fur seal (adult female)
KBP Burke 0135		Gull		KBP Burke 0155		**Coyote**
KBP Burke 0136		Murre		KBP Burke 0156		Fur seal
KBP Burke 0137		Cormorant		KBP Burke 0157		Fox
KBP Burke 0138		Cormorant		KBP Burke 0158		Harbor seal
KBP Burke 0139		Gull		KBP Burke 0159		Fur seal (pup)
KBP Burke 0140		Goose		KBP Burke 0160		Deer
KBP Burke 0141		Teal		KBP Burke 0161		Harbor seal
KBP Burke 0142		Mallard		KBP Burke 0162		Harbor seal
KBP Burke 0143		Gull		KBP Burke 0163		Fox
KBP Burke 0144		Murre		KBP Burke 0164		Fur seal (adult female)
KBP Burke 0145		Cormorant		KBP Burke 0165		Harbor seal (pup)
KBP Burke 0146		Goose		KBP Burke 0166		Deer
KBP Burke 0147		Gull		KBP Burke 0167		Harbor seal
KBP Burke 0148		Murre		KBP Burke 0168		Fox
KBP Burke 0149		Mallard		KBP Burke 0169		Fur seal (adult male)
KBP Burke 0150		Murre		KBP Burke 0170		Harbor seal
KBP Burke 0151		Gull		KBP Burke 0171		Harbor seal
KBP Burke 0152		Cormorant		KBP Burke 0172		Fox
KBP Burke 0153		Mallard		KBP Burke 0173		Fur seal

Possible species: Cormorant, Gull, Mallard, Murre, Deer, Fox, Fur seal, Harbor seal, Unknown.
The unknown "challenging" bone should be the coyote (in bold).

Student Worksheet guide

Age and Growth

Exercise

Step 1:

Using reference bones included in this section and the illustrations as a guide, separate the diaphysis (long bone shafts) into two piles, one for humeri and one for femora.

Step 2:

Using the illustrations **AND** the sorted bones, determine which of the loose end caps (unfused epiphyses) belong with the humeri and which belong with the femora.

Step 3:

Using the broad categories in the table below, how many bones of each age are in your sample of humeri? How many bones of each age are in your sample of femora? You do not need to count the reference bones in your totals. You can ignore the fact that the bones may be from different species. However, if an unfused epiphysis definitely fits onto a diaphysis, count the matched pair as ONE bone.

	Humerus	Femur
Juvenile (no fused epiphyses)	4	6
sub-adult (only one epiphysis fused)	1	0
adult (all epiphyses fully fused)	1	1

Step 4:

Using the information about the age when different epiphyses fuse in different species of animals, determine as precisely as possible the age-at-death for the samples listed below. (D = distal; P = proximal):

species	bone	state of fusion	Age Estimate
dog	humerus	D unfused; P unfused	**answer:** < 5 months
red fox	femur	D unfused; P fused	**answer:** < 26 weeks, >28 weeks
deer	femur	D fused; P fused	**answer:** > 26 months
harbor seal	femur	D unfused; P unfused	**answer:** < 3 years
male fur seal	humerus	D fused: P unfused	**answer:** 7-9 years
female fur seal	humerus	D fused; P unfused	**answer:** 5 years
fur seal, sex unknown	humerus	D unfused; P unfused	**answer:** < 4 years

(these specimens are not included in the box)

Advanced:

Coyotes are intermediate in size between dogs and red foxes. Assuming that their growth patterns are also intermediate between dogs and red foxes, fill in the following table with your predictions of the age of fusion for the humerus and femur.

species	Proximal Humerus	Distal Humerus	Proximal Femur	Distal Femur
dog	10 months	5-8 months	6-9 months	6-8 months
coyote	**ans:** 6-8 months	**ans:** 6 months	**ans:** 7-8 months	**ans:** 7-8 months
red fox	17 weeks	16 weeks	26 weeks	28 weeks

Question 1:

Keeping in mind that this exercise includes only two skeletal elements (humerus and femur), outline the steps you would take to determine what the MNI (minimum number of individuals) is for the sample. Then follow these steps to answer the questions that follow.

Answer:

[Younger students may need some guidance with this]. Separate the bones into two separate piles, one for femora and one for humeri. Then separate those piles into "rights" and "lefts." Determine which pile has the largest number of bones. (It is not terribly important that the students be able to tell which side these bones come from, just that one side is the mirror image of the other). MNI is the number of bones in the larger pile.

Question 2:

What is the MNI for this sample, and what was it based on?

Answer:

There are four left humeri, so many students will answer that the MNI of humeri is 4. However, some students may notice that one of the right humeri is much larger than any of the other left humeri. They would be correct if they argued that the right humerus is likely to have come from a different individual than any of the other left humeri, with an MNI of 5.

Both answers could be considered to be correct! One of the limitations to the use of MNI is that different researchers use different criteria to quantify the minimum number of individuals likely to be represented in a collection.

Question 3:

Suppose that all of the skeletal elements in your sample came from different individuals. What is the maximum number of individuals that could be represented in your sample?

Answer: MNI = 11.

Question 4:

What is the NISP (total number of specimens identified for each species) of the sample, and how does that relate to your answer to Question 3?

Answer:

If all of the skeletal elements in your sample came from different individuals, the NISP and the maximum number of individuals will be the same. In this case, NISP = 11.

Question 5:

What is the MNI for femora. Is it the same as for humeri? Why or why not? Which MNI would you use to represent the number of animals at the site?

Answer:

There are five femora, but the MNI is 3, as there are three left femora. It is different from the humerus MNI because the division between left and right elements is different. The larger MNI of 4 (or 5) that is obtained from humeri is the better representation of animals found at the site.

Lesson 2: Analyzing Data

This portion of the Zooarchaeology Module deals with analyzing zooarchaeological data. If you have not already explored the "**QUANTIFICATION**" portion of Lesson Activity 2, please take a few minutes to review the different ways zooarchaeologists tally their identification data.

The non-human bones that are recovered in archaeological sites[1] most typically derive from three main sources: accumulated trash or refuse from human foraging activities; tool-making and construction debris; and intrusive remains of burrowing species like mice. The job of the zooarchaeologist is to try to determine which of those three categories any particular bone fits into, identify what species the bone came from, and then tally the identification data to answer a variety of research questions.

[1]The Kuril Biocomplexity Project did not excavate any human burials, as they would not have provided data relevant to the research questions our team was interested in pursuing.

Those research questions range from purely descriptive (For instance, "What species were being use for food, and in what proportions?") to socioeconomic in nature ("Did Household A have access to higher-quality resources than Household B?"). Other research questions may be only indirectly related to human activity at the site, such as "What evidence of climate change do we see in the zooarchaeological samples?"

Analyzing Data, Part 1:

The following set of exercises is based on realistic data for three archaeological sites in the Kuril Islands.

Step 1 (optional). Using the spreadsheet of raw data, tally the total number of specimens identified for each species (NISP), from each stratum, for each of the three archaeological sites. Put your totals in the appropriate boxes on the table "Bone ID NISP blank table" (data for Simushir, Stratum 1, are already provided).

PAY CAREFUL ATTENTION TO INFORMATION PROVIDED IN THE "COMMENTS" COLUMN OF THE DATA TABLE.

Step 2. Using either your results from Step 1, or the provided data table ("Bone ID NISP data"), answer the following questions:

1. Are there significant changes through time in the number of albatross that were harvested at Rasshua? (Answer: Yes, there seems to be a significant drop in the number of albatross bones. The sample size in Stratum 1 is large enough so

that if there had been more albatross bones, they probably would have shown up in the sample.

2. Do you think the changes in albatross use at Simushir are significant? (Answer: While it is true that there are three times as many albatross bones in Stratum 1 as in Stratum 3, the overall sample size of albatross bones is quite small. With a sample size this small, it is difficult to tell if there is any patterning or not).

3. Is it safe to conclude that the people living on Ushishir did not own dogs? Why or why not? (Answer: No, this is not a safe conclusion—people could have easily had dogs as pets on Ushishir. Dog remains wouldn't necessarily show up in the midden samples. Also, one of the fur seal ribs (KBP 0345.08) is listed as having carnivore gnaw marks on it, which could have come from either a dog or a fox. While this still doesn't answer the question about whether or not the inhabitants of Ushishir had dogs, it is a piece of evidence to consider).

4. List at least two hypotheses that could explain the increase in sea otters at Rasshua. Be sure to examine the dates of occupation (see "Stratigraphic dates" table) (Answer: Answers will vary, but could include (a) the people living at Rasshua may have become involved in the commercial sea otter trade and/or (b) there may have been a shift in climate that made sea otters more locally abundant).

Step 3 (optional). Using the spreadsheet of raw data, tally the minimum number of individuals (MNI) represented by the sample of bones for each species FOR ONE STRATUM from only ONE SITE (data for Simushir, Stratum 1, are already provided). Use information about the skeletal element that is represented, any age or sex information that is recorded, as well as information in the "Comments" column of the spreadsheet. Enter your MNI data in the appropriate boxes in the table "Bone ID MNI blank table," including what you based your calculations on (for instance, in Stratum 1 at Simushir, the MNI of salmon is 1 based on the presence of either bone, while the MNI of albatross is based on the presence of a single humerus).

Step 4. Using either your results from Steps 1 & 3, or the provided data tables ("Bone ID NISP data" and "Bone ID MNI data"), answer the following questions:

1. When the data are quantified using MNI instead of NISP, do you come to a differenct conclusion about the trend in albatross use at Rasshua? Why or why not? (Answer: The differences are much less pronounced when the minimum number of individuals is considered. Although the overall samples sizes of Stratum 1 (NISP = 16) and Stratum 3 (NISP = 13) are similar, a reduction from 4 individuals to 1 individual could simply reflect (a) where on the site the bones were discarded and (b) where the excavation units were placed).

2. When the data are quantified using MNI instead of NISP, do you come to a differenct conclusion about the trend in albatross use at Simushir? Why or why not? (Answer: When the MNIs for albatross from Simushir are considered, there appear to be no differences at all between strata).

Step 5. Imagine that you have lost the stratigraphic information from the deepest part of your excavations at Rasshua (Stratum 3 and Stratum 5). You still have the data table of identifications, but now you must recalculate the NISPs and the MNIs with these two strata combined.

Fill out the table "Combined Strata Blank" and answer these questions:

1. How do the NISPs change relative to the original, un-combined strata? (Answer: The NISPs for the combined strata are simply the sum of the NISPs from the strata considered separately).

2. Do the MNIs change in the same way? Why or why not? (Answer: No. Because the MNIs are calculated based on the most commonly encountered skeletal element in that stratum, you cannot simply combine strata and add the MNIs together. The raw data must be examined to determine what the most commonly encountered skeletal element is for the combined strata to recalculate the new MNI).

Analyzing Data, Part 2:

Now you'll have the opportunity to explore real data from your own state! (requires internet access). You'll have an opportunity to explore the actual Kurils data in "**Analyzing Data, Part 3"**.

Archaeological and paleontological data are typically available to the public, especially if the project is funded through a federal agency like the National Science Foundation. Although the standard approach scientists use to make their data available is to publish their results in scientific and popular journals, the internet is an increasingly popular outlet for making data broadly available.

One of the most comprehensive on-line databases is called the "Neotoma Paleoecological Database." The database is named after a curious rodent called a pack rat (scientific name *Neotoma*), which has a habit of collecting scraps of vegetation and storing them in large piles in caves. These piles accumulate and in the right conditions can preserve for tens of thousands of years. Paleoecologists study the vegetation in these pack rat "middens" to understand how climate has changed through time.

The Neotoma database is an on-line archive of a wide range of paleoecological data, including pollen studies, and mollusk studies, as well as paleontological and archaeological bone data.

To access this on-line database, open the URL for the "Neotoma Paleoecological Database" (using the web browser of your choice):

http://www.neotomadb.org

You should see a screen that looks something like this (it changes occasionally, so don't be alarmed if it doesn't look exactly like this):

Use your mouse to move the cursor over the word "DATA" at the top left of the screen. When the line of words appears that reads

"Overview Contribute Data Tilia FAQ Explore Data etc..."

move the cursor to the word "Explore Data" and click on that to open the link.

Finally, click on the map or the "Go to the Neotoma Explorer" link at the bottom of the page to launch the "EXPLORER" function of Neotoma.

[You can by-pass all of this by simply loading the following URL. However, this also by-passes interesting and potentially important back-ground information about the Neotoma database].

http://www.neotomadb.org/data/category/explorer

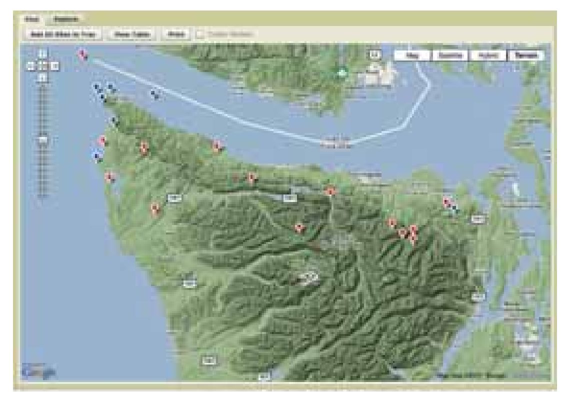
VERY IMPORTANT NOTE ABOUT NEOTOMA MAPPING FUNCTION: You must specify if you want Neotoma to search only within the area of the map visible on your screen, or if you want to search globally [see "Geographic Coordinates" at bottom left of screen]. Either approach works fine, just be aware that the area visible on your screen might determine how complete your search is.

The first search you will perform will be to find all the paleontological and archaeological data that have been recorded for Clallam County, which lies at the extreme northwest corner of Washington State.

To do that, start typing "United States" in the "Place Name" section of the Search window on the left-hand side of the screen. A drop-down list will appear. You can either scroll down through the list, or you can continue typing "United States_Washington_Cl...." until the following appears:

Once you have "United States_Washington_Clallam" showing in the "Place Name "section, click the "SEARCH" button at the bottom left corner of the screen.

There are several ways to view the search results. Most immediately, you should see a map with several pin-flags showing the locations of sites with paleontological and archaeological data. Adjust the zoom level either by using the slider on the left, or by double-clicking on the map (to re-center and zoom in). Blue pin flags represent archaeological/paleontological sites (there are 7 on the map), and red pin flags represent pollen sites (14 total, with some modern and some ancient).

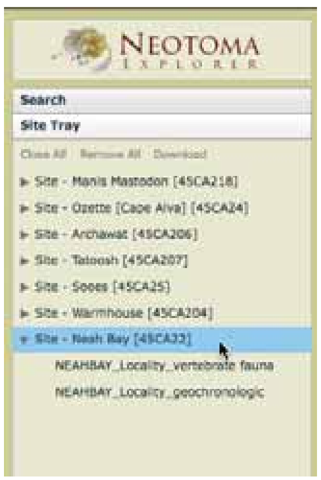


Student Worksheet guide

Analyzing Data

Part 2 - continued

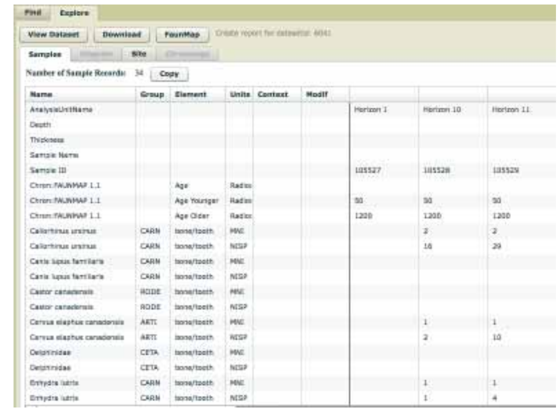
You can also view the search results in table format by toggling the "View Map/View Table" button. To find data for a specific site, you need to load the site on the "Site Tray." To do this, either double-click on a pin-flag, or in the map view, click on the "Add All Sites To Tray" button.



To see what has been loaded onto the "Site Tray," click on the white bar at the bottom left corner of the screen (the white bar that says "Site Tray").

Now double-click on the site you are interested in. If it is a modern sample, the table entry will expand to show only one additional line of text, which will lead you to the data for that site (by double-clicking on the text). If the data are from an ancient site, the table entry will expand to show two additional lines: one for the data, and one for the geochronological information (i.e., the dating for that site).

As an example, navigate to the data table for the archaeological site called "Neah Bay." It is represented by the blue pin flag out near the middle of the Strait of Juan de Fuca [this is not actually the true location of the site; the true location has been intentionally "blurred" to limit the amount of illegal and destructive looting of this sensitive archaeological site]. Double-click on the text that reads "NEAHBAY_Locality-vertebrate fauna" and you should see this table:



Name	Group	Element	Units	Context	Modif			
AnalysisUnitName						Horizon 1	Horizon 10	Horizon 11
Depth								
Thickness								
Sample Name								
Sample ID						105527	105528	105529
Chron:FAUNMAP 1.1		Age	Radio					
Chron:FAUNMAP 1.1		Age Younger	Radio			50	50	50
Chron:FAUNMAP 1.1		Age Older	Radio			1200	1200	1200
Callorhinus ursinus	CARN	bone/tooth	MNI				2	2
Callorhinus ursinus	CARN	bone/tooth	NISP				16	29
Canis lupus familiaris	CARN	bone/tooth	MNI					
Canis lupus familiaris	CARN	bone/tooth	NISP					
Castor canadensis	RODE	bone/tooth	MNI					
Castor canadensis	RODE	bone/tooth	NISP					
Cervus elaphus canadensis	ARTI	bone/tooth	MNI				1	1
Cervus elaphus canadensis	ARTI	bone/tooth	NISP				2	10
Delphinidae	CETA	bone/tooth	MNI					
Delphinidae	CETA	bone/tooth	NISP					
Enhydra lutris	CARN	bone/tooth	MNI				1	1
Enhydra lutris	CARN	bone/tooth	NISP				1	4

Adjust the column widths if you need to by dragging-and-dropping the edges of the column, or by double-clicking on a column boundary. Here are some of the key components of the data table for Neah Bay:

Date of deposits:
Ranges from 2,000 radiocarbon years BP to 50 radiocarbon years BP.

Species represented:
Callorhinus ursinus (northern fur seal), *Canis lupus familiaris* (domestic dog, entered here as a sub-species of wolf, *Canis lupus*), and so on.

Student Worksheet guide

Analyzing Data

Part 2 - continued

Quantification Units used:
Both MNI (minimum number of individuals) and NISP (number of identified specimens) were recorded for this particular collection of bones [see the "QUANTIFICATION" lesson if you need to review quantification methods]. Occasionally species are recorded in Neotoma only as present/absent, with a "1" indicating that at least one bone was identified from that stratum.

Using the Neah Bay data table answer these questions:

1. How many horizons, or strata, are represented by the data? (**answer**: 10)

2. What is the total NISP for raccoons (*Procyon lotor*) for all horizons combined? (**answer**: 3)

3. What is the total NISP for northern fur seals (*Callorhinus ursinus*) for all horizons combined? (**answer**: 55)

4. What is the total MNI for northern fur seals (*Callorhinus ursinus*) for all horizons combined? (**answer**: 12)

OTHER SEARCHES
You can also narrow your search by other search terms.

Start by first clearing the previous search results (unless you want to combine two or more searches). To do this, click on the "Remove All" button at the top of the Search Tray. Then click on the white bar at the top left corner of the screen (the white bar that says "Search").

To search for data for different species, use the "Taxon Name" section of the Search window. To see a map of all the sites that have a particular species (black-tailed deer (*Odocoileus hemionus*) in this example) recorded in them, start typing "Odocoile..." and use the drop-down list to select black-tailed deer.

Using the same approach as you did for extracting data for the Neah Bay site, answer these questions [Remember that the "Geographic Coordinates" setting may affect your search results]:
1. How many total sites are recorded in North

Analyzing Data, Part 3:

America that contain black-tailed deer bones? (**Answer**: 194. One of the site records is mapped in northern Canada, but it should really be located in Kansas).

2. Describe the geographic distribution of the sites that contain black-tailed deer bones. (**Answer**: With two exceptions (Frankstown Cave, in Pennsylvania, and Squaw Creek, in northern Canada), all of the records for black-tailed deer are in the western United States. If you look more closely at the two outliers, Frankstown Cave dates to 13,000 years ago, so it may be accurate. The Squaw Creek site is actually located in Kansas, but there is an error in how the coordinates for the site have been entered.

3. How many sites in Washington State contain black-tailed deer bones? (**Answer**: 11 (for some reason only 10 flags appear, so that answer should be considered correct).

All of the zooarchaeological data for the Kuril Islands sites have also been entered into the Neotoma database.

In order to see the map distribution of all the sites with faunal remains, enter "Russia_Sakhalin [Sakhalinskaya]" into the "Place Name" section of the Search window.

1. How many sites in the Kuril Islands are reported to have faunal remains?
Answer: 51 sites.

2. Based on information presented in the Settlement modules of the Kurils Burke Box, what is the total number of archaeological sites recorded?
Answer: Approximately 70 sites.

3. Are the answers to Question 1 and Question 2 the same? Why do you think this is the case?
Answers will vary, but there will typically be more sites documented than there are sites with faunal remains because faunal remains do not always preserve).

TSUNAMI & STRATIGRAPHY

Teacher's Manual

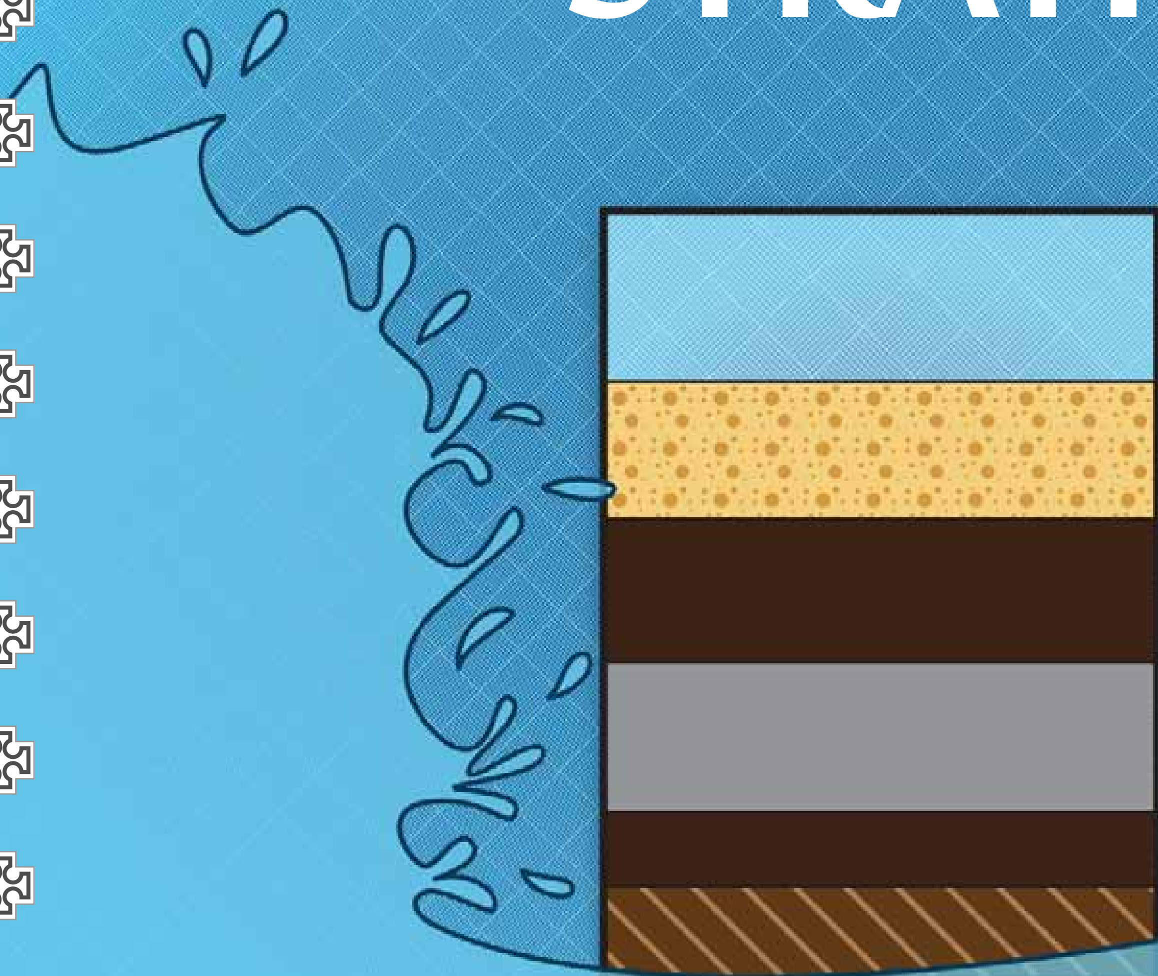


Table of contents

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:

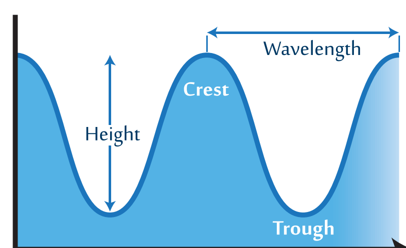
- Wind waves: 100 - 200 m
- Tsunami: 200 - 500 km

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



The Kuril Biocomplexity Project: www.kbp.org

Procedure

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.

Student Worksheet guide

Plotting topographic profiles

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	

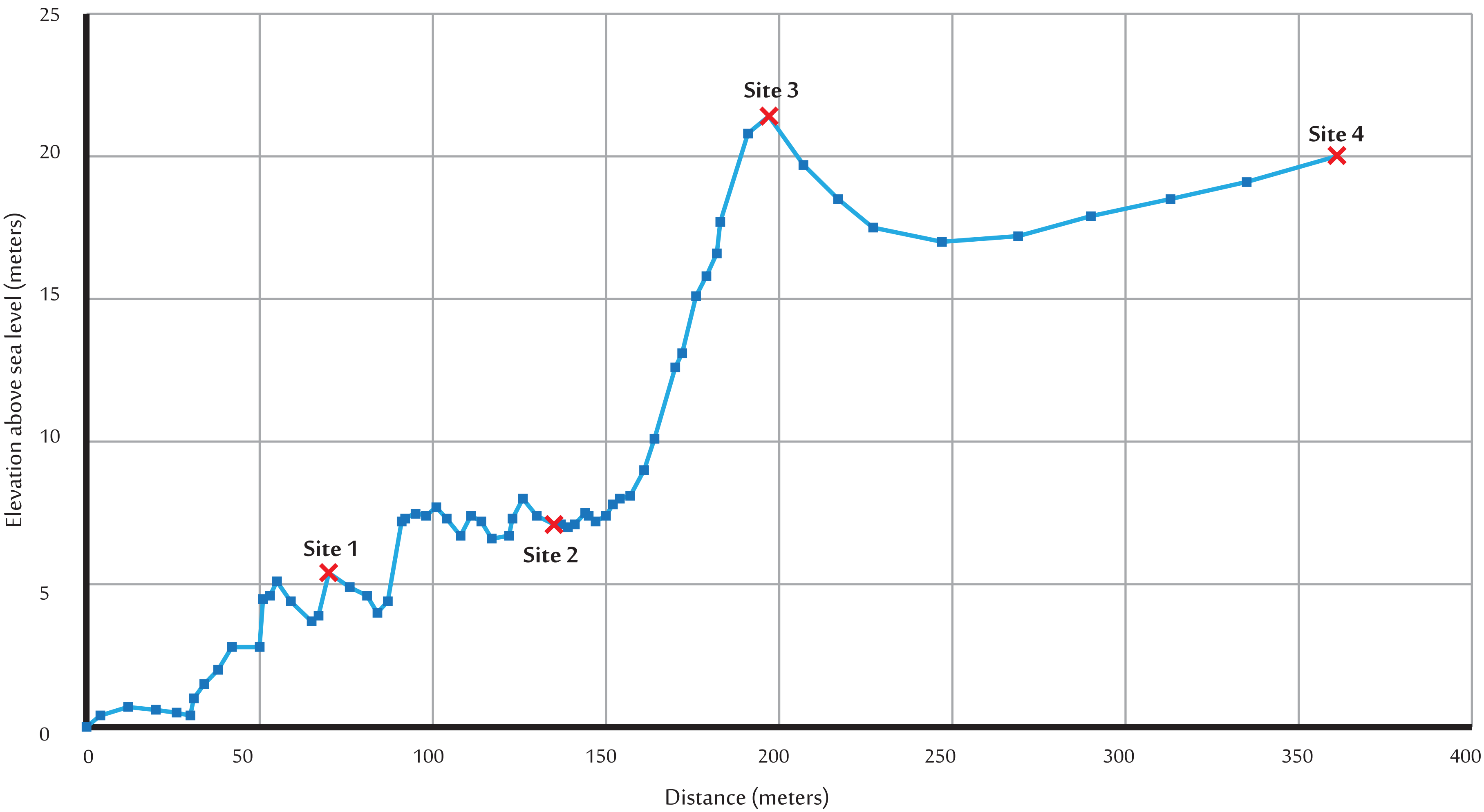
Student Worksheet guide

Plotting topographic profiles - continued

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

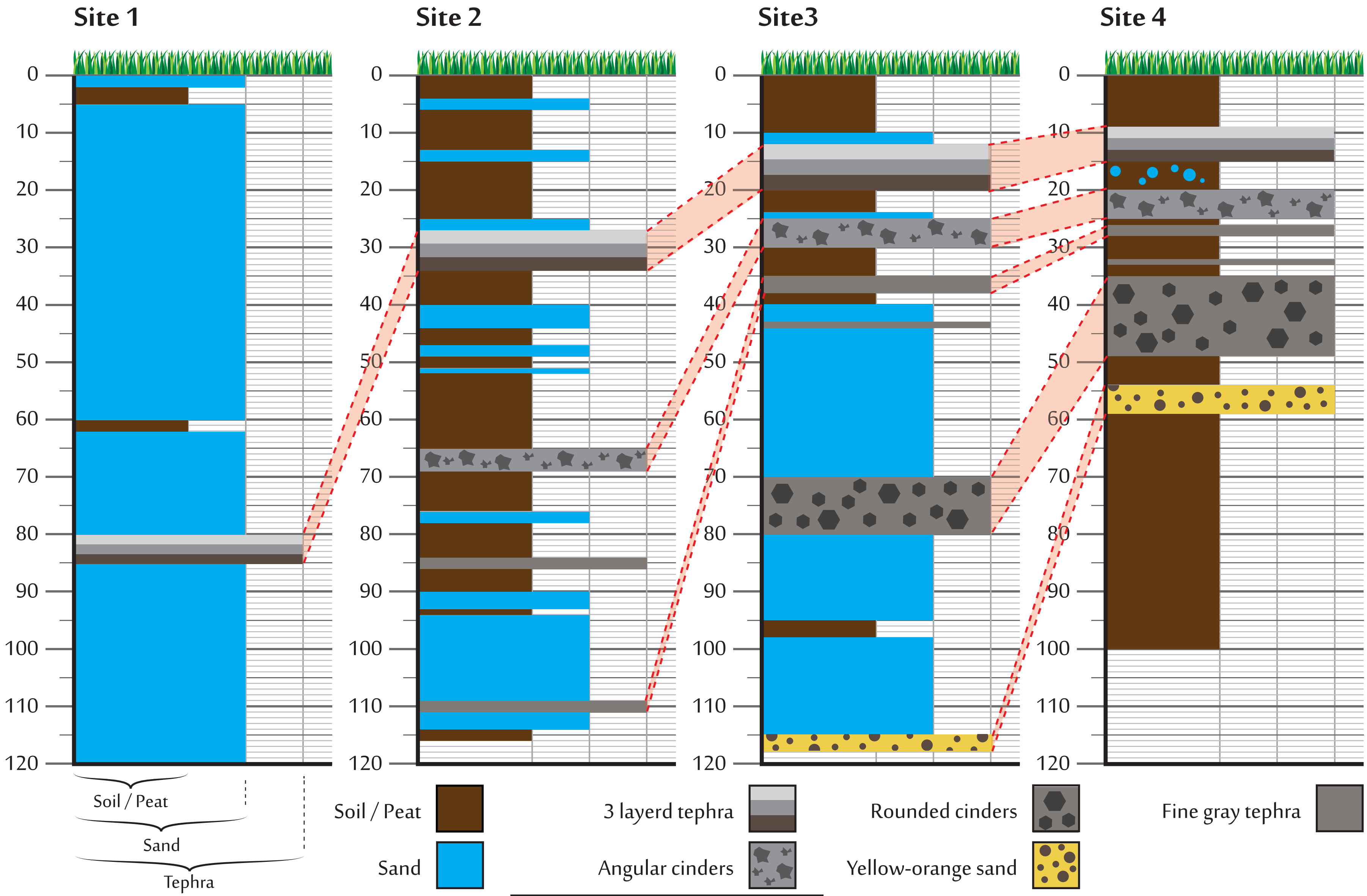
Excavation 102

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



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.

SETTLEMENT

Teacher's Manual

Table of contents

Subjects:
History, Geography, Science, Social Studies

Duration:
Two class periods

Class size:
10 - 30

Summary

Overview:

In this module, students will be introduced to statistical distributions to address questions about historical changes in human settlement patterns and to raise questions about the causes of these changes. Through an exercise designed to engage students in statistical data manipulation, they will learn how archaeologists use radiocarbon-dated settlements to reconstruct changes in the intensity of occupation in different locations. They will then compare these patterns to explore changes in settlement over time and space. The final component of this module gives students a chance to think about possible causes of historical changes in settlement distributions through correlation with environmental phenomena such as volcanic eruptions. Exercises engage students in quantitative and basic descriptive statistical manipulations (data aggregation and histogram construction) and in hypothesis formation and testing. The exercise is designed to convey the important realization that human settlement is not static but changes, sometimes dramatically, over time.

Goals:

- To teach students how archaeologists interpret settlement history based on site distributions and radiocarbon dates, and how they seek to explain change through analysis of correlations with environmental phenomena and changes in culture.
- To engage students in the analysis and interpretation of distribution data.
- To engage students in interpretations about human-environment interactions.
- To engage students in integrative/ systemic thinking exercises.

Objectives:

1. Students will learn how to observe changing frequencies of dated archaeological settlements by organizing data into histogram form and how differing the intervals ("bins") of a histogram can change the graphical representations. This is a basic aspect of scientific data analysis and a descriptive statistical procedure.

2. Students will learn to compare proxy data for environmental events and human settlement and to develop and evaluate hypotheses about the causes of human settlement change. Correlation is a basic aspect of scientific reasoning. Students will also learn to critically examine the methods used and the strength of conclusions.

Material Included in the Box:

A PowerPoint slide show (with a narrative script for the teacher)

Handouts with real radiocarbon data from a segment of the Kuril chain, data on historic catastrophic events (tsunamis and volcanic eruptions), and a climatic reconstruction.

Vocabulary

Deposit:

Sediment laid down on the earth's surface in the past, either by natural or human action. Archaeological deposits were created by people in the past and can include soil, artifacts, structures, or other traces of human activity that signal anthropogenic (human) involvement in the deposition process. Individual deposits usually form horizontal layers or "strata" that stack up over time like a layer cake, with the oldest at the bottom and the youngest at the top. Consequently, the oldest archaeological deposits (or geological deposits, for example volcanic ash layers) are found below younger ones, allowing us to develop histories of events by studying the stratigraphy. However, material within deposits can be out of place for a number of reasons (for example, through disturbance by burrowing animals), leading to possible misinterpretations of the stratigraphy of a disturbed site or excavation. (See Stratigraphy module.)

Distribution:

An arrangement of observations or values according to some variable(s). For example, a geographical distribution might refer to the location of settlements in space, according to their latitude and longitude coordinates (the variables), whereas a stylistic distribution might refer to the frequency of pottery specimens according to designs on them (the variables).

Histogram:

A graph which visually represents the distribution of data by showing the frequency of data points lying between two values along a variable axis, i.e. within a specific "bin." The distance between these two values is referred to as the "bin width." Histogram bins are usually of equal size.

Landscape:

In archaeological usage, a landscape is a geographical space larger than a single settlement across which people conduct their activities. This concept provides a framework for discussing the ways that past people have interacted with the environment and with each other at a broad scale, e.g. in their regular movements between settlements, hunting grounds, agricultural fields, institutional facilities, monuments, resource extraction locations, etc. Thus, cultural landscapes typically subsume multiple settlements, towns, and/or cities, as well as their hinterlands, within them. Over time, cultural landscapes change as human lifeways are reorganized, and untangling these changes based on archaeological evidence is an archaeological challenge.

Radiocarbon Date:

A numerical date which approximates the time of death of an organism (plant or animal) based on the amount of radioactive carbon that remains in it. Radiocarbon dates are often used by earth scientists and archaeologists to understand the timelines of geological or cultural events.

Vocabulary

Continued

Settlement:

A location occupied by a group of people for some period of time. Settlements can be recognized by archaeologists by the cultural remains left behind at such locations, such as artifacts (stone tools, pottery, etc.) and features (remains of house structures or depressions, hearths, etc.), as well as by changes in the composition of local vegetation (human activities often enrich soils, encouraging lush vegetation growth).

Settlement Pattern:

The geographic distribution of settlements during a specific time period. Studying settlement patterns reveals information about initial colonization of areas by people and eventual changes in their habitation and/or resource use.

Site:

A location in space. This term is used by researchers to refer to a location where data have been collected. In archaeology this term has a more specific meaning, refering to a location where archaeological materials/deposits are found in great concentration, typically surrounded by areas exhibiting little or no archaeological material. Often, archaeological sites are the remains of settlements, though alternatively some were created by other kinds of human activity.

Years BP (years before present):

The amount of time which has passed between the occurrence of an event and the year A.D. 1950. To prevent confusion, radiocarbon scientists defined A.D. 1950 as the 'present' so that radiocarbon ages always refer back to this same fixed point in time. For example, 537 years BP will always refer to the year which preceded A.D. 1950 by 537 years, in other words A.D. 1413.

Background Information

Archaeologists seek to understand how people lived in the past based on the material remains people left behind, in the form of artifacts, features (e.g., house storage pits, house structures, and sometimes monumental buildings), and other traces of their activities (e.g., transformed soils, chemical stains). Some archaeological questions require the analysis of the distribution of artifacts, soil deposits, and features at specific locations called "sites," but an important part of archaeology also asks questions about changes at the broader scale of cultural landscapes. The analysis of settlement distributions across landscapes is called "settlement pattern analysis." Archaeologists use this approach to discover where people lived at different times in the past. Archaeologists generate this kind of understanding through survey, the process of looking for archaeological sites across vast areas of land.

The Kuril Biocomplexity Project surveyed the entire Kuril Archipelago between 2006 and 2008, finding a total of 68 different archaeological sites, distributed from the southern island of Kunashir to the northernmost island of Shumshu. These sites can be presented on a map showing their distribution throughout the islands. By itself this information indicates that people have lived throughout the island chain, but it does not tell us anything about how they came to live there or when, whether or not colonization occurred in a single event or multiple times, from which direction people came, or who they were.

To put archaeological settlement distributions into a historical framework, archaeologists need to assign ages to site occupations. One of the most common ways to do this today is to find organic material in the archaeological deposit (such as wood, charcoal, bone, seeds, or textiles) and submit this to a special laboratory for radiocarbon dating (see Chronology module). If the site has a deep archaeological deposit comprising multiple archaeological layers, it is important to collect several dates from different layers or depths. If the site covers a large area, it is also important to collect dates from across the site. These dates then help the archaeologist determine the history of occupation at the site and ultimately how the site formed. Combining dates from many sites provides critical information for building a picture of changes in the distribution of populations across space. This is often done by building histograms, which describe the changing frequency of settlements over time, per some standard interval (commonly labeled a "bin," e.g., per 200-year interval). As forms of statistical description, such histograms are convenient tools for looking at changes in the frequency of archaeological materials deposited over time. However, archaeologists also need to think carefully about a number of factors that can bias the pattern observed in such histograms. For example, we don't want our results to be influenced by the possibility that some sites or regions have been studied more intensively than others. To avoid these problems, we often decide to include only one date per site per histogram bin, or only one date per portion of a site per bin. Doing so minimizes the possibility that we are dating multiple samples deposited by the same group of people – in other words, double-counting them – while counting other groups only once.

Lesson Plan

Activity 1 (Day 1)
Students learn how archaeologists search for data that can be used to reconstruct settlement patterns in a region.

Warm Up:
Have students think back to earlier history lessons and compare a mobile and a sedentary way of life. What are the characteristics of each? (Example: size of groups, size and permanence of dwellings, amount of possessions, prevalence of communicable diseases, etc.)

Procedure:
1. Use the slideshow included to familiarize students with how archaeologists study settlement patterns in a region and how archaeologists worked in the Kuril Islands. The script attached to the slideshow has several questions that can be used to initiate discussion during the slideshow to make it more interactive. (slides 1-13).

2. Explain what histograms are (plots of changing frequency over time) and why they are a useful way of visualizing data.

3. To help students practice constructing and reading a histogram, use data from a few of the oldest sites in North America to (slides 14-19; the text under the slides in PowerPoint should help directing this activity). The first step in this exercise is to build a timeline (see the slides) as a reference, after which students can transition to constructing a histogram. Ask students to think about what the histogram indicates about the settlement or population of the region during the last 14,000 years.

Wrap up:
Ask students to name the steps in the process of settlement pattern research. They should come up with the following six steps based on the PowerPoint:

- Locate archaeological sites, test them, and collect organic materials from their archaeological contexts suitable for radiocarbon analysis (see the Chronology module).

- Submit these samples to a professional lab to get radiocarbon age determinations.

- Organize the radiocarbon data and create histograms based on them.

- Compare changes in frequency through time, between different regions, and with other information (e.g., environmental histories).

- Formulate hypotheses to account for the patterns observed through comparison.

- Evaluate these hypotheses with additional evidence (tip: students might not think of this, ask them to think about how science works - progressively, constantly testing what has been discovered).

Lesson Plan

Continued

Activity 2 (Day 2)

Students use real data from the Kuril Islands to reconstruct population history of the chain during the last 4,000 years and try to draw links between catastrophic natural events and settlement history of the islands.

Warm Up:

Review material from the previous day. Discuss what natural hazards could influence whether people stay on or abandon an island or the chain. Have students remember the 6 steps of the settlement pattern research (see above).

Procedure:

1. Show the class the map (slide 20) of the location which they will be investigating in the exercise.

2. Hand out the data for the exercise (radiocarbon dates and ages of catastrophic events plus the templates for histogram plotting) and a worksheet with questions about the data. You may chose to divide students into groups which focus on the same island and construct histograms using 3 different bin sizes to consider how the bin size can influence the conclusions. Alternatively, groups can work using the same bin size and compare the three islands. You could also have some groups work on the first option and some – on the second.

3. Students work in small groups to construct the histograms and answer related questions.

Conclusion:

Discuss as the whole class what the data tells you about the occupation on each island and in the region in general. Discuss the possible causal links with the catastrophic events. Ask students to brainstorm about what might be additional evidence that people were influenced by these events? For example, what kind of features would indicate that people abandoned an island after a volcanic eruption? (Possible answers: abrupt change in stratigraphy to ash or a lava flow with a gap in occupation.)

Wrap Up:

There are many complications that make using radiocarbon dates as indicators of population change less straightforward than we would like. To convey this point, have a discussion with class about what could make the interpretation of radiocarbon dates biased (i.e. not reflective of reality). Here are potential answers:

- Due to a change in climate patterns, more large storms or tsunamis caused more erosion following some period of settlement and differentially eliminated sites of that period.
- Sites in some area got buried under volcanic deposits and are too deep to be discovered by the archaeologists digging shovel tests.
- Archaeologists sampled sites in a biased way, for example they only looked at the coastal areas, but not in the inland parts of the islands, where people lived during some time. In that time period, population estimates would be much lower, because archaeologists missed those sites.
- Archaeologists collected more samples from certain kinds of sites or worked only in regions that are easier access (closer to roads, etc.).
- Using data from several different projects to reconstruct population adds potential difficulties, because different projects may have had different focus or different funding possibilities (some sites or areas were perhaps more intensely surveyed and dated than others).

To use radiocarbon dates as indicators of past population change, archaeologists have to rule out these factors to the best of their abilities.

Archaeologists sometimes estimate the history of human settlement across a region by comparing the relative frequencies of **radiocarbon dates** from different site locations.

To do this, the first step is to generate a large set of **samples** for dating. This is done by finding sites through **survey**, excavating test pits and collecting charcoal, bone, and other organic materials from within archaeological **strata** or **deposits**.

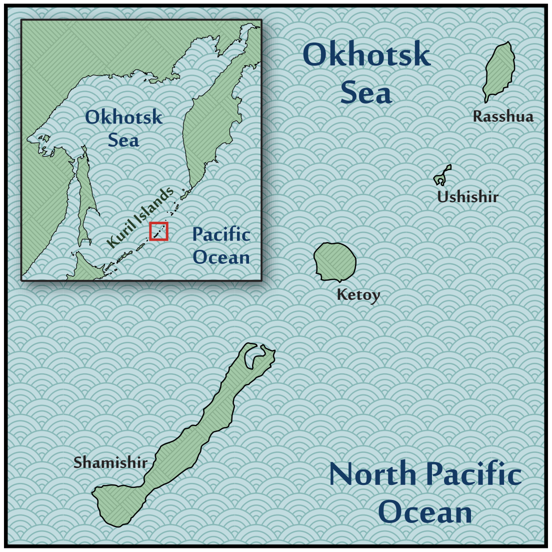
The next step is to submit as many of these samples as possible to a radiocarbon lab, which specializes in measuring the ages of the samples based on the amount of radiocarbon contained in them. While radiocarbon dating is expensive (between \$300 and \$600 per sample), having a large number of dates is important to get a clear picture of past history. The samples submitted should be randomly selected from the total to make sure that the results do not over-emphasize just one kind of site or time period.

When the lab sends back the results, the third step is to count the number of dates per time period and to look at changes through time. If a larger number of dates occurs in one time period than in another, this might tell us that more people lived in the region during that period.

The fourth step is to try to explain changes observed in the number of dates over time.

In this exercise, you will practice the third and fourth steps of this process, using actual data from the Kuril Islands.

During the Kuril Biocomplexity Project, archaeologists worked in the segment of the island chain shown on this map.



Step 1:

Using survey techniques, archaeologists found prehistoric human settlements, which they tested to find datable materials. They then submitted organics like wood and charcoal to radiocarbon labs to be dated, to find out when each island was occupied. The attached table of radiocarbon dates shows the results of these tests. To tell whether there were significant changes in the populations of different islands (including the abandonment of some islands), your task is to compare changes in the frequencies of dates from each island. To do this, you will construct histograms from radiocarbon dates. Histograms are graphs which plot the frequency (quantity or number) of observations occuring within a sequence of intervals or "bins." Different histograms have bins of different sizes, called "bin widths" (e.g., 100, 200, or 400 years per interval). Histograms of radiocarbon dates provide a convenient way to look at changes in population size through time.

Plot the number of dates on the graphs provided, grouping them into sets per time interval (bin). Your teacher will indicate whether you will plot dates using the same interval on all three islands or take one island and use three different bin sizes for the dates from that island.

For example, if you are using bins having 100-year bin widths, you would count the number of dated samples that fall between 1,600 and 1,699 years BP (before present), then 1,700 to 1,799 years BP, and so on. If you have counted eight samples falling between 1,600 and 1,699 years BP, you would then shade in a bar that is eight units high in the column between 1,600 and 1,700 years BP. Follow the same procedure for all intervals.

After completing these histograms, answer the following questions:

Question 1:

a. How similar are the occupation histories of the different islands to each other?

b. Does it look like people lived in all three regions at the same time?

c. Did they leave all three regions at the same time?

Answer:

The occupation histories for each island are somewhat different, but agree in many respects. Simushir has two modes (peaks) between 800 and 1,299 BP and between 1,500 and 1,999 BP. These modes are matched in the Rasshua distributions, suggesting that people inhabited and left both islands at the same times. Even so, the older mode on Rasshua extends back to 2,699 BP, if we ignore small gaps that might be sampling errors. One could say that the earlier start indicated in the Rasshua histogram represents an earlier colonization there, eventually expanding to Simushir. In fact, this is more likely a sampling problem, since Simushir was more likely on the migration route to Rasshua than vice versa and would thus have been colonized first.

The Ushishir sample is too small and the resulting histogram is not reliable on its own, at any bin width.

Question 2:

If the histograms differ by region, are the patterns complementary? That is, might people have abandoned one island in favor of one of the other two?

Answer:

As noted above, the Simushir and Rasshua distributions suggest a possible earlier occupation of Rasshua, with later movement to Simushir. Both islands appear to have been abandoned at about 1,600 BP, then recolonized, then once again abandoned at about 800 BP.

Step 2:

Now you are going to compare your population histories with information about environmental impacts and changes, to see if you can explain why settlement patterns changed over time.

When archaeologists were looking for the settlements left behind by the prehistoric inhabitants of the Kurils, geologists were researching the geological history of the islands, using radiocarbon dating and other methods to determined when the largest volcanic eruptions and tsunamis in the area occurred. Meanwhile, paleoclimatologists studied lake cores and other evidence to determine when the climate was wetter or drier, cooler or warmer, in the region.

Examine the results of their studies. Compare these results to the histograms you created. You might want to indicate on your histograms when these environmental events or changes occurred. This will help you to see the relationships between human populations and natural conditions. Then answer the following questions.

Question 3:

a. Do the patterns of population change correspond with **catastrophic events** recorded for the region? For example, can you justify assertions that volcanic eruptions, tsunamis, or climate changes forced regional abandonment or movement of the population from one island to another?

b. How convincing do you find your conclusions to be (how well do the patterns match up)?

Answer:

3a: Climate changes appear to happen both during and between occupations, rarely corresponding with times of transition in our population data. Volcanic eruptions are only slightly more interesting, as follows:

The most recent eruption of the Simushir volcano (Zavaritsky 1) at 1,000 BP could have caused decline in population there, leading to abandonment 200 years later. On Ushisir, there is no strong case to be made for an impact, but the archaeological sample is too small to conclude one way or the other. Students are likely to think the gap from 1,000 to 800/700 years BP is meaningful. It could be, but the conclusion is not statistically justified. On Rasshhua, located two islands (or about 40 km) north of the eruption, no negative impact on populations is observed. Conversely, the data are consistent with the suggestion that people from Simushir and Ushishir moved away in response to the eruption, leading to an increase in population on Rasshua after 1,000 BP.

The massive caldera-forming eruption of Ushishir 2,000 years ago destroyed any evidence of prior occupation on that island and may have made it uninhabitable for the next 600 or more years. The archaeological record of northern Simushir starts more or less right after this eruption, and it is possible that the event forced people to move to this location from Ushishir island. Contradicting this hypothesis, however, is the evidence that Rasshua populations did not react. This is especially surprising because the Ushishir eruption caused an ash cloud that moved north and dropped as much as half a meter of volcanic ash on the largest human settlement on Rasshua. People must have temporarily left, but they came right back and carried on as if nothing had changed!

The two older eruptions of 2,400 and 2,600 years ago can only be compared to the Rasshua data. As with the other events, these eruptions appear to have had no impact on the settlement of these islands. People were already inhabiting Rasshua when these eruptions occurred, and population estimates indicate no negative change following these events. This is not unexpected for the 2,400 BP eruption, which occurred hundreds of kilometers to the south. Conversely, the 2,600 BP eruption on the island immediately to the north of Rasshua and could have forced people to migrate from that island toward their neighbors on Rasshua.

As for the tsunami evidence, one could argue that tsunamis played a role in instigating new settlements (e.g., around 2,900/2,750; 1,250; and 400 BP) and that they played a role in the ending of settlements (1,600/1,500 and 700/800 BP). However, tsunamis also occured in the middle of the periods of occupation (900 BP). We thus get a mixed picture in which tsunamis either appear to be really important or to have had no effect at all. What do students think?

Climate also appears to be poorly correlated with settlement or abandonment. The modes of population density occur both during cold and warm intervals.

From these various comparisons, we might conclude that catastrophic natural events and climatic phases had minimal influence on the settlement of these islands. This is in fact what our research in the Kurils has indicated. Yet, if natural events and changes were of minor importance, this leaves open the question about why people came and left the islands. While these factors were less important than we originally suspected, we still think they could have played an indirect role in human history there, for example by amplifying the adverse effects of other stresses such as the loss of preferred food sources or the disruption of trade networks. At the individual level, the impact of tsunamis or volcanic eruptions can be huge, swaying individuals' decisions about whether to stay put or to leave, even if the larger population does not change much.

Step 3:

Step back and look critically at the analyses you conducted. Do you think there may be problems with the way this analysis was done?

Question 4:

a. Are there problems with the datasets used in your analysis, and what steps could be taken to reduce these problems, if any?

b. What assumptions support this analysis (list several)? For example, what must we assume to treat a single radiocarbon date as an indication of a unit of population (number of people)?

c. Are there problems with these assumptions?

d. How convincing are the correlations between settlement changes and environmental effects?

Answer:

a. Problems: 1. Small sample sizes (especially for Ushishir) limit the reliability of the histograms. Wider bin widths increase the robustness of the analysis but at the cost of precision. Solving this problem requires the collection of more data. 2. Interpreting these results in terms of human history requires that we accept several assumptions which may not be correct (see below).

b. and c. Assumptions: 1. The radiocarbon sample was collected in an unbiased way. 2. The charcoal record itself was not biased by natural filters (e.g., loss of large numbers of sites from a specific time period due to abrupt sea level change and erosion). 3. The samples that were dated were randomly selected, so that we don't have a disproportionate number of dates from one site or from the deepest or shallowest parts of sites. For example, archaeologists often date the oldest (lowest) layers of sites because they are interested in discovering when people first inhabited a location. If too many of these "basal" dates are counted, it could make the earlier populations appear large compared to more recent times. 4. There is no appreciable difference between target and dated events (see the Chronology module for an explanation of this assumption).

e. Correlations: The correlations between settlement and environmental information are quite weak. Rather, they provide evidence supporting a lack of causal relationship between natural conditions and population dynamics. However, for the purposes of this question, we should also note that the environmental data are of fairly low resolution, as are the settlement data. Attempting to match them in time is problematic because the precision on any of these dates is about ± 100 years. A tsunami could appear to have occured in the middle of two-century period of stable occupation but in fact could have occured right at the start or end of this period.

Student Worksheet guide

Plotting Date Distributions

Material - Question 1

Simushir

Sample Number	^{14}C Age (years BP) reported with error term*
AA-44258	1003 ± 43
AA-44259	1121 ± 38
AA-44260	1164 ± 44
AA-44261	1011 ± 40
AA-44262	1818 ± 43
AA-44263	935 ± 42
AA-40944	1695 ± 36
AA-44264	1732 ± 43
AA-44265	897 ± 38
OS-59199	1940 ± 40
OS-59197	1600 ± 25
OS-59381	1090 ± 25
OS-59421	1300 ± 30
OS-59346	1740 ± 30
OS-59201	1650 ± 25
OS-59202	1260 ± 30
OS-59203	1700 ± 30
OS-59204	1820 ± 30
OS-67420	1800 ± 25
OS-67269	1470 ± 30
OS-67616	1100 ± 30
OS-67586	1690 ± 30
OS-67617	1570 ± 25
OS-67470	1930 ± 35
OS-67471	1280 ± 25
OS-67587	1850 ± 30
OS-67472	1930 ± 30
OS-67492	1650 ± 30
OS-67588	1100 ± 30

Ushishir

Sample Number	^{14}C Age (years BP) reported with error term
OS-59419	1130 ± 25
OS-67329	1390 ± 30
OS-59418	1090 ± 30
OS-80150	430 ± 25
OS-80149	615 ± 25
OS-59420	100 ± 25

Rasshua

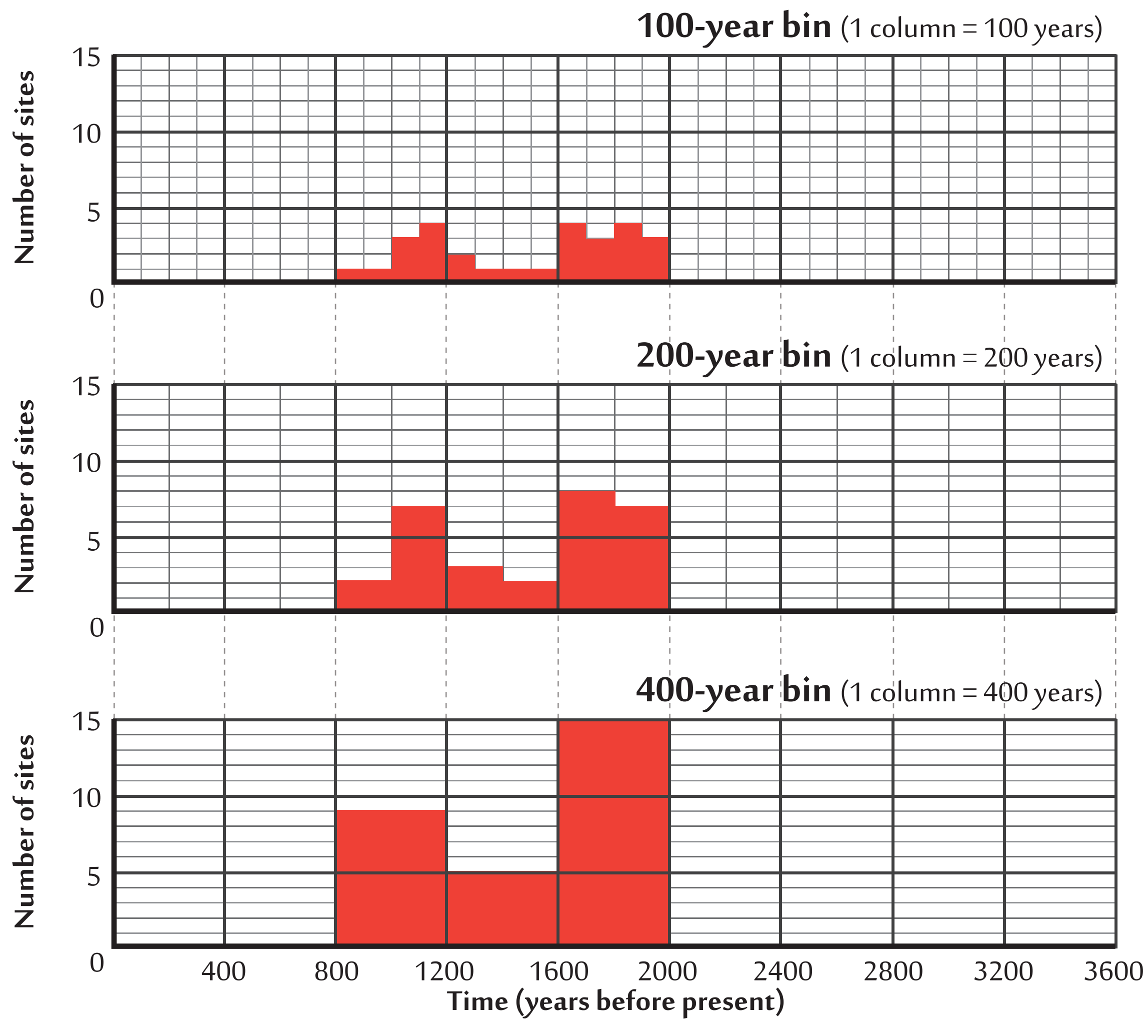
Sample Number	^{14}C Age (years BP) reported with error term
OS-67086	2430 ± 25
OS-67143	3260 ± 30
OS-67330	2570 ± 30
OS-67130	30 ± 30
OS-67131	1990 ± 30
OS-79721	905 ± 25
OS-79722	1000 ± 30
OS-79861	1860 ± 30
OS-79724	935 ± 25
OS-79726	950 ± 25
OS-79744	915 ± 30
OS-79863	2250 ± 25
OS-79864	2010 ± 30
OS-79862	1920 ± 25
OS-79727	245 ± 25
OS-79725	1820 ± 25
OS-79723	1100 ± 35
OS-79865	2020 ± 30
OS-79866	2040 ± 25
OS-79867	2040 ± 30
OS-79868	2160 ± 35
OS-79741	1700 ± 35
OS-79742	925 ± 30
OS-79743	3280 ± 35
OS-79728	315 ± 30
OS-79731	215 ± 25
OS-79730	205 ± 35
OS-79729	225 ± 30
OS-79896	2640 ± 30
OS-79600	1930 ± 25
OS-80139	1120 ± 50
OS-79601	1000 ± 25
OS-79602	3450 ± 30

Sample Number	^{14}C Age (years BP) reported with error term
OS-79603	1940 ± 30
OS-79594	1970 ± 30
OS-79595	1280 ± 25
OS-79596	905 ± 25
OS-79597	1970 ± 25
OS-79598	2260 ± 30
OS-79599	835 ± 30
OS-80015	1810 ± 25
OS-80016	1920 ± 30
OS-80017	2130 ± 25
OS-80018	2080 ± 25
OS-80019	1720 ± 25
OS-80020	1670 ± 30
OS-79668	1950 ± 25
OS-79669	2080 ± 25
OS-79670	2110 ± 25
OS-79671	2210 ± 25
OS-79720	2430 ± 25
OS-79665	2860 ± 25
OS-79666	2480 ± 35
OS-79667	2660 ± 25
OS-79604	2490 ± 25
OS-79664	170 ± 30
OS-79859	2230 ± 30
OS-79860	830 ± 25
OS-67133	130 ± 25
OS-67134	1720 ± 30
OS-67135	1100 ± 35
OS-67136	1190 ± 35

*see Chronology module for explanation of error terms

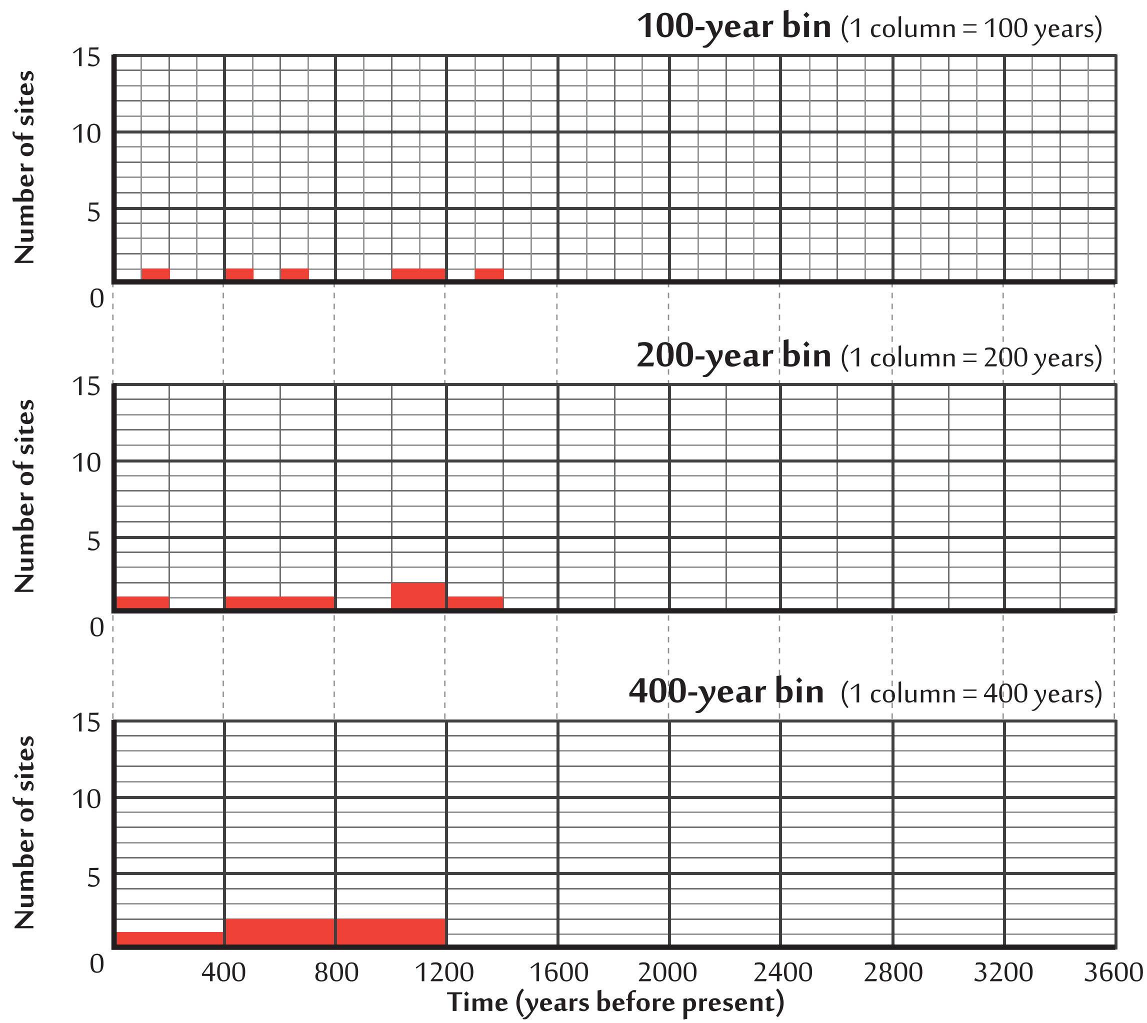
Simushir

Teacher background information: Histograms of radiocarbon dates from Simushir Island at 100, 200, and 400-year bin intervals for comparison.



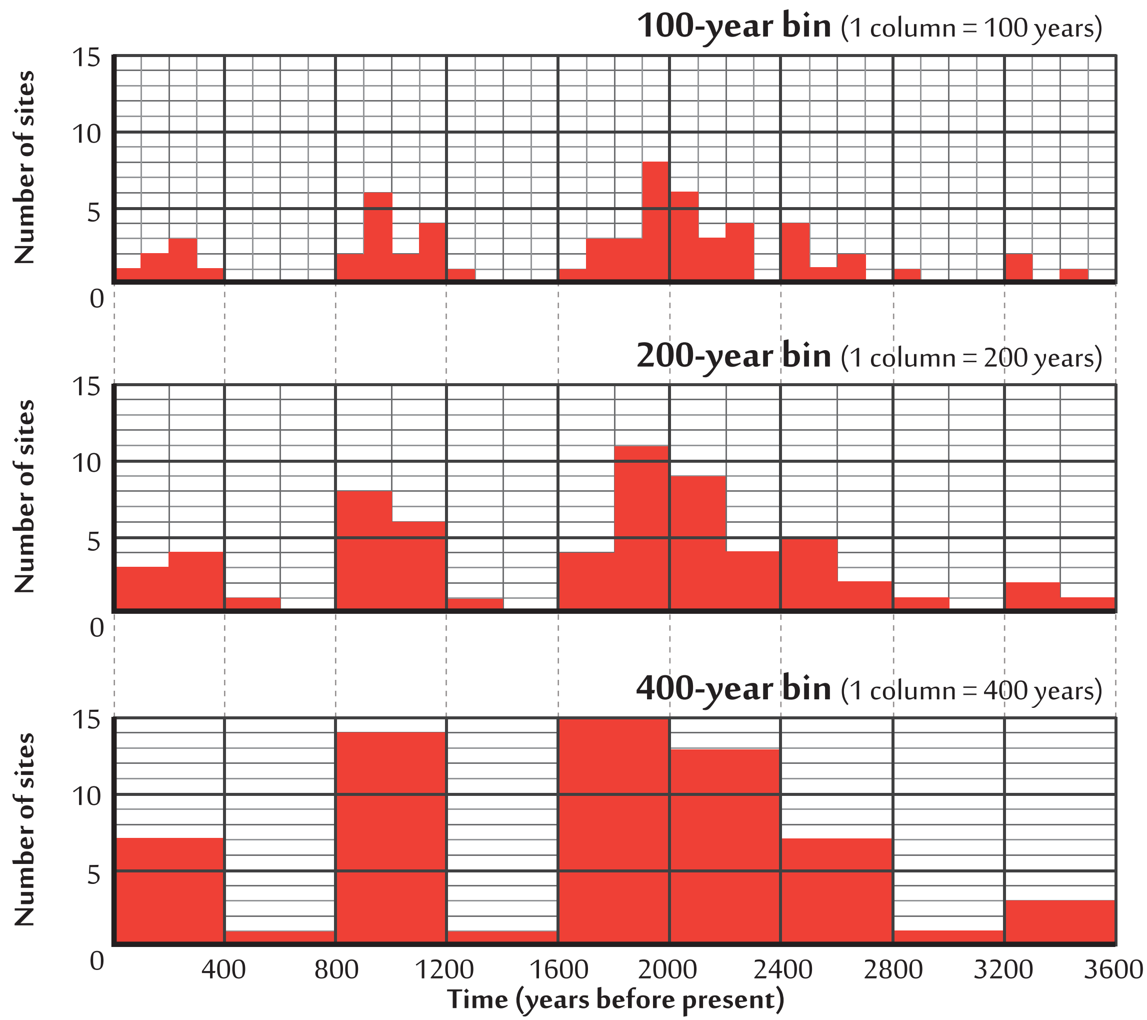
Ushishir

Teacher background information: Histograms of radiocarbon dates from the small Ushishir Islands at 100, 200, and 400 year bin intervals for comparison.



Rasshua:

Teacher background information: Histograms of radiocarbon dates from Rasshua Island at 100, 200, and 400 year bin intervals for comparison.



Student Worksheet guide

Plotting Date Distributions

Material - Question 3

Climate:

Age of Event	Notes
0-200 years BP	warm
200-700 years BP	cold/dry
700 - 1,100 years BP	warm
1,100-2,000 years BP	cold/dry
2,000-2,400 years BP	cooling

Climatic conditions (compared to presend) were determined using evidence such as pollen from lake cores (see paleoclimate module).

Eruptions:

Volcano	Island	Age of the Event
Zavaritsky 1	Simushir	1,000 years BP
Us-Kr	Ushishir	2,000 years BP
CKr	Iturup*	2,400 years BP
Sarychev	Matua **	2,600 years BP

Volcanic eruption ages were determined by dating tephras deposited by each eruption.

Notes:

*Iturup Island is over 200 km south of Simushir Island

**Matua Island is ~40 km north of Rasshua Island

Years BP: years before present ("present" refers to A.D.1950)

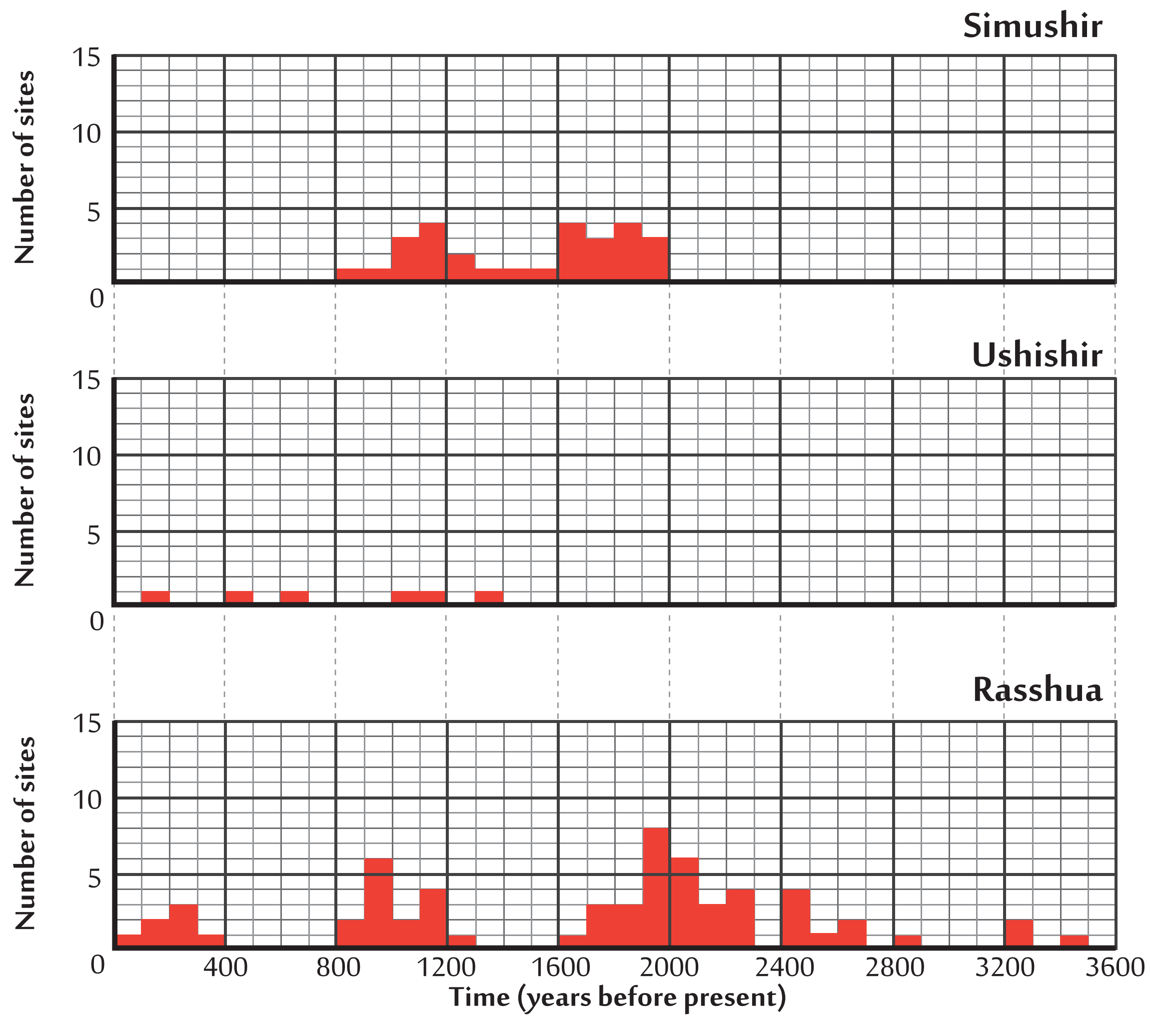
Tsunami:

Number	Age of the Event	Notes
1	100 years BP	
2	400 years BP	
3	700 years BP	
4	800 years BP	
5	900 years BP	
6	1,250 years BP	
7	1,500 years BP	
8	1,600 years BP	
9	2,750 years BP	(possibly)
10	2,900 years BP	(possibly)

Tsunami ages were determined by dating layers of beach sand deposited by large tsunami waves on the affected islands.

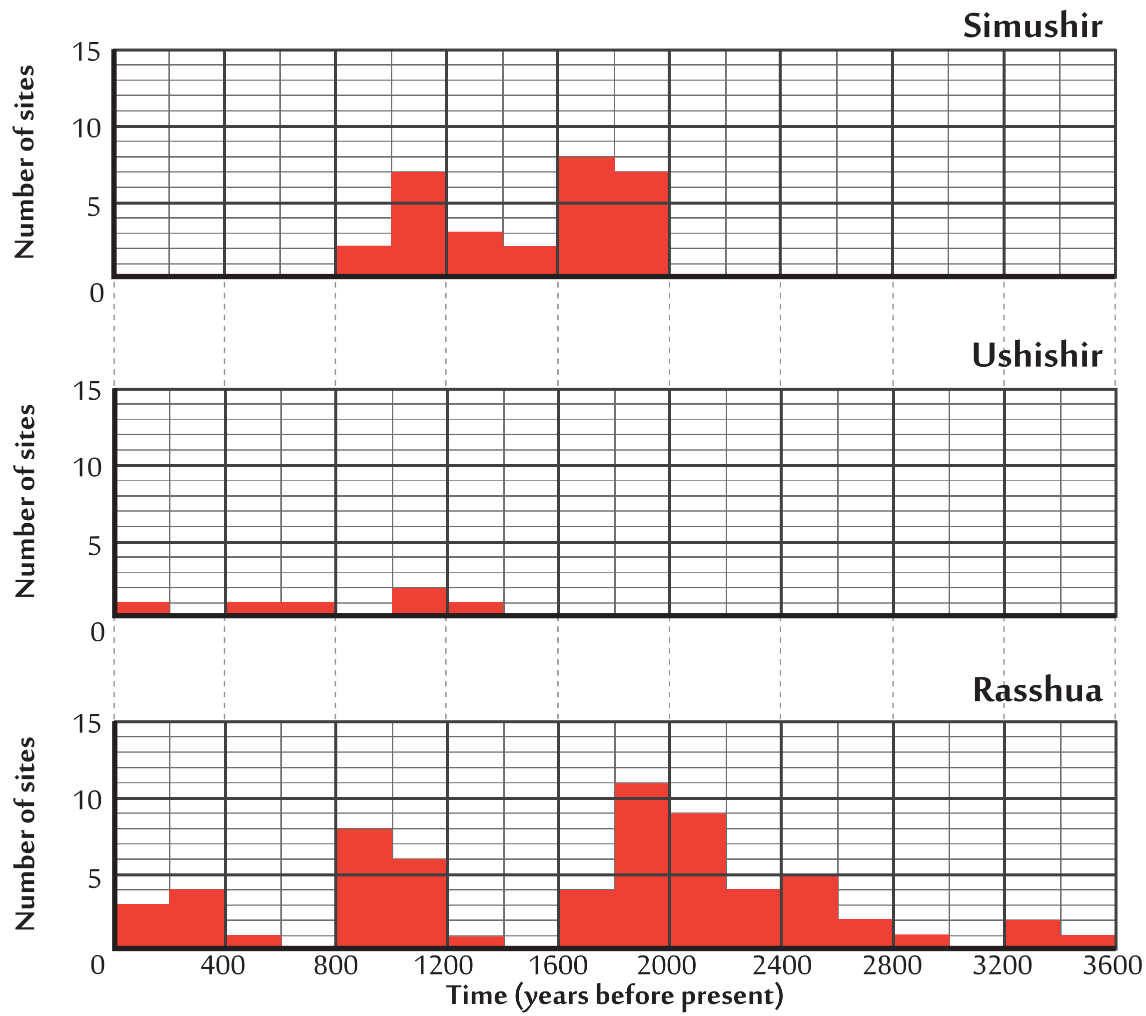
100-year interval

Teacher background information: Histograms of radiocarbon dates from all three islands using 100-year bin interval.



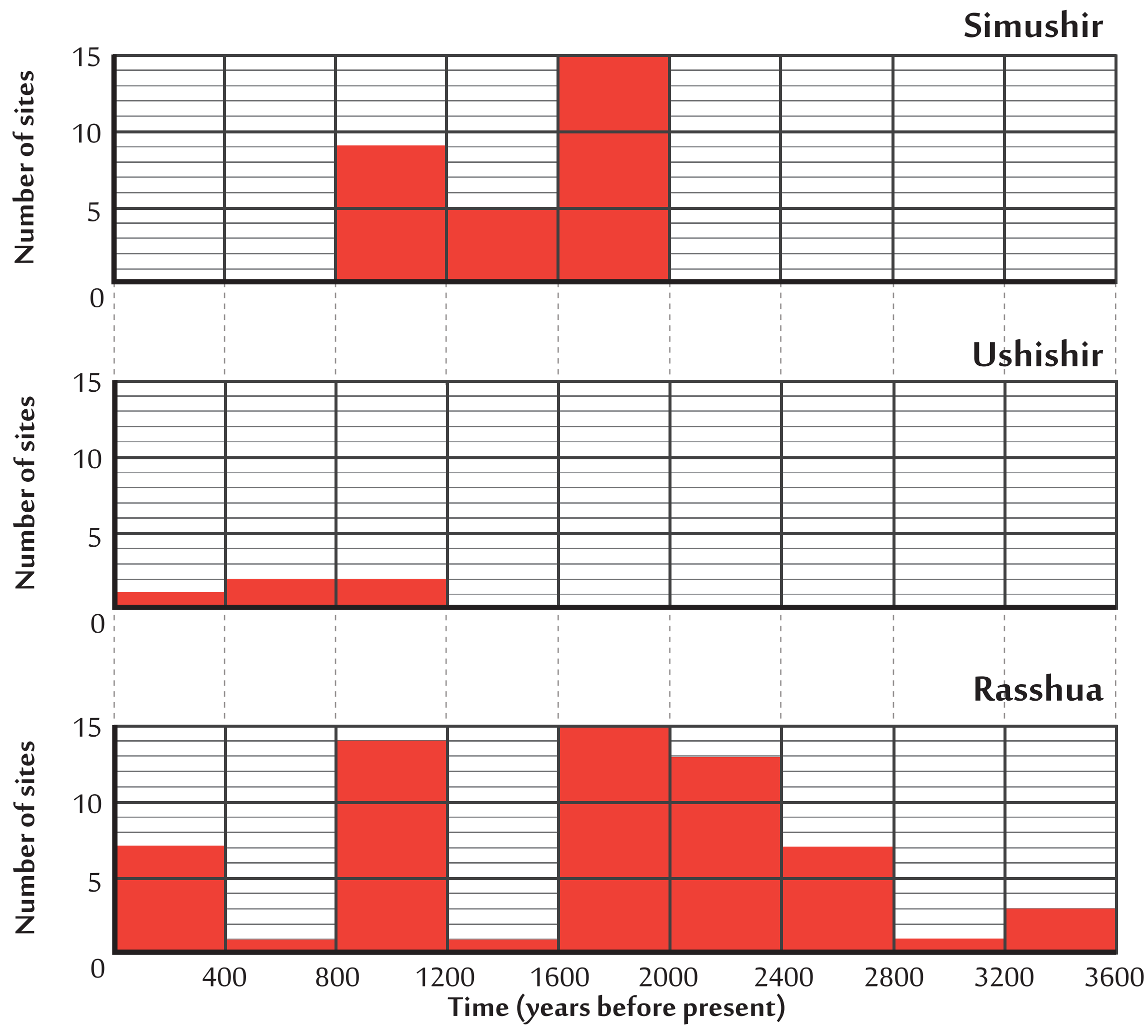
200-year interval

Teacher background information: Histograms of radiocarbon dates from all three islands using 200-year bin interval.



400-year interval

Teacher background information: Histograms of radiocarbon dates from all three islands using 400-year bin interval.



NATURAL HAZARDS

Teacher's Manual

Table of contents

Subjects:
Earth Sciences

Duration:
Two class periods

Class size:
10 - 30 students

Note
Approximately a week before this lesson, ask students to discuss the common natural hazards in Washington State with their family members, neighbors ,or other adults in their life. They should specifically ask for stories, photos, or information about events that people experienced. They should also write a report (half-page long) about these interviews to turn in on the day when oral and written records of natural disasters are discussed.

Summary

Overview:

Humans primarily care about natural hazards when events affect individuals by destroying or disturbing habitation, livelihoods, food resources, and daily activities. Natural hazards contribute to difficulties encountered in surviving in the remote, harsh landscapes of the Kurils. This module teaches students to understand how environment (with a focus on natural hazards) contributes to daily life, human activities, and cultural decision-making. It builds on the foundation students get in the Tsanami and Stratigraphy module, as well as geology classes which provide material on natural hazards, but allows the class to focus more on how people cope with the natural hazards and pass on information about them.

Students will be introduced to the natural hazards that occur in the Kuril Islands, including volcanic eruptions, earthquakes, tsunamis, and landslides, including how and why these events occur. Students will learn to assess hazard potential and relate this to where/how one would want to live. Students will practice communication skills, including distilling and relaying complicated information.

Objectives:

- Students will learn to assess hazard potential and relate it to where/how one lives or wants to live.
- Students will practice distilling complicated information, effectively conveying it to their classmates, and discussing decision-making.
- Students will consider the difference between oral and written histories.
- Students will practice reading and interpreting maps.

Material Included in the Box:

- PowerPoint presentation for introduction
- Hand-outs with maps for each team of where they "live" and surrounding landscape, as well as information about each site
- Maps and questions related to natural hazards of Washington State

Vocabulary

Lahar:

A mudflow or debris flow that starts on a volcano. Lahars can travel up to 95 kph and are very destructive.

Oral history:

Stories passed from one generation to the next through verbal communication

Resilience:

The ability of a person or community to recover readily from adversity such as a natural hazard

Seal and sea lion haul-outs:

Rocky outcrops and beaches where seals and sea lions come out of the water and are easy to hunt

Tsunami:

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

Volcano:

An opening in the earth's surface through which lava and gasses from below the earth's surface escape.

Written history:

Stories passed from one generation to the next through written communication

Background Information

The Kuril Islands are one of the most geologically hazardous places to live in the world. Active volcanoes erupt many times in a single lifetime, large earthquakes and tsunamis occur ever few generations, and other natural hazards, such as flooding, lahars, and large storms, also are common. One of the goals of the Kuril Biocomplexity Project is to understand how people living in the Kuril Islands responded to catastrophic events, and how human interactions could reduce the vulnerability of the island population.

Today, many natural hazards (but not all) are continuously monitored by government agencies around the world using seismometers, Global Positioning Systems, many types of satellites, and oceanographic buoys. Volcanologists monitor volcanoes to see if they are becoming more active while seismologists and oceanographers can immediately register on seismometers when an earthquake has occurred and use buoys around the ocean to determine if a tsunami was generated. See the list of websites below to learn more about recent events and see if there are any active volcanic or tsunami warnings.

Before the technological innovations of the 20th and 21st centuries, monitoring of natural hazards was not easy. Written records, especially historical archives, provided some estimates of how frequently a nearby volcano might erupt, how often earthquakes or tsunamis occurred, and how large those events were.

In the absence of written records, such as was the case in the Kuril Islands for thousands of years, the only means of knowing the hazards of a region is through the oral exchange of knowledge. Children can be taught to read the signs of increasing activity of a volcano, and can be told through stories what happened during past eruptions. Large earthquakes can be followed by big tsunamis, so children can be taught to vacate the beach. Oral traditions are a means of protecting settlements, especially in the situations where the recurrence of events spans more than one generation. Often myths and legends can contain a kernel of truth on how to survive natural hazards. In our techno-savy culture, this can be a hard idea to grasp— that ancestors we never met could instruct us how to survive (or what to expect) in a natural disaster through a story that our parents and grandparents repeated.

U.S. websites for monitoring volcanoes, earthquakes and tsunamis:

Smithsonian and USGS Global Volcanism Program - Weekly Volcanic Activity Report
http://www.volcano.si.edu/reports/usgs/

USGS - U.S. Volcanoes and Current Activity Alerts
http://volcanoes.usgs.gov/

USGS - Cascade Volcano Observatory Weekly Update
http://volcanoes.usgs.gov/cvo/current_updates.php

USGS - Latest Earthquakes in the World
http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/quakes_all.php

NOAA - Pacific Tsunami Warning Center
http://ptwc.weather.gov/

NOAA - West Coast/Alaska Tsunami Warning Center
http://wcatwc.arh.noaa.gov/

USGS booklet -
"Surviving a Tsunami - Lessons from Chile, Hawaii, and Japan"
http://pubs.usgs.gov/circ/c1187/

Procedure

Lesson Activity 1: Students learn how decisions about settlement placement would have made by prehistoric inhabitants of the Kuril Islands.

Note

Approximately a week before this lesson, ask students to discuss the common natural hazards in Washington State with their family members, neighbors, or other adults in their life. They should specifically ask for stories, photos, or information about events that people experienced. They should also write a report (half-page long) about these interviews to turn in on the day when oral and written records of natural disasters are discussed

Warm Up:

Ask students to imagine life in the Kuril Islands 1,000 years ago. Tell them they will get food on the island by hunting, gathering, and fishing. Have students make a list of 5-10 things they need around their settlement and 5-10 things they would not want on the island. Think about landscape features and desirable resources. Do not list items that you could bring with you or build such as dwellings or tools.

- Ideas for want: Food resources: fish, game, berries, wood or stone for building, animals or plants to make clothing, favorable weather, proximity to other islands (not isolated), nice beaches for landing boats, protected harbors, fresh water for drinking
- Ideas for unwanted things: Natural hazards (tsunamis, earthquakes, tornadoes, landslides, etc.), predatory animals, bad weather, angry neighbors

Procedure:

1. Use the slideshow included to review the following natural hazards:
    a. volcanic eruptions
    b. earthquakes
    c. tsunamis
    d. other hazards, such as flooding, lahars, storms, etc.
2. Break the class into small groups of 2-3 students, and assign each group an island by handing out one of the laminated island maps. Ask students to discuss their village location on the island. Do they have everything on the list they made in the warm-up? Do they have things from their undesirables list (hazards, for example)?
3. Because of population growth all villages have to send a group to live in another location (i.e. there are now too many people in every location to live comfortably and not run out of their available resources). Have each group pick an explorer who will set out to interview other groups about the resources and hazards on other islands (the explorer should take detailed notes).
4. Explorers return to the group and relay the information to their fellow citizens. Together the group, after a discussion, makes a decision where to create a new settlement. Ask students to be respectful to each other as they discuss options and opinions.

Conclusion:

Come back together as a class and discuss what students chose as their new homes. What are the most frequent natural hazard events? The least frequent? Did anyone pick the same location? Discuss how they could negotiate living there together (peacefully, by sharing, or by protecting resources from intruders?).

Lesson Activity 2: Natural Hazards of the Home State

In this activity students will discuss the natural hazards hazards of Washington State or another home state (this material is prepared for Washington State; teachers may modify if they are not in Washington).

NOTE:
Approximately a week before this lesson, ask students to discuss the common natural hazards in Washington State with their family members, neighbors, or other adults in their life. They should specifically ask for stories, photos, or information about events that people experienced. They should also write a report (half-page long) about these interviews to turn in on this day.

Warm Up:
Review material from the previous day. Collect half-page write-ups from the interviews that students conducted in preparation. Read the Legend of the Trout and discuss what its cultural significance would be.

Procedure:
Have students get into groups and answer the worksheet questions, using the information they gathered from family members or neighbors. Come back as a class and discuss the answers. Ask students what their family members and neighbors remembered about the events, what they did to prepare for them, how and how long were they affected? What were the impacts to individuals, towns, cities, states? What was the process of recovery like?

Conclusion:
Ask the students to compare and contrast the hazards in the Kuril Islands and those in Washington State. Compare how much impact these hazards can have on small groups of hunter-gatherers and on the large cities. Discuss what individuals should do in an event of earthquake, tsunami, volcanic eruption.

Optional extension:
Modern hazard planning.

Have students go to **http://www.stopdisasters-game.org/en/home.html** and play two different hazard games. This game gives students a good idea of different methods communities can use to protect themselves from different hazards.

Questions:

1. Is there overlap in the measures you take to avoid different natural hazards? What worked the best?

2. What is a better plan - move buildings out of the hazard zone or upgrade the building to higher building standards? Why?

3. Based on the game, what are the most cost effective ways to make a community more resilient?

4. What natural hazards is your house susceptible to? What could you do to make your home more resilient to natural hazards?

"Before God made the world, there was nothing but swamp to be seen, in which, however, there dwelt a very large trout. This trout was indeed a mighty fish, for his body reached from one end of the swamp to the other. Now, when the Creator produced the Earth, He made this creature to become its foundation. There lies the living trout beneath the world, taking in and sending out the waters of the sea through his mouth. When he sucks the water in, the ebb of the tide takes place, but when he sends it out the tide flows"...

"The trout upon whose back the world is founded is the cause of tidal waves. Every now and again he takes in a vast quantity of water, and then with an extraordinary effort shoots it out of his mouth in one mighty blow of his breath. It is this which makes the tidal waves (tsunami).

"So, again, when he shakes himself the consequence is an earthquake. When he moves gently the earthquake is small, but when he is angry and moves furiously it is great. As this is such a dangerous fish, the Creator has sent two deities to stand one on either side of him, to keep him quiet. These divine beings always keep one hand each on him, to hold him down and prevent any severe movements. Whether they eat or drink they must each keep one hand upon him without fail; they may never on any account take it off."

The Ainu and Their Folklore, by the Rev. John Batchelor (London: The Religious Tract Society, 1901)

Questions about family interviews

The Kuril Islands are not the only location prone to natural hazards. Western Washington is also prone to natural hazards. This activity is designed to look at how we understand natural hazards in western Washington.

Complementary information:

The goal of the first set of questions is to get the students thinking about **1)** How natural hazards impact their lives; **2)** The difference between high frequency, low impact events (like storms and landslides) and low frequency, high impact events (like large earthquakes and lahars); **3)** There is a disconnect between the student's experience, the memory of their family and the range of natural hazards possible for where they live; **4)** People who have recently moved to an area do not understand the range of natural hazards as well as people who have lived in an area for many generations that pass on knowledge.

Oral history:

Question #1:

How long have you lived in Washington? What natural hazards do you remember occurring here? How many of each type of event do you remember? (Storms, landslides, earthquakes, tsunamis, or volcanic eruptions)

Complementary information:

Storms and landslides happen most winters. Every 5-10 winters, there are worse storms. Earthquakes happen ~every 20 years.

Question #2:

Natural hazards are often more dangerous to transient populations. People who have recently moved to an area do not know the natural hazards an area is prone to or how to respond. During the 2004 tsunami in the Indian Ocean, very few people died on Simeulue Island. People in the village remembered stories of a large tsunami in 1907 and taught younger generations to run to high ground after strong earthquakes. On nearby islands, the populations near the coast did not have as long of a history and many people died. How long has your family lived in western Washington? Talk to some of your family that has lived here a long time. What natural hazards do they remember? How many of each type of event do they remember? (Storms, landslides, earthquakes, tsunamis, or volcanic eruptions) Based on your family's oral history, what do you know about all of the natural hazards in Washington?

Question #3:

Based on your family's knowledge, what do you think are the most common natural hazards in western Washington? What do you think are the most severe?

Complementary information:

Most common: Storms, landslides, floods

Most severe: Earthquakes, tsunamis, lahars

Written history:

Question #1:

The Puget Sound was first explored in 1792 by George Vancouver. The first permanent settlement was established in 1833 (Fort Nisqually). The transcontinental railroad arrived in 1888. How good do you think the record of natural hazards is before 1792? Between 1792 and 1833? Between 1833 and 1888? Since 1888?

Complementary information:

The record before 1792 is based on oral traditions of Native Americans. Exact dates are difficult to pinpoint. Some of this record is also known from geology. The record is spotty from 1792- 1833; most people with writing only passed through the area but did not stay. Lewis and Clark were present in 1805-1806. From 1833-1888, there is only one event recorded; if an event occurred far from Fort Nisqually it may not have been recorded. Also, the record is based on a few spotty journals, some smaller events may not have been recorded and the level of detail depends on the writer. Through time more people moved to the area and the record improved. From 1888-present, the arrival of the railroad opened up the area for people to quickly move to the region, and many records have been kept.

Question #2:

Look at the chart. What kinds of natural hazards are not included in the list? Why? Based on the written records in the chart, what is the most common natural hazard in western Washington?

Complementary information:

Frequent hazards such as storms, landslides ,and floods are not included because there are too many of them. Earthquakes are the most common.

Question #3:

What natural hazards would we not know about if not for the geological record?

Complementary information:

Lahars, Cascadia earthquakes

Question #4:

The 1700 Cascadia earthquake is known from written records but the event occurred before there were written records in Washington. How do you think this occurred?

Complementary information:

Written records are present in different areas at different times. There were written records in other areas (like Japan) that recorded the tsunami.

Student Worksheet guide

Modern Planning

Written history:

Question #1:

Look at the natural hazards map of western Washington. It has been stylized to be similar to the maps you used in class. Given what you have learned about natural hazards, where would you build a village? Pick four locations for villages considering proximity to resources and natural hazards and mark them on the map.

Question #2:

Which current city in Washington – Seattle, Tacoma, Everett or Bremerton – is subject to the greatest threat from natural hazards? Why?

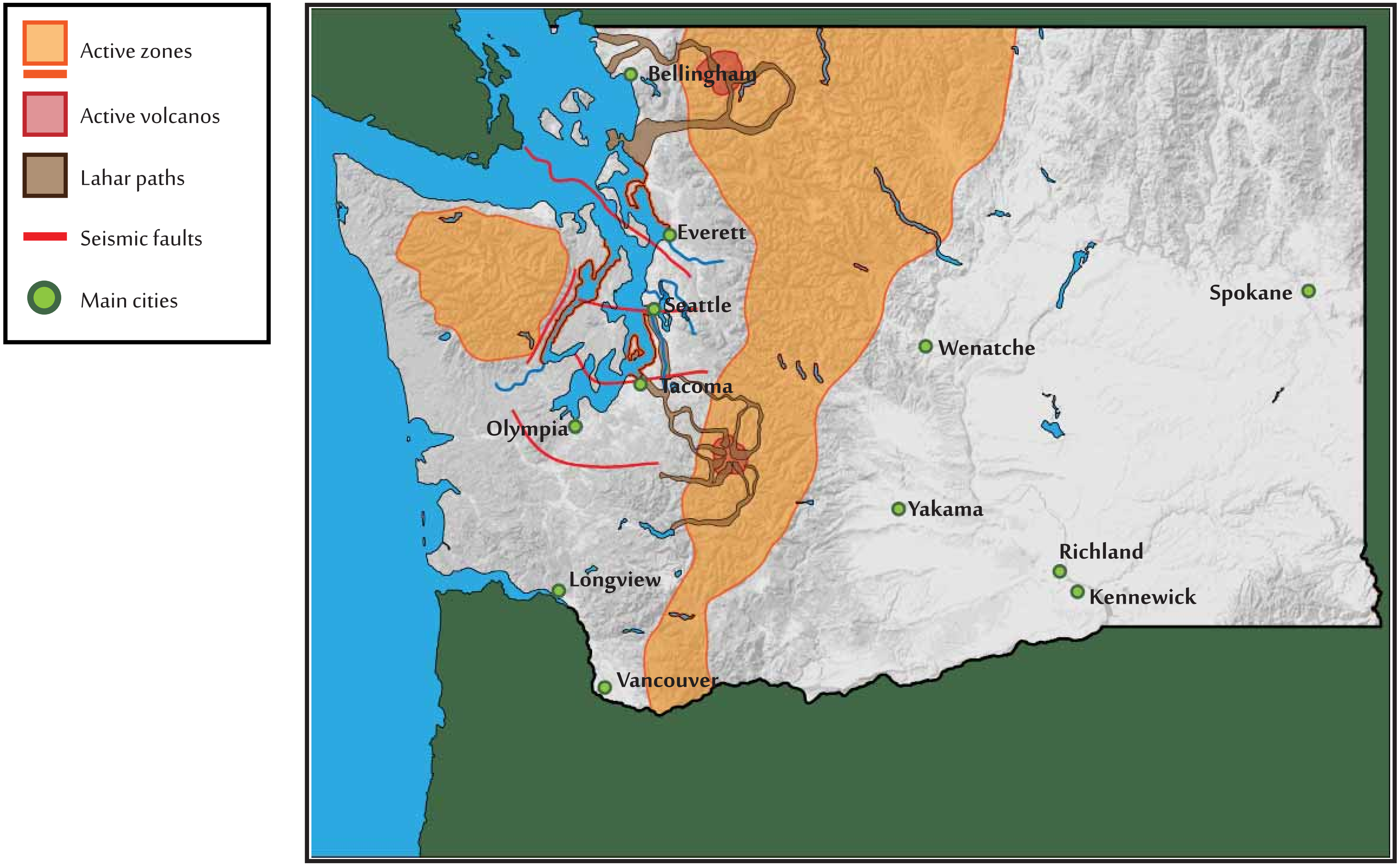
Question #3:

The map shows zones of hazard for tsunamis, landslides, and lahars. What other hazards are we subject to in Washington? Are these events more frequent or less frequent? Do you think these events cause more or less damage? If you are building a town, what hazards would you consider a planning priority, one that happens every year but causes local damage (floods and landslides), or one that only occurs approximately every hundred years but causes widespread damage (large earthquakes and lahars)?

Student Handout

Washington State Map

Available as a laminated handout



Student Handout

Major events in Washington State

Available as a laminated handout

Volcano	Tsunami	Earthquake	Lahar
AD 2004 Mt St. Helens			
		AD 2001	
AD 1980 Mt St. Helens			
		AD 1965	
	AD 1949 Tacoma	AD1949	
	AD 1943 Tacoma		
		AD 1939	
		AD 1936	
	AD 1894 Tacoma		
			AD 1891 Mt. Baker
AD 1884 Mt Rainier			
		AD 1872 Cascade Mountains	
AD1843 Mt. Baker			AD 1843 Mt. Baker
AD 1842 Mt. St. Helens			
	AD 1700 Cascadia	AD 1700 Cascadia	
AD 1480 Mt. St. Helens			
			AD 1420 Mt. Rainier
AD 900 Mt. Rainier	*AD 900 Pudget Sound* *AD 900 Cascadia*	*AD 900 Puget Sound (4 events)* *AD 900 Cascadia*	AD 900 Mt. Rainier
	AD 700 Cascadia	*AD 700 Cascadia*	
	AD 350 Cascadia	*AD 350 Cascadia*	
400 BC Mt. St. Helens			
	500 BC Cascadia	*500 BC Cascadia*	
800 BC Mt. Rainier			
	900 BC Cascadia	*900 BC Cascadia*	
1000 BC Mt. St. Helens			
	1,400 BC Cascadia	*1,400 BC Cascadia*	
1900 BC Mt. St. Helens			

2,000 years of natural hazard history for western Washington. *Italic* events are known from the geological record. Cascadia events are earthquakes and tsunamis generated on the Cascadia subduction zone off the Washington, Oregon, and California coast.

PALEOCLIMATE

Teacher's Manual

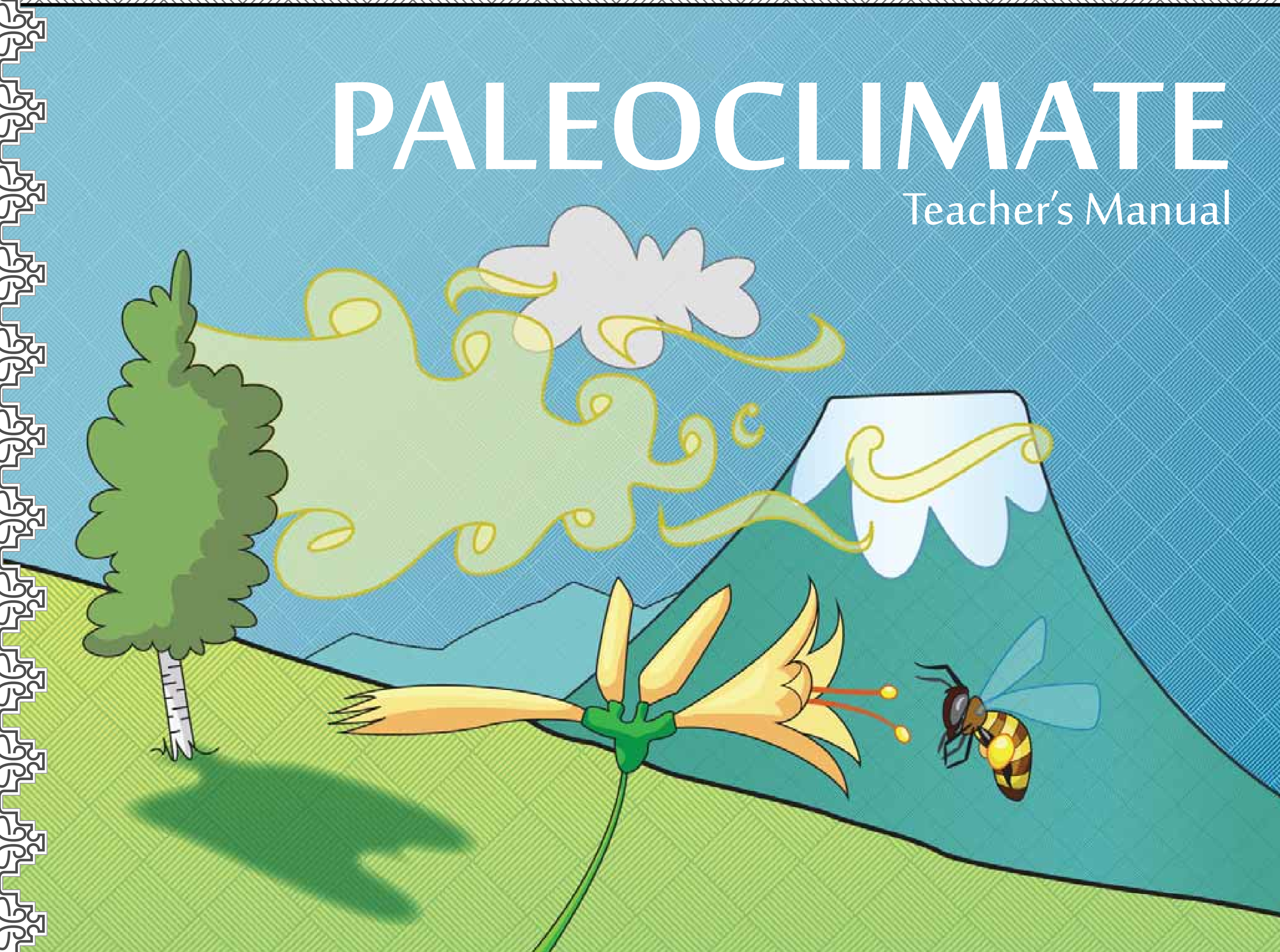


Table of contents

Subjects:
Earth Sciences

Duration:
Two class periods (~60 min.)

Class size:
10 - 30 students

Summary

Overview:

Students are introduced to methods that palynologists use to interpret past vegetation and associated climatic conditions. By introducing students to basic concepts such as biostratigraphy, proxy data, and analog analysis, they will be able to reconstruct the vegetation and climate histories of the southern Kuril Islands over the last ~8,000 radiocarbon years. Students will explore: 1) the relationship between modern climate and modern vegetation; 2) the relationship between modern and ancient vegetation using pollen data; and 3) the application of these relationships to infer past climatic change. Through the exercises the students will: 1) learn how to apply the basic principles of palynology; and 2) improve their appreciation of the dynamic nature of the environment (i.e., that modern ecosystems and climate patterns are not static but can change dramatically over time). Reconstructing paleoenvironments is a key tool that aids archeologists in better understanding possible human-environmental interactions, such as how changes in past environments might have influenced human activities.

Objectives:

- To teach students how palynologists infer past plant communities and how paleovegetation reconstructions act as proxy measurements of past climate.
- To engage students in the analysis and interpretation of biostratigraphic data.
- To allow students to explore the relationship of vegetation types to broader climatic conditions.
- To engage students in the examination of how past conditions may help us understand possible responses of the environment to future climate changes.

Material Included in the Box:

- Slide show illustrating the basic principles of palynological analyses.
- Handouts with modern vegetation and climate data and paleo-data from the Kuril Islands to be used in discussion and exercises.
- The scientists' interpretation of the data provided in the exercises.

Vocabulary

Analog analysis:

A method for analyzing and interpreting paleoenvironments that can be based on either statistics or qualitative observations. The basic principle is that of uniformitarianism — the present is the key to the past. In our exercises we rely on defining qualitative modern pollen-vegetation-climate relationships to aid in interpreting past changes.

Biostratigraphy:

The spatial relationship between biological indicators found in sedimentary deposits. These relationships have a time component: in unmixed deposits the lowermost sediments are the oldest and uppermost units the youngest.

Conifers/Coniferous:

Plants with needle-like leaves.

Deciduous:

Plants that shed there leaves in winter, often having broad leaves. Note that larch, a conifer, is deciduous.

Deposit:

Sediment put down on the earth's surface in the past either by natural or human action. An archaeological deposit was created by people in the past. It can include soil, artifacts, features, or other traces of human activity that signals anthropogenic (human) involvement in the deposition process. Deposits usually form layers or "strata" that stack up horizontally like a layer cake with the oldest at the bottom and the youngest at the top. As a result the oldest archaeological deposits (or geological deposits, such as volcanic ash layers) are found below younger ones, allowing us to develop histories of events by studying the stratigraphy. Even so, material within deposits can be out of place (for a number of reasons, like the action of burrowing animals) resulting in the possibility of misinterpretation of the stratigraphy of a site or excavation. (see Stratigraphy Module)

Gradient:

Change in one variable with respect to another variable. In palynology this change is always in respect to geography or spatial distribution, for example a temperature or a vegetation gradient reflects changes in climate or vegetation over a specific region.

Paleo:

Prefix indicating "past."

Palynology:

The study of pollen and spores. The applications are widespread from providing pollen counts during allergy season to interpreting paleoenvironments. A palynologist is a specialist in the field of palynology.

Pollen:

Microscopic grains produced by higher plant forms (angiosperms and gymnosperms; flower and seed producing plants), containing male genetic material required for sexual reproduction. A dusting of pollen is often seen on surfaces as a yellowish powder during the flowering season. Note: pollen is both the singular and plural form. It is incorrect to refer to "pollens."

Pollen assemblage:
The combination of pollen and spores that characterize a specific pollen zone in a diagram or a specific vegetation type in modern studies.

Pollen diagram:
The basic tool for interpreting palynological records. It consists of an x-y plot of pollen and spore values vs. depth or time. Values, plotted along the x-axis, are usually percentages but can also represent pollen accumulation rates. The shallowest depths and youngest ages appear at the top of the y-axis.

Pollen spectrum/spectra:
Percentages of all pollen and spores from a single (spectrum) or multiple (spectra) sediment samples. Pollen assemblages consist of 2 or more spectra.

Proxy data:
A type of data that is used as a substitute measure for another parameter. For example, current temperatures can be measured using a thermometer. However, it is impossible to directly measure paleotemperatures because paleothermometers do not exist. Therefore, we use another data type or "proxy" (e.g., pollen) which has a known relationship to temperature (e.g., different vegetation types have different temperature requirements) to infer past changes.

Radiocarbon date:
A numerical date which approximates time of death of an organism (plant or animal) based on the amount of radioactive carbon (prone to decay) that remains in it. Radiocarbon dates are often used by earth scientists and archaeologists to understand the time lines of events, geological or cultural, respectively.

Spore:
A microscopic grain produced by lower plant forms (cryptograms) and containing genetic material for asexual reproduction. Unlike the higher plants, cryptograms have no true flowers or seeds.

Years BP (years before present):
The amount of time which has passed between the occurrence of an event and the year A.D. 1950.

Zone:
1) The combination of plant communities into a unique vegetation type that has a regional geographic distribution and is associated with specific climatic characteristics;
2) used in pollen diagrams as a basic unit for interpretation; each pollen zone represents a change in vegetation type and must include at least 2 pollen spectra.

Background Information

Knowledge of past landscapes and climate is an important element of interdisciplinary studies of the past. Although these types of investigations are valuable in and of themselves, they can provide essential information to archeologists who wish to better understand possible human-environment interactions. Such research also can provide useful insights into questions related to future climates and likely landscape responses (e.g., by looking at warm periods in the past, palynologists hypothesize that arctic tundra will disappear and be replaced by birch, poplar, and larch forests).

Many types of paleoenvironmental data are used to unravel the past. Here we focus on palynology, the study of microscopic pollen and spores (to simplify we will use only pollen in our discussion and examples). By taking cores from organic deposits, such as lakes or peats, palynologists can trace the vegetation history of a region by counting the numbers of pollen grains. Their percentages reflect the plants, and thus plant communities, that produced them. Unfortunately, there is not a one-to-one relationship between plants and pollen, although the greater the relative percentage of a given pollen type, the greater the number of plants on the landscape. Therefore, the first step in reconstructing the paleovegetation is determining the characteristic pollen "signature" that identifies modern vegetation types. The modern pollen rain is sampled from the most recent deposits in a lake or peat, for example from a 1-cm^3 specimen of sediment taken from the mud-water interface of a lake. The pollen percentages are plotted and then can be evaluated qualitatively (e.g., by comparing the pollen assemblages to a map of vegetation types) or using statistical analyses. Once the modern pollen-vegetation relationships are established, then paleovegetation can be inferred by searching for analogs of the ancient pollen samples to modern ones. Often this is done qualitatively, as we will do in our exercises, but standard statistical analyses are also used.

Because paleoclimatologists do not have thermometers or rain gages buried in their sites, they must rely on proxy data (i.e., data that indirectly reflects climate). Pollen is one of the best proxies because: 1) vegetation types are strongly controlled by climate; 2) the relationship between modern pollen assemblages and differing vegetation types is well established; and 3) pollen is an abundant and ubiquitous fossil. The first step for inferring paleoclimate is to determine the relationship of present-day vegetation and climate in the study region. This can be done by comparing gradients in maps of temperature or precipitation to vegetation maps (qualitative method) or by assigning modern climate values to the modern pollen sites (quantitative method). Next the fossil samples are counted and plotted in a pollen diagram. Based on the pollen assemblage, scientists then can interpret the past climate either qualitatively (e.g., cooler and drier than present) or with numerical values taken from the modern climate assignments.

The pollen data used in this module are not from actual sites cored during the Kuril Biocomplexity Project. However, the vegetation and climate maps are accurate. The pollen trends have been exaggerated somewhat to aid student interpretation, but they are accurate in showing the dynamic nature of past ecosystems, indicating that modern landscapes and climate conditions have not persisted throughout ancient times.

Introduction

The exercises are designed to allow students to explore basic concepts of ecology and climatology as applied to interpreting past environments. They will learn how to describe, compile, and interpret primary data spatially (across the Kuril Islands) and temporally (through tracing trends in vegetation and climate over the past 8,000 years). The lesson is divided into 2 parts, the first part dealing with modern environments and the second with paleoenvironments. The first part acquaints students with the vegetation and climate of the Kuril Islands and several palynological procedures (e.g., coring, sample analysis). The second part focuses on interpretation of a pollen diagram with associated vegetation and climate histories. The goal of these exercises is to illustrate how paleoenvironmental scientists approach problem-solving when trying to reconstruct vegetation and climate histories.

Activity 1: Climate and Vegetation; Modern Calibration

Students learn about the connection between climate and vegetation.

Warm Up:
Get the class to brainstorm about past environments. Would they expect past environments to be similar to today? An example may be the last ice age when Puget Sound and western Washington were covered in thick glacial ice. Ask students what they know about that period in the history of the state (how thick was the ice? How far south did it reach? What animals were around?). Introduce students to the idea that climate and landscapes are dynamic and changing. You may also discuss whether knowledge of past environments is of any use for understanding possible future climate and landscape changes. Have students come up with examples.

Procedure:
1. Use the slideshow included to introduce the following concepts:
    a. modern environmental analogs (the present is the key to the past)
    b. proxy data (we can not directly measure past temperatures or precipitation)
    c. climate and vegetation are connected in a specific way which differs in different regions
    d. pollen can be used to interpret past climate

2. Have students work on the first set of questions in small groups, then come together as a whole class to discuss their answers.

Activity 2: From Pollen to Past Vegetation and Climate

Students learn how palynologists interpret pollen percentages from the cores and practice doing that themselves.

Warm Up:
Review material from the previous day.

Procedure:
1. Hand out the table with modern pollen percentages by zone and the table with January and July temperatures by zone. The practice diagram should be projected onto the screen (PowerPoint slide 36). Student should determine how many vegetation changes happened during the 8,000 years in this diagram and interpret what past climate was like during these periods. This practice activity should be done together with the teacher in preparation for the next activity, done by students themselves, individually or in groups. Slide 37 shows the scientists' interpretation of this diagram. Here are the climatic interpretations:

a. Zone 3 represents modern climate conditions. The slight decline in oak pollen percentages associated with increases in spruce and tree birch pollen suggests a slight cooling, but not enough to change from one vegetation type to another. While perhaps indicating the Little Ice Age (the time in 1700-1800s when River Thames was covered with ice), additional samples need to be analyzed to confirm any possible cooling.

b. Zone 2 represents the warmest summer climate in our record. This warm period is found in many records in the Russian Far East and other areas of the Northern Hemisphere. The period is called the postglacial thermal maximum, referring to highest summer temperatures following the Ice Ages. Note that in our record January temperature is similar to modern, suggesting that unlike summer, Zone 2 winters were like today.

c. Zone 1 represents the coolest summer and winter climates represented in the pollen diagram. Although our record does not extend into the Ice Ages (>12,000 BP), the cooler than modern conditions in zone 1 (about 8,000 BP) suggest that global climates warmed slowly after the glacial period.

2. Hand out the individual worksheets with pollen percentages from core obtained in the Kuril Islands and an empty diagram (per person or per group) for graphing the percentages. After the diagrams are created, students (individually or in small groups) should use the tables they already have from previous exercise to answer the questions on the worksheet for Activity 2 and then discuss answers as a group.

Conclusion:
Have students tell you and the rest of the class about the climatic and vegetation history of the Kuril Islands.

Wrap Up:
Discuss what may cause climate change and why it is important to study climate change in the past.

Question 1:

If you wanted to live in the warmest area of the Kuril Islands during the summer, which island would you choose? The coolest island during summer? If you wanted to live in the warmest island during winter, would you have to move from your summer island? In each case, what type of vegetation would grow on your island?

Answer:

Mean July temperatures are coolest in the central and northern Kurils, where meadows and meadows with shrub thickets (Paramushir Island) are prevalent. With increased July temperature, birch forests establish on southern Urup and northern Iturup Islands. Moving southward in the archipelago, July temperature continues to increase, associated with the growth of conifer forests (southern Iturup and northern Kunashir Islands) and even further to the south with cool temperate forests (southern Kunashir Island). Thus, the warmest island would be southern Kunashir with forests of oak and other warm tree species. The coolest setting would be in any of the treeless, central and northern islands. In January, the islands are all located between the same isotherms (contour lines of temperature). Consequently, no one would have to move from their summer island. Additionally, the similarity in January temperature throughout the archipelago indicates the Kuril vegetation is insensitive to winter conditions.

Question 2:

Access to fresh water can be a problem in the Kuril archipelago, because some islands have no fresh water and other islands have only small streams. Rain and snow, of course, are also sources of fresh water. If you could not depend on a stream for water, which island(s) might you chose for a summer (winter) settlement, based on the map of July (January) precipitation? If you lived in the Kuril Islands 1,000 years ago, what other landscape elements might you consider in your winter settlement?

Answer:

The contours in the July precipitation map parallel the Kuril Islands, suggesting that any island is equally good concerning rain sources. This pattern also suggests that July rains have little influence on the vegetation. The January precipitation map shows more complex patterns. The wettest winter conditions occur in the meadowy portion of the central Kurils, whereas there is less snow fall in the temperate forests to the south. The birch and conifer forests are moderately wet. Although the central Kurils have the greatest snowfall, they also have no source of fire wood. Thus the decision of where to locate in the winter, if no streams are available, may be a compromise between areas where there are sufficient sources of snow and fuel, i.e., the conifer or birch forests in the southern islands.

Student Worksheet guide

Question 3:

If you were the chief palynologist, how would you summarize the qualitative vegetation-climate relationships for the other scientists working on the Kuril Biocomplexity Project? Hint: first give each vegetation zone a ranking (e.g., vegetation with the warmest July temperatures is given a rank of 1; coolest July temperatures a rank of 4). Rank only those climate variables that influence the vegetation. Provide a qualitative description (e.g., warm, wet summers; warmest, wettest winters) for each vegetation type.

Answer:

The contours for January temperature and July precipitation maps parallel the island chain and thus are factors that do not need to be considered. The rankings are provided in the table below.

Of the four maps, July temperature corresponds most closely with the distribution of the main vegetation zones in the Kuril Islands. This relationship is not surprising as temperature during the growing season is one of the main factors determining plant growth and plant biogeography. The January precipitation map suggests that winter precipitation also plays a role in the Kuril vegetation. Note that January precipitation does not correspond to vegetation zones as precisely as July temperature; thus the mixed rankings in the winter climate category.

Vegetation type	July temp. rank	Janurary precip. rank	Qualitative description
Meadows with thickets	4	1	Summer moderately cool, winter moderately wet
Meadow	5	2	Summer cool, winter wet
Birch forest	4	1/2	Summer moderately warm, winter wet
Conifer forest	3	2/3	Summer moderately warm, winter moderately wet
North temperate forest (Kunashir)	2	4	Summer warm, winter dry
South temperate forest (Hokkaido)	1	4	Summer warm, winter dry

Note to teacher:

Most students will expect July temperature to be a key factor in determining vegetation type, as summer is the growing season. However, they may be surprised that January and not July precipitation is important for the Kuril vegetation, especially as January precipitation is in the form of snow. The snow is important in two ways. Snow cover insulates shrubs and tree seedlings thereby protecting them from the cold winter temperatures. High January precipitation also helps build a snow pack, which will be a moisture source for the plants during late spring into early summer.

Question 1:

As the chief palynologist on the project, you have spent a month doing field work and 6 months in the laboratory. Now you are ready to interpret your data. In the provided template, first plot the pollen percentages from your spreadsheet. Do you see distinctive pollen assemblages for the different vegetation types? How many? What is the pollen “signature” for each vegetation zone?

Answer:

The main vegetation zones are differentiated by their pollen samples as follows:

Cool temperate forest:

Oak is the most frequent pollen taxon with a lower but important contribution by other “warmer” tree types such as magnolia, elm ,and maple. Grass pollen is low. Tree birch is below 20%. Spruce pollen is low to absent. Hokkaido has higher percentages of oak and other temperate tree types because climate is more favorable for the growth of these trees.

Conifer forest:

Spruce is the dominant pollen taxon with higher percentages of tree birch and shrub pine. Temperate tree pollen is absent, except for very low values of oak pollen. The grass percentage is also low.

Birch forest:

Tree birch pollen is most abundant with a modest percentage of shrub pine. Temperate tree pollen is absent with low values of spruce and grass pollen.

Meadow:

Grass pollen is the most common pollen taxon with other types absent or of low percentages.

Meadow with shrub thickets:

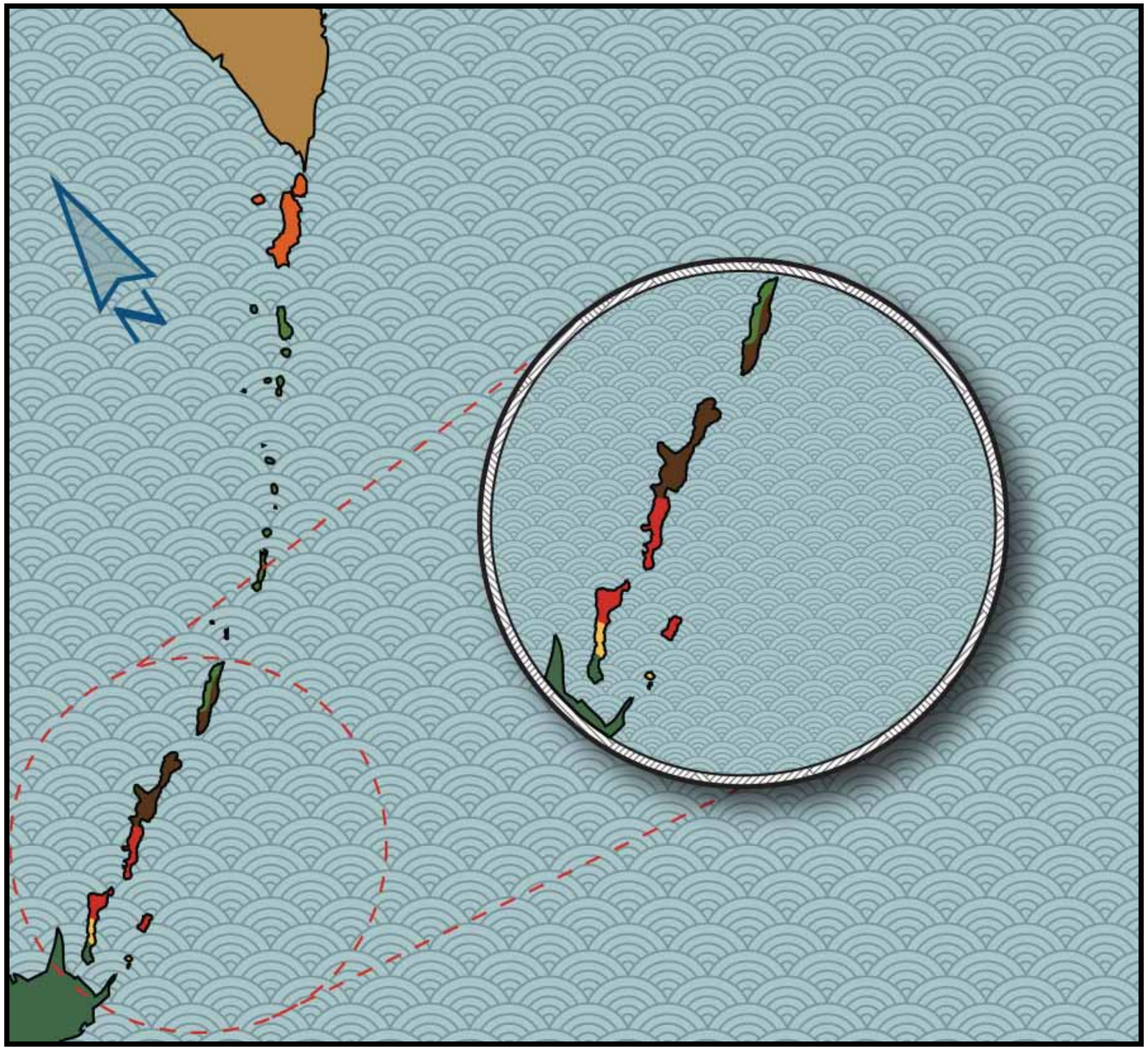
The highest pollen percentage of shrub pine characterizes this vegetation with a moderate percentage of grass pollen. Other illustrated taxa are low to absent.

Question 2:

Describe the vegetation history of your island for your colleagues. Use the handout called "Modern vegetation type & climate change by latitude" to determine how climate changes through the 8,000 years recorded in the core.

Student Worksheet guide

Part 1: Vegetation distribution map



Temperate forest
(oak, maple, elm, ash, magnolia, tree birch)

Temperate forest
(conifers)

Conifers
(fir, spruce, larch, shrub pine, tree birch)

Birch forest
(tree birch, shrub pine, shrub alder, bamboo)

Meadow
(herbs)

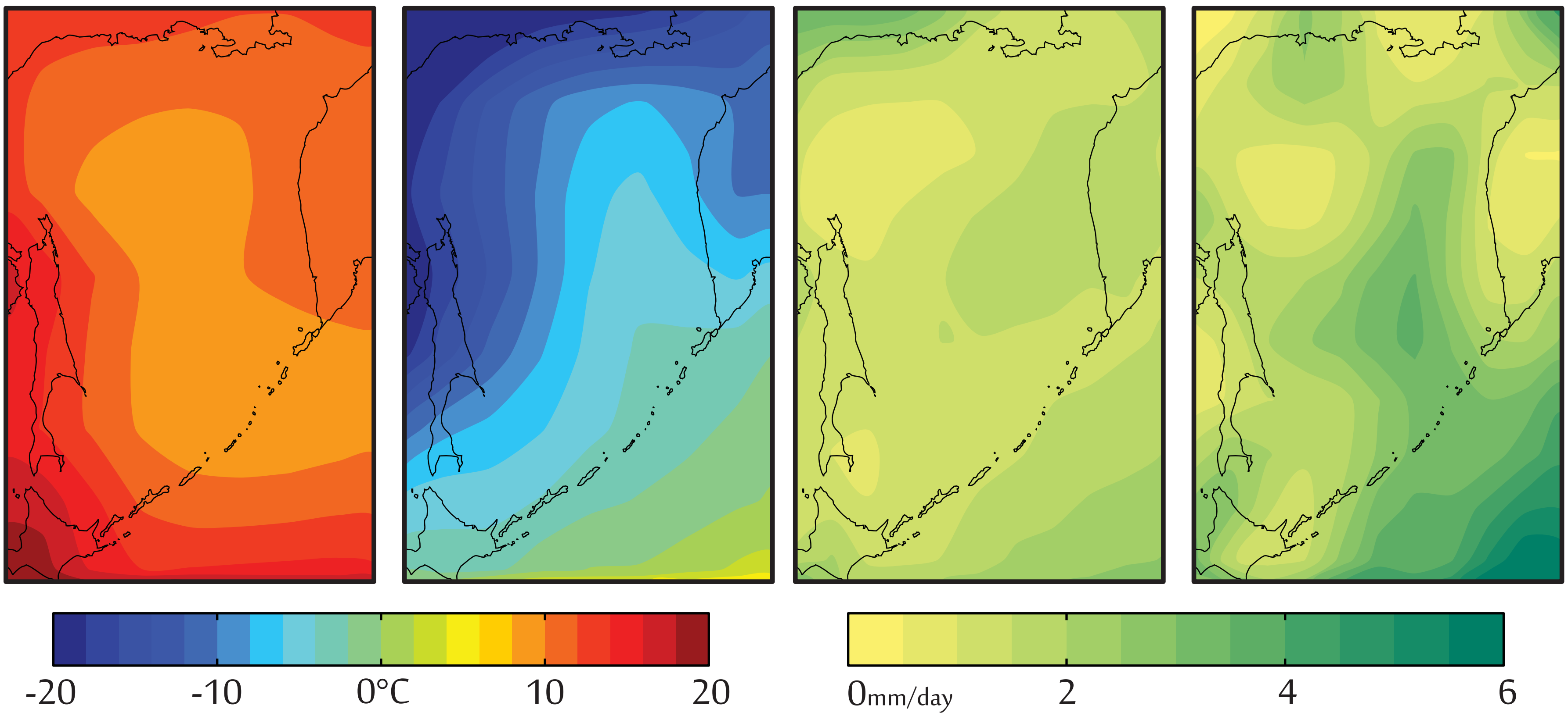
Meadow with high shrub thickets
(shrub pine, shrub alder, herbs)

Birch conifer forest

Student Worksheet guide

Part 1: July & Januray temperature & precipitation maps

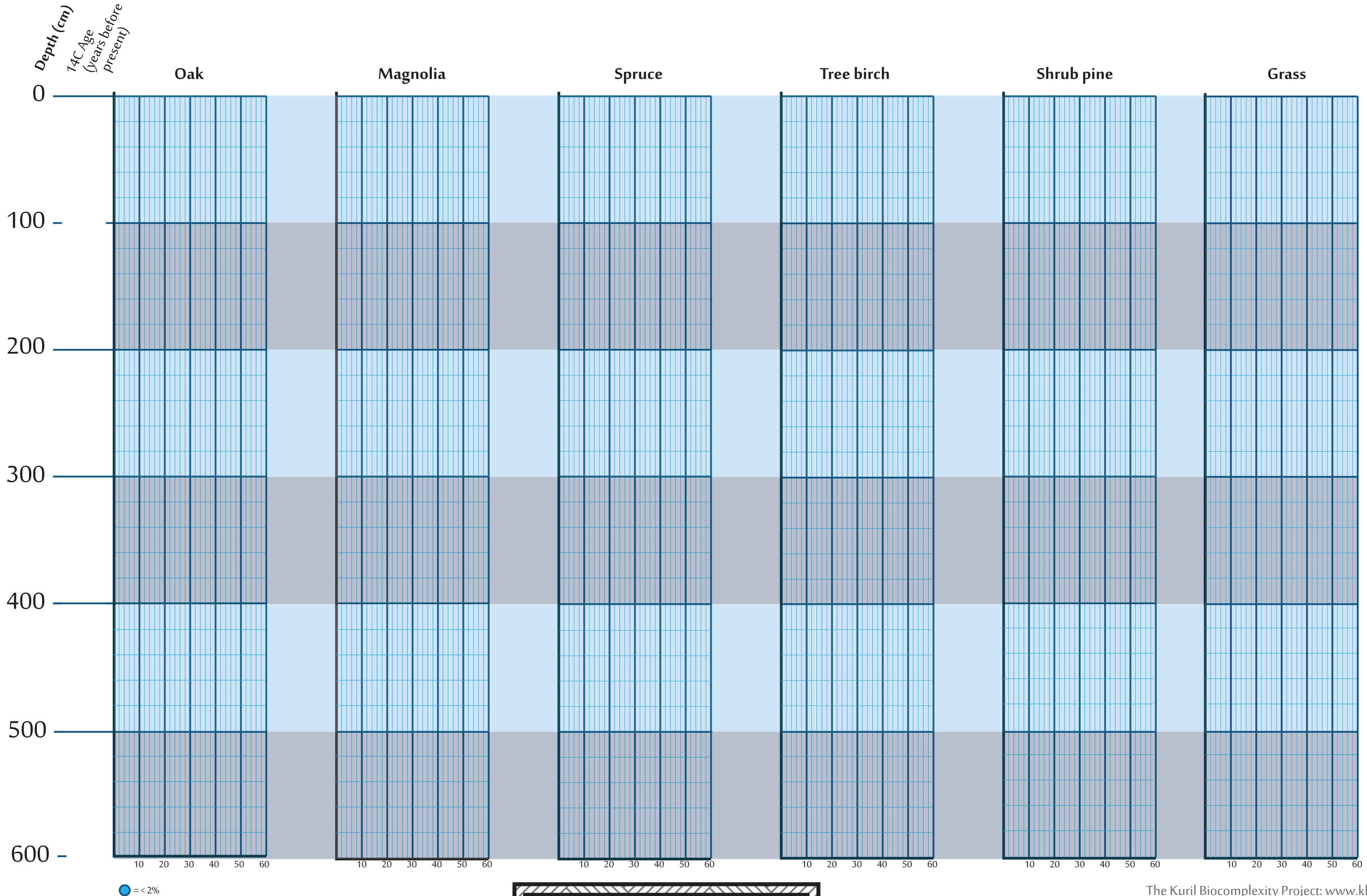
July Temperature **January Temperature** **July Precipitation** **January Precipitation**



Student Worksheet guide

Part 2: Paleoenviroment

Pollen Diagram Template



Student Worksheet guide

Part 2: Paleoenviroment

Data

Pollen Percentages

Depth (cm)	oak	magnolia	spruce	tree birch	shrub pine	grass
0	0	0	1	40	23	10
10	0	0	1	37	20	8
20	0	0	0	35	20	10
25	0	0	0	30	22	10
30	0	0	0	25	25	15
40	0	0	0	28	25	12
50	0	0	1	37	23	8
60	0	0	0	40	20	10
80	0	0	0	40	20	10
100	0	0	1	40	21	9
120	0	0	1	40	22	12
140	0	0	1	40	20	10
160	0	0	2	37	18	8
180	0	0	5	35	20	10
190	0	0	30	20	15	5
200	0	0	37	20	15	5
210	0	0	40	20	15	5
230	30	5	7	13	12	3
240	33	5	5	12	13	3
250	35	5	5	15	15	5
270	50	7	0	10	5	3
290	55	10	0	7	5	3
320	60	15	0	5	2	3

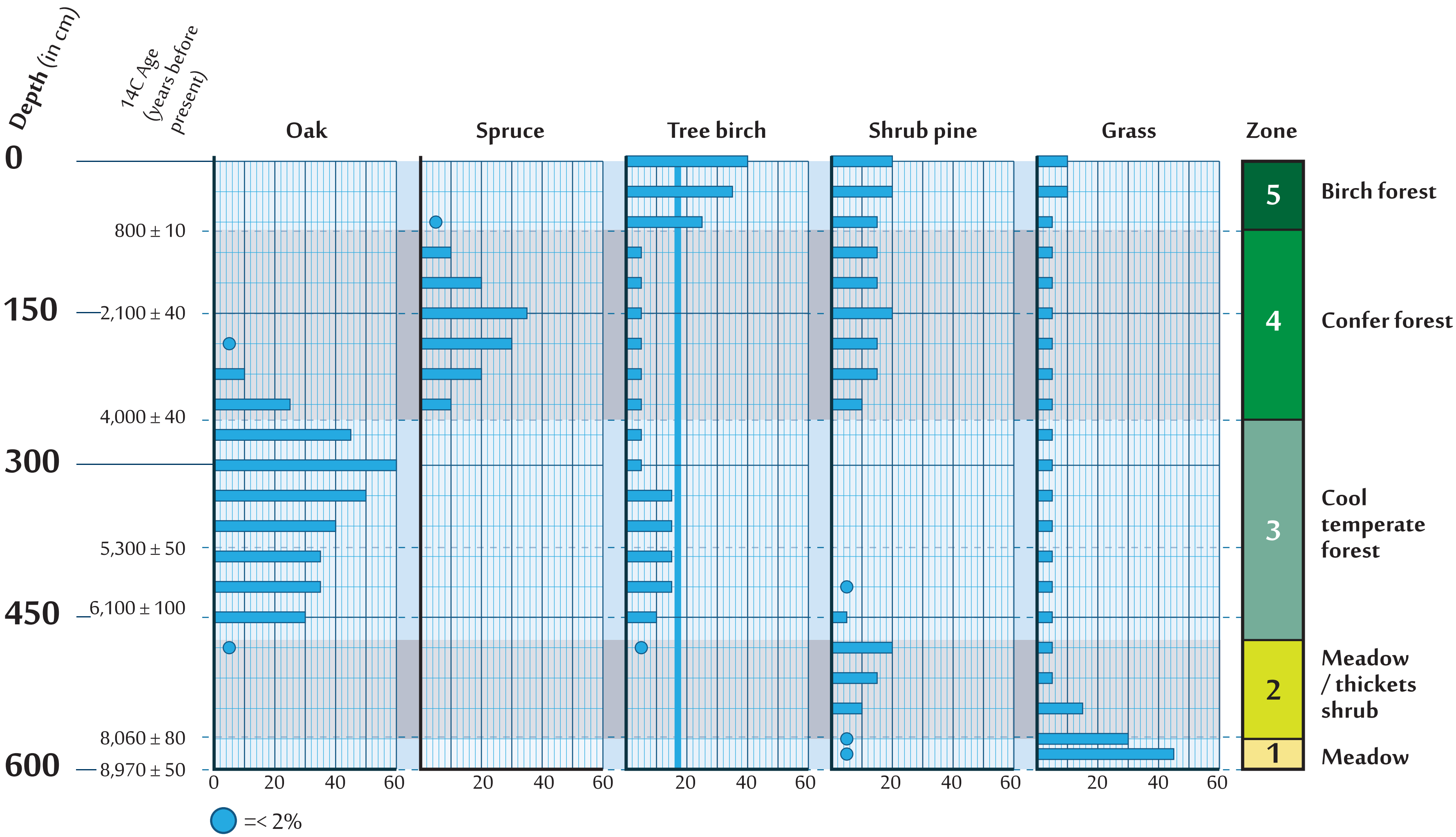
Depth (cm)	oak	magnolia	spruce	tree birch	shrub pine	grass
350	55	12	0	5	2	3
370	55	10	0	5	5	3
400	50	10	0	7	5	3
410	45	9	0	10	5	3
430	35	5	0	12	12	5
450	33	5	0	12	12	5
480	35	5	0	15	15	5
500	30	5	0	15	15	5
520	2	0	0	2	20	10
540	0	0	0	0	25	15
550	0	0	0	1	25	15
560	0	0	0	0	10	15
580	0	0	0	0	2	30
600	0	0	0	0	2	45

Radiocarbon Dates

Depth	Date	Error
75	500	10
125	2,100	40
250	4,000	75
370	5,300	60
420	6,100	100
560	8,060	80
600	8,970	50

Student Worksheet guide

Answer plot of the exercise pollen core data
(with vegetation zones indicated)

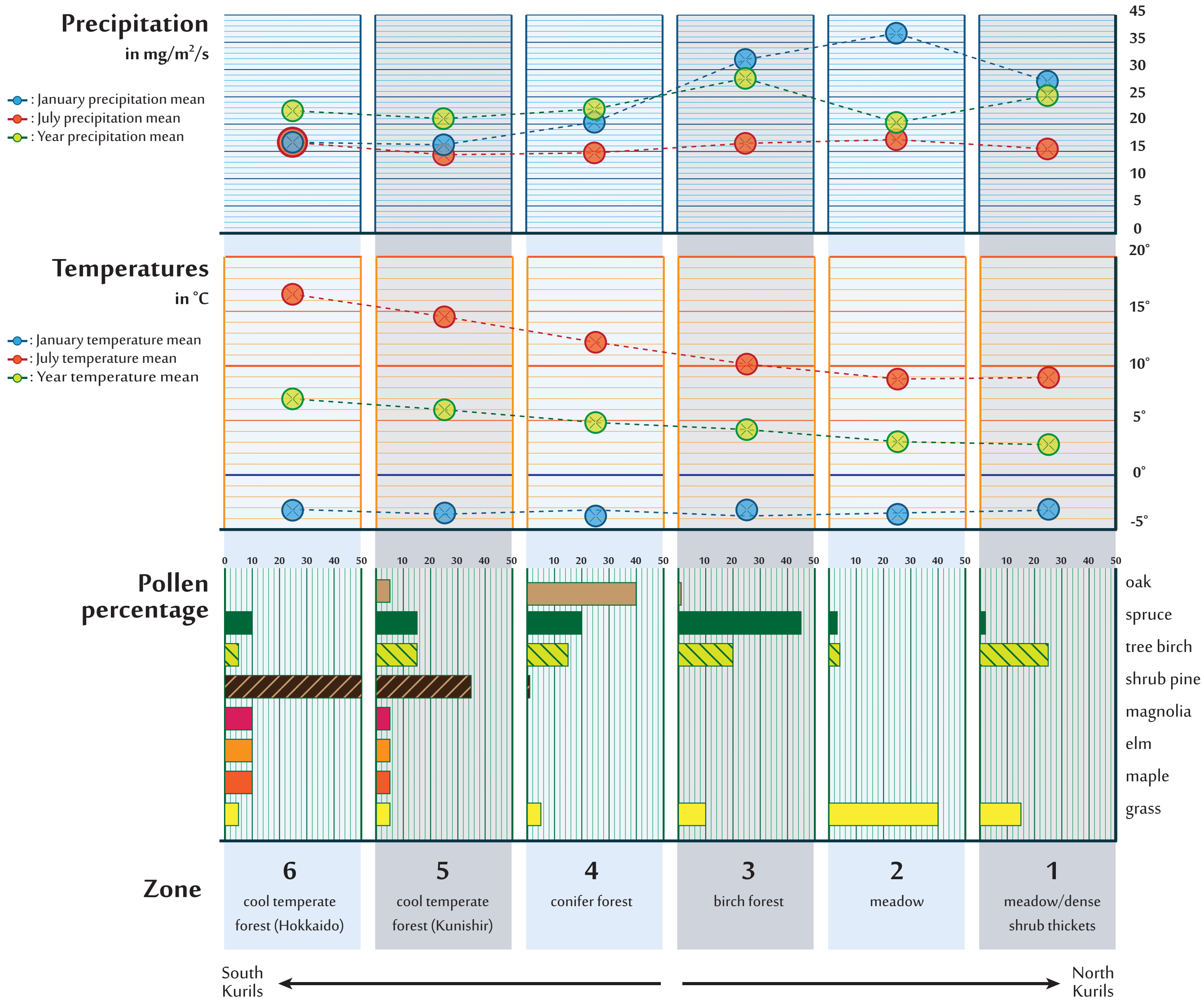


The Kuril Biocomplexity Project: www.kbp.org

Student Worksheet guide

Part 2: Paleoenviroment

Modern vegetation type & climate change by latitude



The Kuril Biocomplexity Project: www.kbp.org

BIOGEOGRAPHY

Teacher's Manual

Table of contents

Subjects:
Earth Sciences, Life Science

Duration:
One class period (~60 min.) +

Class size:
10 - 30

Summary

Overview:

This module deals primarily with the geography of the Kuril Islands and the constraints that this geography puts on the numbers and kinds of animals (including humans) that are able to inhabit the islands. The scientific study of this relationship is called island biogeography. For information on the distribution of plants (phytogeography) and how this might have changed through deep time, please consult the Paleoclimate teaching module.

Goals:

To familiarize students with the science of biogeography, as well as the wide range of physical and geological processes that help to structure biogeographic patterns.

Objectives:

- Students will be able to explain how animals can populate islands
- Students will be able to compare animal distributions in time and space and create hypotheses for changes over time or differences in space

Material:

- Introductory Slide Show
- Student worksheets

Vocabulary

Biogeography:

The scientific study of how geography affects where different species of animals live (see also **phytogeography**).

Chlorophyll A:

A pigment used by plants to store energy from the sun through the process of photosynthesis.

Colonize:

To establish a breeding population in an area that had not previously been occupied.

Disperse:

To spread outward from a species' native home range. To "disperse to" a new area simply means to arrive there safely (see also colonize).

Distribution:

1. The geographical patterning or location/s of something (e.g., the distribution of sea ice in the Sea of Okhotsk).
2. In statistics, the patterning, or spread, of a series of data points (e.g., the distribution of radiocarbon dates through time)

Fast ice:

Ice that is connected to shore.

Pack ice:

Free-floating chunks of ice that drift across the ocean pushed by wind and water circulation.

Phytogeography:

The scientific study of how geography affects where different species of plants live (see also biogeography).

Phytoplankton:

Free-floating plants that are usually made up of a single cell. Phytoplankton get their energy from the sun, and make up the base of the food chain.

Primary productivity:

A measure of how much of the sun's energy is captured by plants and made available in the food chain.

Zooplankton:

Free-floating microscopic and macroscopic animals.

Background Information

The Kuril Island Chain is part of a volcanic island arc that began forming 90 million years ago (during the Cretaceous Period) when an oceanic tectonic plate collided with the Siberian continent. The oldest island in the chain is Urup, which emerged from the sea 4.21 million years ago.

Island chains have a variety of characteristics that make them special in the biological world. They come in all manner of different shapes and sizes. Given that different kinds of animals have different home ranges, the size of an island can have a significant influence on the kinds of animals that are able to survive there.

By the same token, the distance between islands, or between any given island and the mainland, will influence what species are likely to disperse to an island as well.

This is due to the fact that there are only three paths animals can take to get to an island:

- By land
- By sea
- By air

There are, of course, different options within each of these paths. For instance, "by land" can involve crossing dry land during periods of lower sea level, but it could also involve walking across sea ice.

Likewise, one image of how animals might arrive "by sea" involves swimming. This works well for marine mammals and fish, but for most terrestrial mammals this is only feasible for crossing narrow gaps between islands.

Consider, though, that small animals may raft across water crossings on logs, vegetation, or ice, and when it comes to water travel, humans have been very good at making boats for many thousands of years.

Finally, the "by air" pathway is limited to those animals that can fly such as insects, birds, and bats. In this module, the only flying animals we will deal with are birds, although both insects and bats are found throughout the Kurils.

All of these limitations will influence which species can (a) disperse to and (b) successfully colonize islands within the Kuril Island Chain.

Even for many of the animals that can easily swim or fly to islands, such as birds or pinnipeds (seals, fur seals, and sea lions), they are often still tied to terrestrial habitat as part of their breeding cycle. Sea birds, for instance, often nest on cliffs or in burrows. Likewise, even though pinnipeds can stay at sea months or years at a time, they must return to land to mate and give birth to their pups.

This need to return to shore makes sea birds and pinnipeds particularly vulnerable to predation by terrestrial predators such as foxes, bears, and humans.

For a more detailed consideration of how the geography of the islands and the geological history may have affected the resulting animal distributions, examine Figure 1, which shows the relative distances between the islands and the depths of the passes between them. Even during the Last Glacial Maximum (LGM), when world-wide sea levels were 150 m lower than they are today, only a few islands were connected to their neighboring mainlands (Kunashir to Hokkaido, in the south, and Paramushir and Shumshu to Kamchatka, in the north).

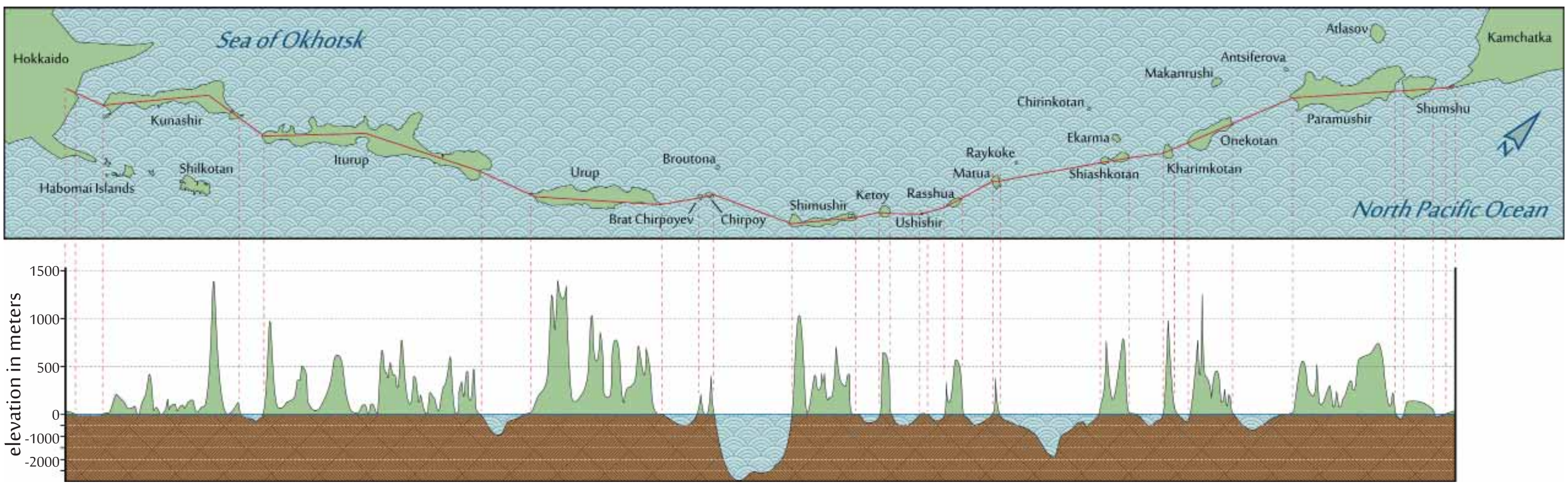


Figure 1: Cross section of Kuril islands showing topography (green) and bathymetry (blue). Vertical scaling is exaggerated to highlight the mail features.

There are two more important pieces to the biogeography "puzzle" at work in the Kuril Islands: sea ice distribution, and the distribution of marine nutrients. Sea ice primarily plays a role as a dispersal mechanism for terrestrial mammals, but sea ice is also important to several species of pinnipeds, including ringed seals and walrus. In most places in the northern hemisphere, northern areas tend to have more ice accumulation than southern areas, but this is not the case in the Kuril Islands. Counter-intuitively, sea ice concentrations in the Kurils tend to be highest in the southern portion of the island chain. This is because sea ice produced in the northern Sea of Okhotsk circulates counter-clockwise in ocean currents, and accumulates in late spring around Kunashir and Iturup, and occasionally Urup, as well. The presence of sea ice provides an important avenue of dispersal for terrestrial mammals coming to the Kurils from Hokkaido.

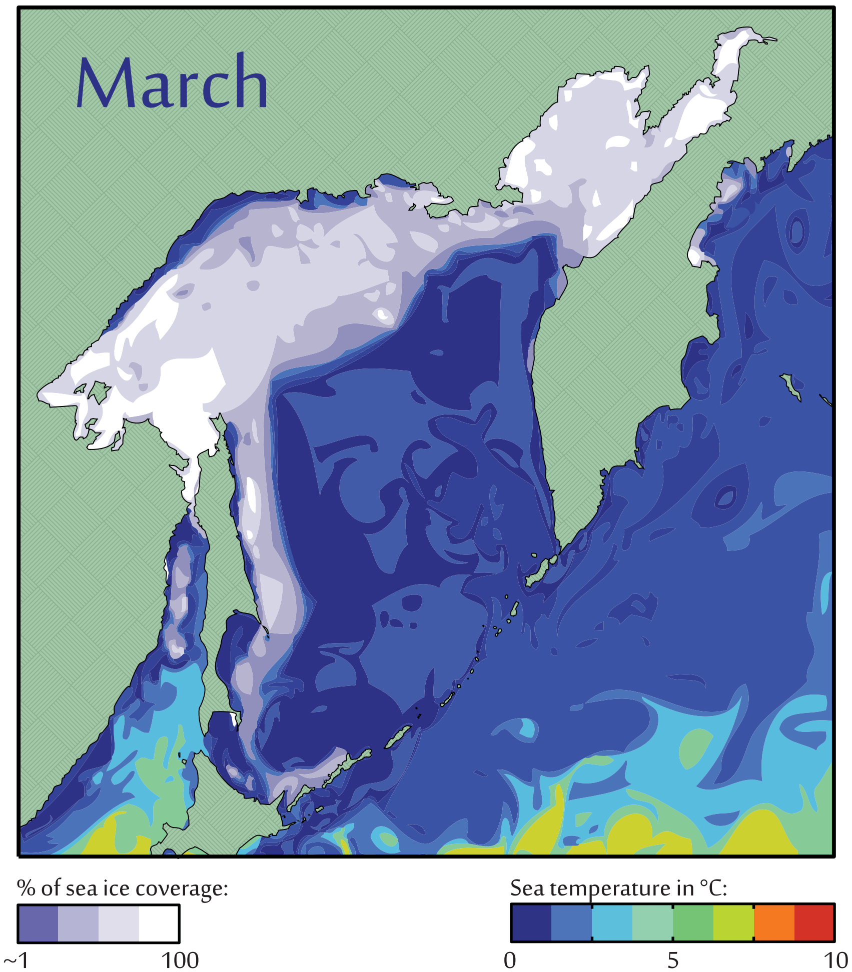


Figure 2: Average sea ice concentration in the Sea of Okhotsk and the Kuril Islands in March.

Background Information
Continued

Another factor that plays a crucial role in determining the distributions of animals throughout the Kuril Islands is the distribution of marine nutrients. Marine nutrients are not uniformly distributed throughout the ocean—they get concentrated in certain areas by a variety of mechanisms. The greatest concentrations actually tend to be on or near the ocean floor, due to the accumulation of dead and decomposing phytoplankton and zooplankton from near the surface. However, phytoplankton, the very base of the food chain, require sunlight and nutrients in order to thrive. As a result, phytoplankton growth is highest in those areas where marine nutrients are brought to the surface from the ocean floor through a process called upwelling.

One of the areas that this happens consistently in the Kurils is in the passes between the islands. With each tidal exchange, huge volumes of water pass between the Pacific Ocean and the Sea of Okhotsk. This exchange of water between the passes results in very well-mixed, nutrient-rich water close to the surface (see Figure 3).

Areas that support high phytoplankton growth also support large populations of zooplankton (feeding on the phytoplankton), which also supports high populations of larger marine predators. (see Figure 4)

Finally, it is quite likely that these concentrated areas of high marine productivity influenced the distribution of human settlements in the Kuril Islands. Please refer to the "Settlement Module" for more information.

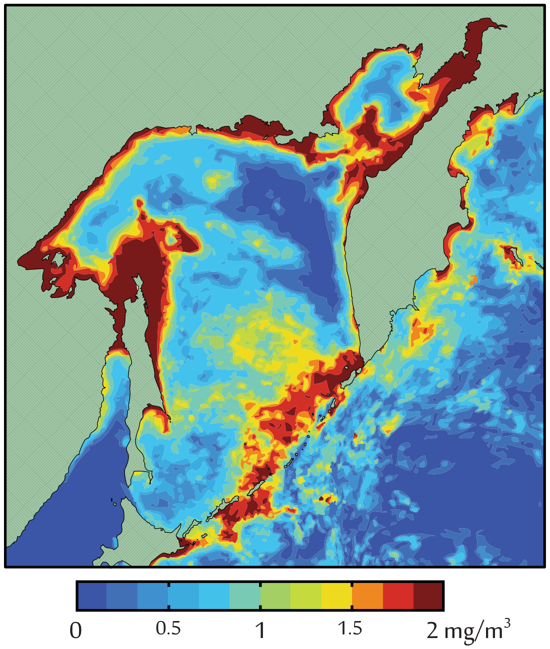


Figure 3: July average concentrations of chlorophyll over 10 years (1999-2008), which is an index of primary productivity (phytoplankton growth).

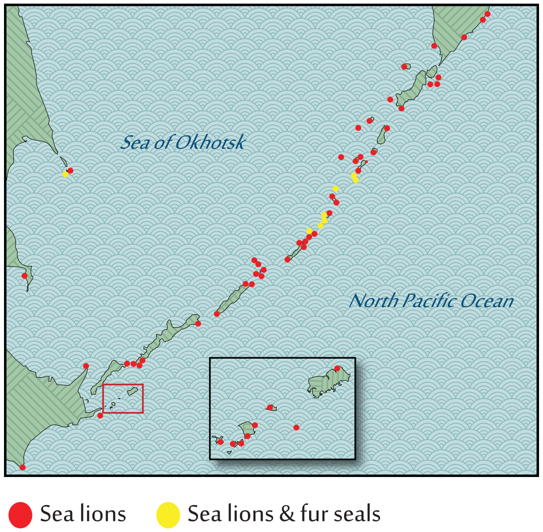


Figure 4: Map showing the distribution of sea lion and fur seal colonies. Note that on large islands, the colonies tend to be located toward the ends of the island (near the passes)

Procedure

Warm up:

Ask students to brainstorm how geography could influence where different kinds of animals live. Introduce the concept of biogeography. Ask students why the concept of biogeography may be important for archaeologists to study. The answer is: biogeography affects people directly (what areas of the planet are habitable), as well as indirectly (what kinds of animal resources are available for food, raw materials, etc.).

Procedure:

1. Present the slide show to your students. The slide show features many of the animals that are commonly found in the Kuril Islands, and provides some commentary on the ecological and cultural roles those species play today or have played in the past.

2. After presenting the slide show, distribute the student packets and have them work on the exercises in small groups.

3. Come back as the whole class and discuss the answers. Talk about comparing current and paleo (or past) species distributions – what would that be useful for? (changes in species over time can tell about environmental changes and influence of humans on the ecosystems).

4. Explore the Smithsonian's North American Mammals website and compare a few of the current mammal distributions with the data from Neotoma, which presents historic ranges of the same species. You can do this by either having each student go to the site on a personal computer and follow the teacher's instructions, or by pulling up the maps on one computer and projecting onto a screen.

a. Go to the Smithsonian's "North American Mammals" web site. http://www.mnh.si.edu/mna/main.cfm .

b. Look at the range maps for white-tailed deer (*Odocoileus virginianus*) and mule deer (*Odocoileus hemionus*, also called black-tailed deer), two very closely-related species. There are several approaches you can use to show the range maps for these species, but one approach will let you display the range maps for both species at the same time. To do that, go to the site listed above, and click on the "Enhanced Map Search (BETA)" link.

c. The simplest way to pull up the maps for the two species of deer is to type "Odocoileus" in the search bar at the top right corner of the screen. Then click the box next to each species' name, and the range map will appear on the left. With both species selected, both the range maps should show at the same time.

d. Ask the students to describe, in general terms, the modern distribution of white-tailed and mule (black-tailed) deer (Answer: Mule deer is mostly limited to the western half of the Continent. White-tailed deer are wide spread across most of the continent) and compare that to the "paleo" map you generated in the Zooarchaeology Unit (They are basically the same).

e. On the Smithsonian web site, clear the "Odocoileus" from the search bar and enter "Elk." Click on the box next to the species, and examine the range map for elk.

f. Ask the students to describe, in general terms, the distribution of elk (Elk are found mostly in the western US).

g. Using the Neotoma web site, conduct a search on "Taxon Name" using the full scientific name for elk (*Cervus elaphus canadensis*).

h. Ask the students to compare the paleo distribution of elk to the modern distribution (Elk were much more widely distributed in the past, with bones showing up in archaeological sites all across the continental US).

Conclusion:
As a class, discuss some of the possible explanations/hypotheses for why the paleo distribution of elk is quite a bit different from the modern range. Encourage students to think of ways that you could test specific hypotheses about why the distribution, or geographic range, of elk has changed (For example, loss of habitat can be tested by determining what the habitat requirements of elk are, and study whether or not that habit has disappeared. You could also search for a map showing human population densities in the US. Another possible explanation is changes in predator abundance which can be tested by determining what the main predators on elk are [wolves and cougars], and then finding out what the modern and paleo distributions for those species are).

Student Worksheet guide

Exercises

List of Terrestrial Mammals Spicies

Name of species	Able to disperse?	Able to colonize?	# of species from Hokkaido	# of species from Kamtchatka
Brown Bear			1	1
Marten			1	1
Moose			0	1
Pica			1	1
Rabbit			1	1
Red fox			1	1
Reindeer			0	1
Shrew			6	5
Squirrel			0	2
Vole			3	6
Weasel			2	2
Wolf			0	1
Wolverine			0	1

Examine the lists of terrestrial mammal species that are native to Hokkaido, Japan, and Kamchatka, Russia. Based on what you know about these species, which would you predict would be able to colonize the Kuril Islands. Does it matter if they are colonizing from the south (from Hokkaido) or from the north (from Kamchatka)? Why?

Answer:

(See table 1 for the characteristics of the different species)

Some possible answers include: brown bear, Sitka deer and reindeer, red fox. The sea ice in the south might make it easier for relatively small animals to cross over to the islands.

Which of these species might be beneficial to humans?

Answer:

Some possible answers include: Deer, squirrels, and rabbits could be hunted as a source of protein and/or skins and furs. Red foxes and river otters are also valuable for their furs.

Which of these species might be detrimental to humans?

Answer:

Some possible answers include: Bears might be a nuisance and/or physically dangerous. Bears and red foxes might destroy caches of stored food. Small rodents might transmit diseases.

Student Worksheet guide

Exercises - continued

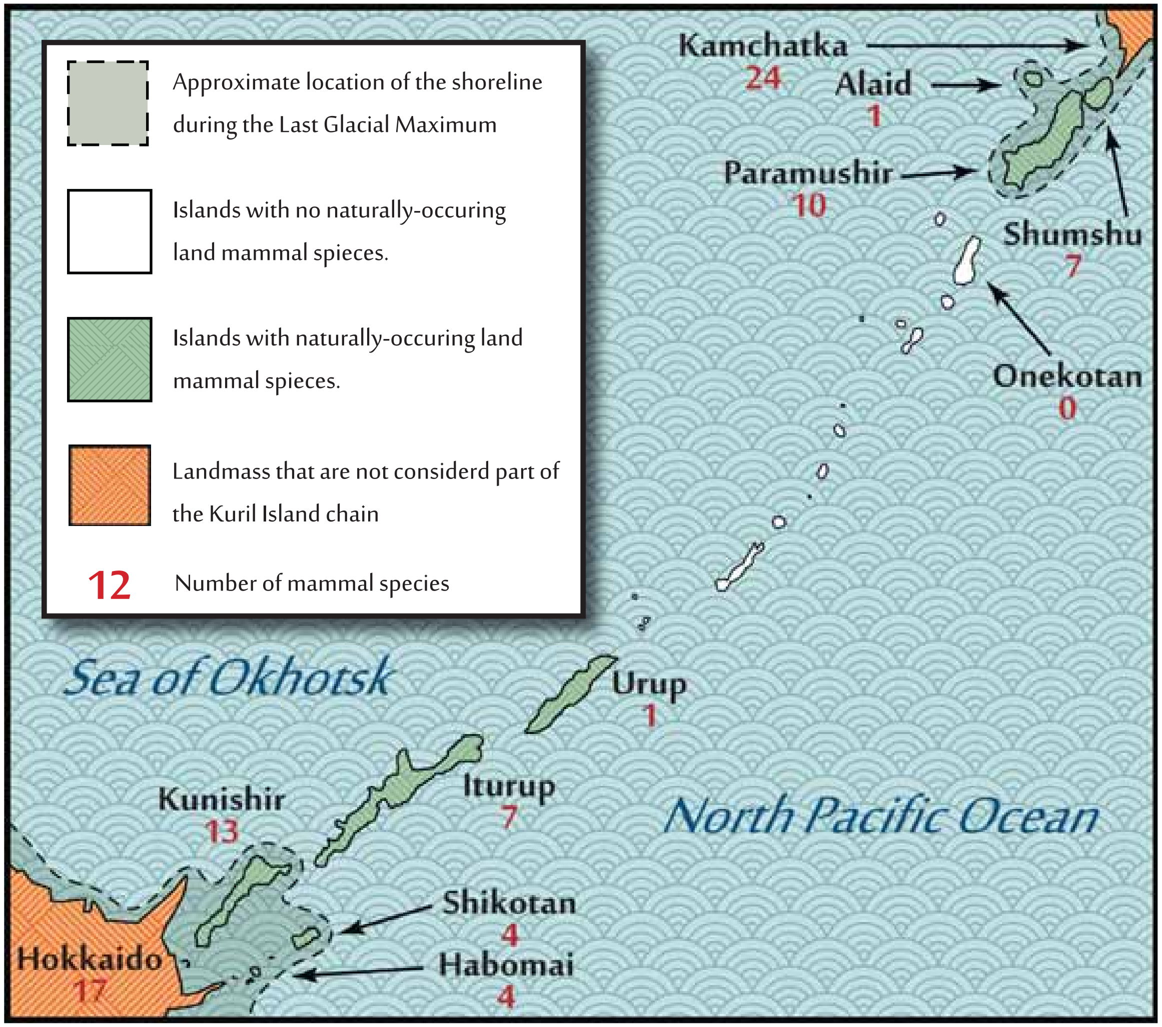
Table 1:

Name	Characteristics
Brown Bear	Can swim large distances; require very large territories
Marten	Can swim moderate distances, but typically live in forests
Pica	Related to rabbits, cannot swim appreciable distances; typically live in high elevation tundra
Rabbit	Poor swimmers; once established, populations grow quickly
Red Fox	Can swim moderate distances, but very good at crossing sea ice; populations often limited by availability of prey during winter
River Otter	Excellent swimmers, often inhabit marine environments;
Shrew	Cannot swim appreciable distances, and high metabolism limits their ability to cross sea ice; once established, populations grow quickly
Sika Deer	Can swim moderate distances; require large territories; prefer areas of shrubs or forests
Squirrel	Cannot swim appreciable distances, and high metabolism limits their ability to cross sea ice; once established, populations grow quickly
Vole	Cannot swim appreciable distances, and high metabolism limits their ability to cross sea ice; once established, populations grow quickly
Weasel	Excellent swimmers, and very good at crossing sea ice
Moose	Can swim moderate distances; require large territories; prefer areas of shrubs or forests
Reindeer	Can swim moderate distances; require large territories; prefer areas of tundra
Wolf	Excellent swimmers; require very large territories
Wolverine	Can swim moderate distances; typically live in mountainous terrain

Student Worksheet guide

Exercises - continued

Now examine the map showing the number of land mammal species that occurs naturally on islands and the adjacent mainland. Island size and distance to the mainland are the two main factors that influence the number of land mammal species any given island can support. For each of the islands identified in Figure 1, indicate which of those two factors you think is MOST important, and indicate why.



Alaid:

Shumshu:

Paramushir:

Urup:

Iturup:

Kunashir:

Shikotan:

Habomai: